Fishery Management Plan for Big Spring Creek (7B)

Bureau of Fisheries

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Executive Summary

Big Spring Creek was historically renowned for supporting a high-quality wild brook trout *Salvelinus fontinalis* fishery. Currently, the creek supports sympatric populations of brook trout, rainbow trout *Oncorhynchus mykiss*, and brown trout *Salmo trutta*. Big Spring Creek is unique relative to other wild brook trout fisheries in Pennsylvania, and is one of only four limestone spring streams afforded a Class A designation by the Pennsylvania Fish and Boat Commission (PFBC) based on wild brook trout biomass. Of these four Class A brook trout stream sections, Big Spring Creek, Section 01, supports the highest biomass of wild brook trout in the Commonwealth, as well as the highest biomass of wild rainbow trout in the Commonwealth. In general, the distribution of wild trout is concentrated in the upstream reaches of Big Spring Creek (Section 01 and the upstream portion of Section 02), with few trout occupying the middle and lower reaches of the stream (downstream portion of Section 02 through Section 04).

Throughout history, numerous impacts associated with agricultural activity and the operation of mill dams, clay mines, and trout hatcheries, have altered the chemical and physical characteristics of Big Spring Creek, resulting in severely degraded fish habitat conditions in some segments of the creek. Prior to 2010, instream physical habitat conditions were enhanced through various projects located between the headwaters and the Nealy Road Bridge (sections 01 and 02). The most recent and most extensive habitat enhancement project was completed during 2010. The goal of this project was to improve instream habitat conditions for the resident wild trout fishery, targeting brook trout if feasible. Project objectives included: (1) to improve instream habitat and riparian vegetative conditions for a variety of aquatic and terrestrial wildlife species; (2) to remove the remnants of the Piper Mill and Thomas Hatchery dams, and implement habitat enhancement activities that would result in a natural-looking stream channel with appropriate dimensions (width and depth); (3) to increase habitat diversity and provide adequate habitat for all life-stages of trout, ultimately resulting in a sustainable, wild trout destination fishery; and (4) to monitor the pre- and post-implementation physical habitat and biological conditions, and to use monitoring information to guide additional restoration activities on Big Spring Creek and other limestone spring creeks.

In May 2012, the PFBC received $586,600 from the Pennsylvania Turnpike Commission (PTC) for the design, permitting, construction, and monitoring of an additional 2,000 feet of habitat enhancement work on Big Spring Creek (Phase 2 Project) immediately downstream of the 2010 project reach. The Phase 2 Project is intended to meet stream mitigation requirements associated with the PTC's Total Reconstruction and Widening Projects proposed in the Conodoguinet Creek Watershed. The dramatic increase in the abundance of rainbow trout

observed in response to the implementation of the 2010 project, in conjunction with the PFBC's desire to optimize the brook trout fishery of Big Spring Creek, drove the impetus for this document. The purpose of this document is to provide an overview of the status of the Big Spring Creek trout fishery, describe the results of the 2010 habitat enhancement project and implications for future habitat enhancement, and to present options to guide future fishery and habitat management activities at Big Spring Creek. In addition, implications of native versus non-native sport fish management are presented.

A review of brook and rainbow trout habitat suitability information reported in various published literature and fisheries agency reports indicated that nearly all of the physical habitat and fish cover conditions observed in the 2010 project model reach were within the optimal range of values for adult, juvenile, and spawning brook trout. However, the implementation of the 2010 Project did create some habitat conditions different than those observed in the model reach which were beneficial to adult and spawning rainbow trout. For example, the 2010 project increased thalweg and mean depth to values significantly greater than those of the model reach. Although these conditions were within the optimal ranges of adult brook trout they also favored rainbow trout. The project also resulted in an increase of mean water column depth conditions for juvenile rainbow trout from suboptimal to optimal conditions. In addition, the 2010 project resulted in an increase in the percent cover for adult fish (cover in water at least 1 ft deep, and suitable for fish at least 200 mm (8 in) in total length) in the project reach to conditions that substantially exceeded those observed in the model reach.

Based on brook and rainbow trout habitat suitability information reported in the literature and data collected in the model reach, future habitat enhancement activities in the proposed Phase 2 Project reach (Willow Tree reach) will address several key habitat parameters. Based on the affinity of rainbow trout for deep water, thalweg depth will be reduced to just below the lower limit of the optimal range for adult rainbow trout. Mean water column depth conditions will be increased to conditions similar to those of the model reach, which are within the optimal range for all life-stages of brook trout and generally suboptimal conditions for adult rainbow trout. The existing, relatively high percent fine gravel composition of the substrate will be maintained, and the amount of adult fish cover provided by objects other than aquatic macrophytes will be increased to conditions similar to those of the model reach. Wetted width/depth ratio values will be reduced to values similar to those observed in the model reach in an effort to reduce: (1) the amount of water surface area exposed to solar radiation, (2) late-afternoon aquatic macrophyte photosynthesis levels, (3) the rate at which the creek's waters warm as they flow downstream, and (4) late-afternoon dissolved oxygen and total dissolved gases percent saturation values. In addition, efforts should be made to increase water surface turbulence to aerate the creek's waters and possibly prevent dissolved gas supersaturation conditions in the Willow Tree reach and downstream segments of the creek.

Future habitat enhancement activities will be designed to create habitat conditions which are optimal for brook trout, but suboptimal for rainbow trout. However, published information about the habitat requirements/preferences of stream-dwelling brook and rainbow trout indicate that the habitat preferences of these species are very similar. Furthermore, the short-term response of the Big Spring Creek trout fishery to the implementation of the 2010 project, and published information about other sympatric brook and rainbow trout populations, suggest that any habitat modifications in Big Spring Creek that benefit brook trout will most likely also benefit rainbow trout to some degree.

At this time, the PFBC will continue to manage Big Spring Creek, sections 01 and 02, as a mixed brook, rainbow, and brown trout fishery, but will manage the fishery preferentially for brook trout. Initially, non-native salmonids will not be removed from the creek, and future habitat enhancement of Big Spring Creek will be designed to favor brook trout. Sampling results in 2011 documented that the brook trout population increased in the project reach, but the rainbow trout population increased by a much greater extent. Population monitoring in 2012 is promising in that rainbow trout numbers have declined since 2011 and brook trout have continued to increase. However, published information about response times of trout fisheries to habitat enhancement activities range from seven to ten years, and this timeframe is incorporated into the following fishery management objectives for sections 01 and 02 of Big Spring Creek. Objectives pertaining to this management strategy include: 1) achieve and maintain a total salmonid density comprised of brook, rainbow and brown trout of greater than or equal to 90.00 kg/ha in sections 01 and 02, within seven years of completed habitat enhancement projects; and 2) achieve and maintain a total salmonid species abundance (number/km) composition of at least 70 percent brook trout to 30 percent rainbow and brown trout in these sections of Big Spring Creek, within seven years of completed habitat enhancement projects. In addition, the PFBC Board of Commissioners will consider Miscellaneous Special Regulations for Big Spring Creek, sections 01 and 02. If adopted, this regulation will take effect beginning January 2014 and will restrict gear to fly-fishing tackle only and catch-and-release of brook trout, but permit harvest of five rainbow and brown trout per day greater than or equal to seven inches.

Introduction

Big Spring Creek is an 8.2 km (5.1 mi) long limestone spring stream located in sub-subbasin 7B, Cumberland County, Pennsylvania. Along its length, the stream forms a portion of the boundary between West Pennsboro and North Newton townships in Cumberland County. Big Spring Creek originates from a large spring source located at approximately 155 m (509 ft) elevation, approximately 4.6 km (2.9 miles) south of Newville, Pennsylvania, and flows north to its confluence with the Conodoguinet Creek at river- mile (RM) 56.54, 40^{o}11’19” latitude and 77^{o}23’32” longitude. Map coverage is provided by the Newville, Pennsylvania, United States Geological Survey 7.5 minute Quadrangle (Figure 1).

The Pennsylvania Department of Environmental Protection (PADEP) 25 PA Code Chapter 93 Water Quality Standards currently designates Big Spring Creek as Exceptional Value, Migratory Fishes (EV, MF) from the source at RM 5.1 downstream to SR 3007 (Big Spring Road Bridge) at RM 4.94, and Cold-Water Fishes, Migratory Fishes (CWF, MF) from SR 3007 downstream to the mouth. Additionally, the PADEP currently offers existing use protection through 25 PA Code Chapter 93 Water Quality Standard of High-Quality, Cold-Water Fishes, Migratory Fishes (HQ-CWF, MF) to the portion of Big Spring Creek from SR 3007 (Big Spring Road Bridge) downstream to the Nealy Road Bridge located at RM 3.54; a distance of 2.25 km (1.4 mi).

The Pennsylvania Fish and Boat Commission (PFBC) purchased the spring and the land adjacent to the upper 4.1 km (2.5 mi) of the stream in the late-1960s to establish the Big Spring Fish Culture Station (BSFCS) and to ensure public access to the stream for recreational angling and boating opportunities. The BSFCS began operation in 1972 and raised between 750,000 and 800,000 catchable-size trout annually for planting into Commonwealth waters prior to being decommissioned in November 2001. Numerous surveys have been conducted at Big Spring Creek to document the population of both wild and hatchery trout. For a detailed account of the results of fishery surveys conducted from the period of 2002 to 2008, refer to Miko and Kuhn (2011).

Big Spring Creek is divided into five stream sections for fisheries management purposes. Section 01 extends 0.95 km (0.59 mi) from the spring source to the former Piper Mill Dam previously located at RM 4.47 (Table 1). Section 02 extends 1.5 km (0.93 mi) from the former Piper Mill Dam downstream to the Nealy Road Bridge at RM 3.54. Sections 01 and 02 are currently managed by the PFBC with Catch-and-Release Fly-Fishing Only Regulations. These regulations allow for year-round angling utilizing fly fishing tackle and no trout may be killed or had in possession. Section 03 extends 1.63 km (1.01 mi) from the Nealy Road Bridge downstream to the Stone Arch Bridge on SR 3007 located at RM 2.53. Section 04 extends 2.03 km (1.26 mi) from the Stone Arch Bridge on SR 3007 downstream to the SR 0641 Bridge in Newville, Pennsylvania, located at RM 1.27. Sections 03 and 04 are included in the PFBC Approved Trout Water (ATW) program and receive annual plants of adult brook trout, and are managed by the PFBC with Commonwealth Inland Waters angling regulations. These regulations allow for angling and harvest of trout with a five trout per day creel limit and seven-inch (178 mm) minimum length limit from the opening day of trout season to Labor Day, and from the day after Labor Day to the last day of February permit a daily harvest of three trout under the seven-inch minimum length limit. No angling is permitted from March 1 to 8 a.m. on the opening day of trout season. Section 05 extends 2.04 km (1.27 mi) from the SR 0641 Bridge downstream to the mouth. Due to limited access, Section 05 is not stocked with trout by the PFBC, and is managed with the previously described Commonwealth Inland Waters angling regulations.

Prior to 2010, instream physical habitat was enhanced through various projects throughout the portion of Big Spring Creek corresponding to sections 01 and 02 (headwaters downstream to Nealy Road Bridge). The most recent and most extensive habitat enhancement was completed during 2010 and is described in greater detail later in this document. In September 2010, the PFBC, Cumberland Valley Trout Unlimited (CVTU), and the Big Spring Watershed Association completed a $363,000 stream habitat enhancement project on a 2,050 ft segment of Big Spring Creek, located at the downstream portion of Section 01 and the upstream portion of Section 02. The project was funded through various grant monies and substantial non-cash contributions from local government and private industry. Electrofishing and detailed physical habitat surveys conducted by PFBC staff before and after the project implementation show the project successfully addressed the objectives of narrowing and deepening the channel, increasing cover for trout, with an emphasis on brook trout.

In May 2012, the PFBC received $586,600 from the Pennsylvania Turnpike Commission (PTC) to be used to cover costs associated with the design, permitting, construction, and monitoring of an additional 2,000 feet of habitat enhancement work on Big Spring Creek. The project is intended to meet stream mitigation requirements associated with the PTC's Total Reconstruction and Widening Projects proposed in the Conodoguinet Creek Watershed. The work will be conducted immediately downstream of and using techniques similar to those used in the 2010 Project. The project is tentatively slated for construction in the summer of 2013, with a termination date of December 2014.

Big Spring Creek was historically renowned for supporting a high-quality wild brook trout *Salvelinus fontinalis* fishery. Prior to the 1930s Big Spring Creek was reported to support a dense population of wild brook trout along most of its length. During this time period, a series of six mill dams were in operation on the stream which had a positive effect on the fishery by continually flushing silt downstream, thus providing clean gavel utilized for spawning activities by trout. However, during the 1930s the mills ceased operation and the dams were no longer being flushed, leading to heavy siltation of Big Spring Creek associated with agricultural activity. By the 1950s, the trout population was reported to be more localized and no longer widespread throughout the watershed. In addition to physical habitat changes that occurred associated with the closure of the mill dams and agriculture practices, the Green Springs commercial trout hatchery began operation in the 1950s in the vicinity of river-mile (RM) 4.31. Some sportsmen opposed the operation of the hatchery due to concerns that hatchery effluent would lead to increased siltation and negatively affect the Big Spring Creek trout fishery. These concerns prompted sportsmen to organize and conduct a large-scale clean up of the Big Spring Creek watershed. However, despite good intentions, the result of this effort was lower water levels and severe degradation of instream and riparian zone habitat. These habitat deficiencies persist currently throughout the portion of Big Spring Creek, with the exception of the 2010 habitat enhancement reach. These events, among others, led to a drastic decline of the Big

Spring Creek brook population, and currently robust densities of brook trout only occur in the upstream portions of the creek. A detailed historical perspective of Big Spring Creek and associated PFBC management strategies are provided by Greene (2002).

Big Spring Creek is unique relative to other wild brook trout fisheries in Pennsylvania. It is one of only four limestone spring streams that are afforded a Class A designation by the PFBC based on wild brook trout biomass. Of these four Class A brook trout stream sections, Big Spring Creek, Section 01, supports the highest biomass of wild brook trout in the Commonwealth. Fertility attributable to numerous limestone springs in the Big Spring Creek watershed creates conditions conducive to produce large brook trout. Currently, sympatric populations of brook trout, rainbow trout *Oncorhynchus mykiss*, and brown trout *Salmo trutta* reside in Big Spring Creek. The Big Spring Creek trout fishery varies along its length, and based on survey data, transitions from a wild brook trout dominated system in the extreme headwaters (upstream portion of Section 01) to a wild rainbow trout dominated system in the middle portion of the creek (downstream portion of Section 01 and Section 02). Based on recent (2012) survey data, Big Spring Creek supports the highest density of wild rainbow trout in the Commonwealth. Brown trout densities are extremely low throughout Big Spring Creek relative to brook and rainbow trout, and low numbers of large individuals characterize the population. Low densities of wild trout occur downstream from Nealy Road Bridge, and recreational trout angling opportunities are maintained in this area through annual plants of adult hatchery-reared brook trout.

In the United States (US) more than 500 exotic fish taxa, fishes that have been introduced through anthropogenic activities to areas or ecosystems outside their historic geographic range, have invaded areas outside their native distribution. Many of these non-native fishes have become established and naturalized resulting in US inland-water fish assemblages drastically altered from their pre-European settlement condition (Nico and Fuller 1999). Widespread habitat alterations and the repeated reintroduction of non-native fishes, the majority of which were introduced to enhance recreational fisheries, have facilitated the proliferation of non-native fishes throughout the US (Gido and Brown 1999). In many cases, non-native species introductions, whether intentional or unintentional, have resulted in decline, extirpation, or extinction of native fishes through direct competition for limited resources and predation.

Naturalized, non-native fishes have routinely been cited as the primary cause for most fish species declines, as well as the most substantial limitation to native fish species restoration (Wilcove et al. 1998; Ritchter et al. 1997; Miller et al. 1989; Sheldon 1988). Despite this, many introduced non-native species provide valuable sport fisheries and are routinely stocked in waters outside their native range, thus providing important local and regional recreational and economic benefit. However, biological integrity, the ability to support and maintain a community of organisms having species composition comparable to that of the natural habitat of the region (Hughes and Noss 1992), is being threatened throughout the US by invading and naturalized non-native species (Moyle and Light 1996).

As a result of declines in habitat quality and native fishes, fisheries management agencies are tasked with deciding among difficult tradeoffs regarding game, non-game, native, and non-native species management (Beamesderfer 2000). In this regard, fisheries management agencies must decide whether non-native sportfish management is compatible with the restoration of native fish assemblages, and formulate appropriate policy. Restoration of native fishes not only depends on a thorough understanding of the ecological systems and processes, but also of social and economic issues (Quist and Hubert 2004).

The spirit of native species conservation and the PFBC's desire to optimize the brook trout fishery of Big Spring Creek drove the impetus for this document. Its purpose is to provide an overview of the status of the Big Spring Creek trout fishery, describe the results of the 2010 habitat enhancement project and implications for future habitat enhancement, and to present options to guide future fishery and habitat management activities at Big Spring Creek. Additionally, implications of native versus non-native sport fish management are presented. Due to differences in management philosophies associated with native versus non-native species management, two alternative management options are presented along with two distinct goals, associated objectives, and recommendations pertaining to each of the two options.

The goal pertaining to *Option 1* presented below is to continue to manage Big Spring Creek, sections 01 and 02, as a mixed brook, rainbow, and brown trout fishery and to manage the fishery preferentially for brook trout without initial removal of non-native salmonids. This mandates that any future habitat enhancement of Big Spring Creek preferentially be designed to favor brook trout. As such, the response of the brook trout fishery to habitat enhancement will measure success of existing and future projects. Objectives pertaining to this management option are: 1) achieve and maintain a total salmonid density comprised of brook, rainbow and brown trout of greater than or equal to 90.00 kg/ha in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects; and 2) achieve and maintain a total salmonid species abundance composition of at least 70 percent brook trout to 30 percent rainbow and brown trout in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects. The biomass criterion pertaining to the first objective is based on brook and rainbow trout biomass estimates at long-term monitoring sites located at RM 4.77 and RM 4.29 and considers biomass estimates from 2005 through 2012, with the exception of 2010 as no surveys were completed during that year. Due to the small sample size and the presence of outlier values, nonparametric statistics were used to determine a median biomass value for brook trout and rainbow trout combined of 93.81 kg/ha. The abundance criterion pertaining to the second objective is based on abundance estimates at a long-term monitoring site located at RM 4.77, which was used as a model for the 2010 habitat enhancement project. During 2009, 2011 and 2012, brook trout comprised 72 percent, 71 percent and 82 percent (median = 72 percent), respectively, of the total estimated abundance of brook and rainbow trout at RM 4.77.

The goal pertaining to *Option 2* presented below is to optimize the brook trout fishery and manage preferentially for brook trout. This option includes mechanical removal of non-native salmonids. Removed non-native salmonids would be relocated to nearby waters to provide immediate recreational angling opportunities. In addition to removal of non-native salmonids, this goal also mandates that any future habitat enhancement of Big Spring Creek preferentially be designed to favor brook trout, and the response of the brook trout fishery to habitat enhancement and removal efforts will measure success of existing and future projects. Objectives pertaining to this management option are: 1) achieve and maintain a total salmonid density comprised of brook, brown and rainbow trout of at least 90.00 kg/ha in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects; and 2) achieve and maintain a total salmonid species abundance composition of at least 90 percent brook trout to 10 percent rainbow and brown trout in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects. The rationale for the biomass criterion pertaining to the first object is explained above. The abundance criterion pertaining to the second objective was developed to provide brook trout with a greater advantage than provided for in *Option 1*, but acknowledges that it is unlikely that all non-native salmonids will be completely eradicated from Big Spring Creek during removal efforts.

Fishery Status and Recent Population Trends

Surveys have been conducted at sampling stations located in sections 01, 02, 03, and 05 annually from 2002 – 2008. For a detailed account of population trends from 2002 through 2008 following the closure of the BSFCS in 2001 consult Miko and Kuhn (2011). Most recently, the Big Spring Creek trout fishery was evaluated during 2009, 2011, and 2012 at four sampling stations. Sampling stations were located at RM 4.77 and RM 4.47 in Section 01, and RM 4.29 and 3.88 (2011 and 2012 only) in Section 02, and comprised 70 percent and 42 percent of the total section lengths, respectively (Table 2). All procedures were carried out according to those outlined by Detar et al. (2011).

Sampling Station 0102 – RM 4.77

Station 0102, was located 300 m downstream from the McCracken Mill Dam at 40°07’56” latitude and 77°24’27” longitude (Table 2). The 300 m (984 ft) long station averaged 15.2 m (50 ft) wide and comprised 31.6% of the section length. The east bank was loosely paralleled by Big Spring Road (SR 3007) along most of the station length, while a woodlot provided a small buffer from agricultural and rural residential activities along the western bank. Extensive habitat improvement work in the form of numerous log vane deflectors, overhead cover deflectors, and a channel block (Karl Lutz, PFBC, personal communication) was constructed within this station. Flowing water habitat consisted of a series of short and shallow (0.20 m; 0.66 ft) riffles, medium-length runs up to 0.40 m (1.31 ft) deep, and slow moving deep-water (0.50 m; 1.64 ft) along the stream margins. Water depth and the overhead cover attributable to the habitat improvement devices and overhanging trees, grasses, and shrubs provided suitable adult trout habitat. The habitat characteristics of a portion of this sampling station were used as a model for habitat enhancement completed downstream during 2010, and habitat characteristics remained unaltered during the 2009 and 2011 fisheries surveys.

Brook trout

During 2009, a total of 383 wild brook trout ranging from 50 mm (2 in) to 424 mm (17 in) in total length (TL) were captured during the survey with 114 (30 percent) being greater than or equal 175 mm (7 in). Total brook trout biomass was estimated to be 63.59 kg/ha. Brook trout abundance was estimated at 1,642 trout/km (2,642 trout/mi) with 412 trout/km (663 trout/mi) being greater than or equal to 175 mm (Table 3).

During 2011, a total of 584 wild brook trout ranging from 50 mm (2 in) to 449 mm (18 in) in total length (TL) were captured during the survey with 140 (24 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 78.69 kg/ha. Brook trout abundance was estimated at 2,351 trout/km (3,783 trout/mi) with 504 trout/km (811 trout/mi) being greater than or equal to 175 mm (Table 4).

During 2012, a total of 536 wild brook trout ranging from 50 mm (2 in) to 449 mm (18 in) in total length (TL) were captured during the survey with 172 (32 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 90.34 kg/ha. Brook trout abundance was estimated at 2,669 trout/km (4,294 trout/mi) with 606 trout/km (975 trout/mi) being greater than or equal to 175 mm (Table 5). At sampling station 0102, brook trout biomass increased from 63.59 kg/ha during 2009 to 90.34 kg/ha during 2012 and abundance increased from 1,642 trout/km during 2009 to 2,669 trout/ km during 2012 (Table 6).

Rainbow trout

During 2009, a total of 174 wild rainbow trout ranging from 100 mm (4 in) to 499 mm (20 in) in total length (TL) were captured during the survey with 46 (26 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 35.44 kg/ha. Rainbow trout abundance was estimated at 654 trout/km (1,052 trout/mi) with 168 trout/km (270 trout/mi) being greater than or equal to 175 mm (Table 7).

During 2011, a total of 268, wild rainbow trout ranging from 100 mm (4 in) to 699 mm (28 in) in total length (TL) were captured during the survey with 76 (28 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 74.38 kg/ha. Rainbow trout abundance was estimated at 959 trout/km (1,543 trout/mi) with 280 trout/km (451 trout/mi) being greater than or equal to 175 mm (Table 8).

During 2012, a total of 159, wild rainbow trout ranging from 75 mm (3 in) to 549 mm (22 in) in total length (TL) were captured during the survey with 78 (49 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 68.00 kg/ha. Rainbow trout abundance was estimated at 588 trout/km (946 trout/mi) with 289 trout/km (465 trout/mi) being greater than or equal to 175 mm (Table 9). At sampling station 0102, rainbow trout biomass increased from 35.44 kg/ha during 2009 to 68.00 kg/ha during 2012 and abundance decreased from 654 trout/km during 2009 to 588 trout/km during 2012 (Table 6).

During 2009, brook trout comprised approximately 72 percent of the estimated total rainbow and brook trout abundance in sampling station 0102, and brook trout greater than or equal to 175 mm comprised approximately 71 percent. During 2012, brook trout comprised approximately 82 percent of the estimated total rainbow and brook trout abundance in sampling station 0102, and brook trout greater than or equal to 175 mm comprised approximately 68 percent. Ratios of brook trout to rainbow trout abundance estimated in sampling station 0102 (physical habitat modeled for 2010 habitat enhancement projected) shifted more in favor of brook trout during 2012 and were the most favorable for brook trout from 2009 to 2012 than in any of the following sampling stations presented below.

Sampling Station 0103 – RM 4.47

Station 0103, was located at the former Piper Mill Dam (old fish barrier) at 40°08'11" latitude and 77°24'22" longitude (Table 2). During 2009, the 366 m (1,201 ft) long station averaged 21.4 m (70.2 ft) wide and comprised 38.5% of the section length. Big Spring Road (SR 3007) paralleled the station for some of its length along the eastern bank, while along the western bank a woodlot provided a buffer from agricultural and rural residential activities. Flowing water habitat was poor, particularly for adult trout, and most of the sampling station was characterized by shallow and wide glides. The entire sampling station directly corresponded to the upstream portion of the 2010 habitat enhancement reach, and the data presented below were collected one year prior to and one year post-construction of the project. A more thorough description of the physical habitat of this sampling station pre- and post-habitat enhancement is provided in the following section of this narrative.

Brook trout

During 2009, a total of 106 wild brook trout ranging from 50 mm (2 in) to 374 mm (15 in) in total length (TL) were captured during the survey with 34 (32 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 8.19 kg/ha. Brook trout abundance was estimated at 373 trout/km (600 trout/mi) with 111 trout/km (179 trout/mi) being greater than or equal to 175 mm (Table 10).

During 2011, a total of 226 wild brook trout ranging from 50 mm (2 in) to 399 mm (16 in) in total length (TL) were captured during the survey with 152 (67 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 54.10 kg/ha. Brook trout abundance was estimated at 824 trout/km (1,326 trout/mi) with 471 trout/km (758 trout/mi) being greater than or equal to 175 mm (Table 11).

During 2012, a total of 278 wild brook trout ranging from 50 mm (2 in) to 399 mm (16 in) in total length (TL) were captured during the survey with 111 (40 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 61.23 kg/ha. Brook trout abundance was estimated at 1,287 trout/km (2,071 trout/mi) with 353 trout/km (568 trout/mi) being greater than or equal to 175 mm (Table 12). Brook trout biomass increased from 8.19 kg/ha during 2009 to 61.23 kg/ha during 2012 in sampling station 0103, exceeding PFBC minimum criteria (30.00 kg/ha) for designation as a Class A brook trout water. Additionally, total brook trout abundance increased from 373 trout/km during 2009 to 1,287 trout/km during 2012 (Table 13).

Rainbow trout

During 2009, a total of 102 wild rainbow trout ranging from 100 mm to 449 mm in total length (TL) were captured during the survey with 25 (25 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 10.12 kg/ha. Rainbow trout abundance was estimated at 325 trout/km (523 trout/mi) with 74 trout/km (119 trout/mi) being greater than or equal to 175 mm (Table 14).

During 2011, a total of 855 wild rainbow trout ranging from 75 mm (3 in) to 549 mm (22 in) in total length (TL) were captured during the survey with 182 (21 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 136.22 kg/ha. Rainbow trout abundance was estimated at 2,909 trout/km (4,681 trout/mi) with 571 trout/km (919 trout/mi) being greater than or equal to 175 mm (Table 15).

During 2012, a total of 634 wild rainbow trout ranging from 75 mm (3 in) to 599 mm (24 in) in total length (TL) were captured during the survey with 286 (45 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 174.30 kg/ha. Rainbow trout abundance was estimated at 1,963 trout/km (3,158 trout/mi) with 819 trout/km (1,318 trout/mi) being greater than or equal to 175 mm (Table 16). Rainbow trout biomass increased from 10.12 kg/ha during 2009 to 174.30 kg/ha during 2012 in sampling station 0103. Additionally, total rainbow trout abundance increased from 325 trout/km during 2009 to 1,963 trout/km during 2012 (Table 13).

During 2009, brook trout comprised approximately 53 percent of the estimated total rainbow and brook trout abundance in sampling station 0103, and brook trout greater than or equal to 175 mm comprised approximately 60 percent. During 2012, brook trout comprised approximately 40 percent of the estimated total rainbow and brook trout abundance in sampling station 0103, and brook trout greater than or equal to 175 mm comprised approximately 30 percent. This reduction in the ratio of brook trout abundance compared to rainbow trout abundance observed from 2009 to 2012 was primarily associated with a drastic increase in abundance of rainbow trout less than or equal to 175 mm.

Sampling Station 0201 – RM 4.29

Station 0201, was located 300 m downstream from the former Piper Mill Dam (old fish barrier) at 40°08’20” latitude and 77°24’24” longitude (Table 2). During 2009, the 300 m (984 ft) long station averaged 11.1 m (36.4 ft) wide and comprised 20.0% of the section length. Big Spring Road (SR 3007) closely paralleled the station for most of its length along the eastern bank, while along the western bank a woodlot provided a buffer from agricultural and rural residential activities. Prior to the 2010 habitat enhancement project, minimal habitat improvement occurred in the upstream-most portion of this station in the form of instream random boulder placement. Flowing water habitat consisted of one long riffle downstream from the remnants of the Piper Mill Dam, and a short riffle downstream from the remnants of the Thomas Hatchery Dam separated by relatively flat, shallow (0.20 – 0.40 m; 0.7 – 1.3 ft deep) water. Pockets of slightly deeper water associated with the boulders, turbulence in the riffle areas, and overhead cover from overhanging trees and shrubs along the stream margins provided limited habitat for adult trout. The entire sampling station directly corresponded to the downstream portion of the 2010 habitat enhancement reach, and the data presented below were collected one year prior to and one year post-construction of the project. A more thorough description of the physical habitat of this sampling station pre- and post-habitat enhancement is provided in the following section of this narrative.

Brook trout

During 2009, a total of eight wild brook trout ranging from 75 mm (3 in) to 274 mm (11 in) in total length (TL) were captured during the survey with seven (88 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 2.30 kg/ha. Brook trout abundance was estimated at 27 trout/km (43 trout/mi) with 24 trout/km (39 trout/mi) being greater than or equal to 175 mm (Table 17).

During 2011, a total of 39 wild brook trout ranging from 75 mm (3 in) to 374 mm (15 in) in total length (TL) were captured during the survey with 26 (67 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 13.00 kg/ha. Brook trout abundance was estimated at 143 trout/km (230 trout/mi) with 100 trout/km (161 trout/mi) being greater than or equal to 175 mm (Table 18).

During 2012, a total of 31 wild brook trout ranging from 50 mm (2 in) to 424 mm (17 in) in total length (TL) were captured during the survey with 17 (55 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 20.61 kg/ha. Brook trout abundance was estimated at 106 trout/km (171 trout/mi) with 60 trout/km (97 trout/mi) being greater than or equal to 175 mm (Table 19). Brook trout biomass increased from 2.30 kg/ha during 2009 to 203.61 kg/ha during 2012 in sampling station 0201. Additionally, total brook trout abundance increased from 27 trout/km during 2009 to 106 trout/km during 2012 (Table 20).

Rainbow trout

During 2009, a total of 195 wild rainbow trout ranging from 100 mm (4 in) to 574 mm (23 in) in total length (TL) were captured during the survey with 74 (38 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 96.84 kg/ha. Rainbow trout abundance was estimated at 798 trout/km (1,284 trout/mi) with 284 trout/km (457 trout/mi) being greater than or equal to 175 mm (Table 21).

During 2011, a total of 725 wild rainbow trout ranging from 75 mm (3 in) to 599 mm (24 in) in total length (TL) were captured during the survey with 173 (24 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 228.58 kg/ha. Rainbow trout abundance was estimated at 2,769 trout/km (4,455 trout/mi) with 673 trout/km (1,083 trout/mi) being greater than or equal to 175 mm (Table 22).

During 2012, a total of 428 wild rainbow trout ranging from 75 mm (3 in) to 599 mm (24 in) in total length (TL) were captured during the survey with 167 (39 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 193.49 kg/ha. Rainbow trout abundance was estimated at 2,309 trout/km (3,715 trout/mi) with 633 trout/km (1,018 trout/mi) being greater than or equal to 175 mm (Table 23). Rainbow trout biomass increased from 90.93 kg/ha during 2009 to 193.49 kg/ha during 2012 in sampling station 0201. Additionally, total rainbow trout abundance increased from 798 trout/km during 2009 to 2,309 during 2012 (Table 20).

During 2009, brook trout comprised approximately 3 percent of the estimated total rainbow and brook trout abundance in sampling station 0201, and brook trout greater than or equal to 175 mm comprised approximately 8 percent. During 2012, brook trout comprised approximately 4 percent of the estimated total rainbow and brook trout abundance in sampling station 0201, and brook trout greater than or equal to 175 mm comprised approximately 9 percent. The lowest abundance of brook trout and the highest abundance of rainbow trout in Big Spring Creek, sections 01 and 02, have historically corresponded to this sampling station (Miko and Kuhn 2011).

Sampling Station 0202 – RM 3.88

Station 0202, was located at the PFBC Willow Tree parking area at 40°08’40” latitude and 77°24’20” longitude (Table 2). During 2009, the 325 m (1,066 ft) long station averaged 23.3 m (76.4 ft) wide and comprised 21.7% of the section length. Big Spring Road (SR 3007) loosely paralleled the station over its length along the eastern bank, while along the western bank a woodlot provided a buffer from agricultural and rural residential activities. Flowing water habitat, particularly for adult trout, was highly variable and fish cover was primarily associated with several upstream oriented rock vanes and seasonal aquatic macrophytes. Stream channel width was overly wide with deep-water habitat associated with the thalweg and rock vanes. This sampling station directly corresponds to the portion of Big Spring Creek being considered for future habitat enhancement activities. A more thorough description of the physical habitat of this sampling station is provided in the following section of this narrative.

Brook trout

During 2011, a total of 23 wild brook trout ranging from 75 mm (3 in) to 324 mm (13 in) in total length (TL) were captured during the survey with 13 (57 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 3.23 kg/ha. Brook trout abundance was estimated at 73 trout/km (117 trout/mi) with 42 trout/km (68 trout/mi) being greater than or equal to 175 mm (Table 24).

During 2012, a total of 15 wild brook trout ranging from 75 mm (3 in) to 399 mm (16 in) in total length (TL) were captured during the survey with 6 (40 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 1.87 kg/ha. Brook trout abundance was estimated at 49 trout/km (79 trout/mi) with 21 trout/km (34 trout/mi) being greater than or equal to 175 mm (Table 25). Brook trout biomass and abundance remained low during both years (Table 26).

Rainbow trout

During 2011, a total of 122 wild rainbow trout ranging from 100 mm (4 in) to 574 mm (23 in) in total length (TL) were captured during the survey with 37 (30 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 16.75 kg/ha. Rainbow trout abundance was estimated at 427 trout/km (687 trout/mi) with 122 trout/km (196 trout/mi) being greater than or equal to 175 mm (Table 27).

During 2012, a total of 240 wild rainbow trout ranging from 100 mm (4 in) to 599 mm (24 in) in total length (TL) were captured during the survey with 87 (36 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 62.70 kg/ha. Rainbow trout abundance was estimated at 1,034 trout/km (1,664 trout/mi) with 302 trout/km (486 trout/mi) being greater than or equal to 175 mm (Table 28). Rainbow trout biomass increased from 16.75 kg/ha during 2011 to 62.70 kg/ha during 2012 in sampling station 0202. Additionally, total rainbow trout abundance increased from 427 trout/km during 2011 to 1,034 trout/km during 2012 (Table 26).

During 2011, brook trout comprised approximately 15 percent of the estimated total rainbow and brook trout abundance in sampling station 0202, and brook trout greater than or equal to 175 mm comprised approximately 26 percent. During 2012, brook trout comprised approximately 5 percent of the estimated total rainbow and brook trout abundance in sampling station 0202, and brook trout greater than or equal to 175 mm comprised approximately 7 percent.

Habitat Enhancement Reach

To assess the response of the fisheries to the 2010 habitat enhancement project two years post-completion, fishery data were combined for sampling stations located at RM 4.47 and RM 4.29 (sampling stations 0103 and 0201) as these sampling stations directly corresponded to the habitat enhancement reach. A more thorough description of the physical habitat of this sampling station pre- and post-habitat enhancement is provided in the following section of this narrative.

Brook trout

During 2009, a total of 114 wild brook trout ranging from 50 mm (2 in) to 374 mm (15 in) in total length (TL) were captured during the survey with 71 (36 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 5.24 kg/ha. Brook trout abundance was estimated at 199 trout/km (320 trout/mi) with 66 trout/km (106 trout/mi) being greater than or equal to 175 mm (Table 29).

During 2011, a total of 265 wild brook trout ranging from 50 mm (2 in) to 399 mm (16 in) in total length (TL) were captured during the survey with 178 (67 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 33.54 kg/ha. Brook trout abundance was estimated at 481 trout/km (774 trout/mi) with 284 trout/km (457 trout/mi) being greater than or equal to 175 mm (Table 30).

During 2012, a total of 309 wild brook trout ranging from 50 mm (2 in) to 424 mm (17 in) in total length (TL) were captured during the survey with 128 (41 percent) being greater than or equal to 175 mm. Total brook trout biomass was estimated to be 40.93 kg/ha. Brook trout abundance was estimated at 697 trout/km (1,122 trout/mi) with 206 trout/km (332 trout/mi) being greater than or equal to 175 mm (Table 31).

Brook trout biomass increased from 5.24 kg/ha during 2009 to 40.93 kg/ha during 2012 in the habitat enhancement reach; above PFBC minimum criteria for designation as a Class A brook trout fishery (30.00 kg/ha). Additionally, total brook trout abundance increased from 66 trout/km during 2009 to 697 trout/km during 2012 (Table 32).

Rainbow trout

During 2009, a total of 297 wild rainbow trout ranging from 100 mm (4 in) to 574 mm (23 in) in total length (TL) were captured during the survey with 99 (33 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 54.49 kg/ha. Rainbow trout abundance was estimated at 563 trout/km (906 trout/mi) with 181 trout/km (291 trout/mi) being greater than or equal to 175 mm (Table 33).

During 2011, a total of 1,580 wild rainbow trout ranging from 75 mm (3 in) to 599 mm (24 in) in total length (TL) were captured during the survey with 355 (22 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 182.39 kg/ha. Rainbow trout abundance was estimated at 2,840 trout/km (4,570 trout/mi) with 622 trout/km (1,001 trout/mi) being greater than or equal to 175 mm (Table 34).

During 2012, a total of 1,062 wild rainbow trout ranging from 75 mm (3 in) to 599 mm (24 in) in total length (TL) were captured during the survey with 453 (43 percent) being greater than or equal to 175 mm. Total rainbow trout biomass was estimated to be 182.88 kg/ha. Rainbow trout abundance was estimated at 2,137 trout/km (3,439 trout/mi) with 727 trout/km (1,170 trout/mi) being greater than or equal to 175 mm (Table 35). Rainbow trout biomass increased from 54.49 kg/ha during 2009 to 182.88 kg/ha during 2012 in the habitat enhancement reach. Additionally, total rainbow trout abundance increased from 563 trout/km during 2009 to 2,137 trout/km during 2012 (Table 32).

During 2009, brook trout comprised approximately 26 percent of the estimated total rainbow and brook trout abundance, and brook trout greater than or equal to 175 mm comprised approximately 27 percent. During 2012, brook trout comprised approximately 25 percent of the estimated total rainbow and brook trout abundance, and brook trout greater than or equal to 175 mm comprised approximately 22 percent.

2010 Habitat Enhancement Project Analysis

In 2010, the PFBC, Cumberland Valley Chapter of Trout Unlimited, and the Big Spring Watershed Association implemented a habitat enhancement project on a 2,050 foot segment of Big Spring Creek formerly impounded by the Piper Mill and Thomas Hatchery Dams. The goal of this project was to improve instream habitat conditions for the resident wild trout fishery, targeting brook trout if feasible. Project objectives included: (1) to improve instream habitat and riparian vegetative conditions for a variety of aquatic and terrestrial wildlife species; (2) to remove the remains of the Piper Mill and Thomas Hatchery Dams, and implement habitat enhancement activities that would result in a natural-looking stream channel with appropriate dimensions (width and depth); (3) to increase habitat diversity and provide adequate habitat for all life-stages of trout, ultimately resulting in a sustainable, wild trout destination fishery; and (4) to monitor the pre- and post-implementation physical habitat and biological conditions, and to use monitoring information to guide additional restoration activities on Big Spring Creek and other limestone spring creeks.

This project used the segment of Big Spring Creek immediately downstream from the Big Spring Road (SR 3007) Bridge at RM 4.82 as a model for the project. This stream reach was the only un-impounded segment of Big Spring Creek where brook trout abundance and biomass exceeded that of rainbow and brown trout and directly corresponded to a portion of sampling station 0102 at RM 4.77. Furthermore, the physical habitat conditions at this portion of Big Spring Creek were similar to conditions commonly described as being optimal for brook trout in published literature. Continuing with the current management strategy would include implementing a similar habitat enhancement project in the middle-segment of Section 02 starting immediately downstream from the 2010 Project reach (approximately RM 4.29) extending downstream to the downstream end of the PFBC parking lot locally known as the Willow Tree Lot at approximately RM 3.88. This project would be funded entirely with Pennsylvania Turnpike Commission mitigation funds currently in the possession of the PFBC.

Prior to construction of the 2010 habitat enhancement project, this portion of Big Spring Creek was characterized by a shallow and over-widened channel with higher velocity waters, and limited cover for adult trout relative to the model reach at RM 4.82. The overall goal of the 2010 habitat enhancement project was to improve trout habitat conditions in the project area with an emphasis on improving habitat for brook trout. The primary objective of this project was to replicate the physical habitat conditions observed in the model reach where estimated brook trout abundance and biomass exceeded those of rainbow and brown trout. Specific objectives of the 2010 project were to reduce water velocity, increase depth, and increasing the amount of cover for trout to conditions similar to those observed in the model reach.

A review of brook and rainbow trout habitat suitability information reported in various published papers and fisheries agency reports indicate the velocity, depth, substrate composition, and fish cover conditions observed in the model reach are generally within the optimal range of values for adult, juvenile, and spawning brook trout. However, the results of this literature review confirm that, in general, the physical habitat requirements/preferences of stream-dwelling brook and rainbow trout are quite similar, and support the findings of Weigel and Sorensen (2001) and the views of Moore (personal communication). Brook and rainbow trout habitat suitability information is summarized in Table 36 and discussed in more detail below.

Water Column Velocity

Adults

Baker and Coon (1995) and SRBC (1998) reported optimal mean water column velocity values for adult brook trout that ranged from 0.00 to 0.89 ft/sec. PCWA (2010) reported optimal mean water column velocity values for adult rainbow trout that ranged from 0.50 to 1.20 ft/sec, and Pert and Erman (1994) observed a statistically significant preference of adult rainbow trout for mean water column velocities that ranged from 0.49 ft/sec to 0.98 ft/sec (Table 36). Transect mean water column velocity values recorded in the model reach by PFBC staff between 2008 and 2011 ranged from 0.45 to 1.15 ft/sec, with a mean value of 0.72 ft/sec. Transect mean water column velocity values were generated by dividing the stream discharge value recorded at the United States Geological Survey (USGS) Big Spring Creek gage at the time of field data collection by the wetted channel area calculated at each transect surveyed in the field. In general, the mean water column velocity conditions documented in the model reach were within the optimal velocity ranges for both adult brook and rainbow trout (Figure 2).

Juveniles

Baker and Coon (1995) and SRBC (1998) also reported optimal mean water column velocity values for juvenile brook trout that ranged from 0.00 ft/sec to 0.98 ft/sec. PCWA (2010) reported optimal mean water column velocity values for juvenile rainbow trout that ranged from 0.20 ft/sec to 0.75 ft/sec. In general, the mean water column velocity conditions documented in the model reach are within the optimal velocity ranges for both juvenile brook and rainbow trout (Figure 3).

Spawning

Both brook and rainbow trout spawn in the fall in Big Spring Creek. Although rainbow trout generally start spawning before brook trout, there is substantial overlap in the spawning periods of these species in Big Spring Creek. Optimal mean water column velocity values for brook trout spawning reported in the literature vary dramatically, and some of the ranges reported are much different than the values recorded at redds in Big Spring Creek. For example, SRBC (1998) reported optimal mean water column velocity values for brook trout spawning that ranged from 0.00 ft/sec to 0.38 ft/sec, Reiser and Wesche (1977) reported optimal values that ranged from 0.12 to 1.11 ft/sec, and Raleigh (1982) reported optimal values that ranged from 0.90 ft/sec to 1.97 ft/sec (Table 36). Mean water column velocity values recorded at a combined total of 85 redds (of unknown species origin) in Big Spring Creek by the Pennsylvania Cooperative Fish and Wildlife Research Unit at Pennsylvania State University in 2001 (Snyder and Carline, 2003) (n=20) and PFBC staff in 2007 (n=35) and 2011 (n=30), ranged from 0.65 ft/sec to 3.00 ft/sec, with a mean value of 1.56 ft/sec. Since none of the mean water column velocity values recorded at the 85 Big Spring Creek redds surveyed by Snyder and Carline and PFBC staff were within the optimal range of values reported in SRBC (1998), we concluded that the SRBC values were not appropriate for use on Big Spring Creek (Figure 4).

Although Witzel and MacCrimmon (1983) did not provide criteria for optimal brook trout spawning velocity conditions, they documented depth, velocity, and substrate conditions observed at 133 brook trout redds and the fork length of mature brook trout in southwestern Ontario streams. Witzel and MacCrimmon (1983) reported that mature brook trout in their study ranged from 3.3 to 11.4 inches in length, and velocity values measured approximately 10 cm above the surface of redds that ranged from 0.10 to 1.38 ft/sec (mean = 0.58 ft/sec). The redd velocity values reported by Witzel and MacCrimmon (1983) correspond reasonably well with the range of optimal mean water column velocity values of 0.12 ft/sec to 1.11 ft/sec reported by Reiser and Wesche (1977) (Figure 5).

The range of optimal values reported by Raleigh (1982) of 0.90 ft/sec to 1.97 ft/sec, for brook trout throughout their entire range, including the long-lived, large, predacious forms associated with large lakes, rivers, and estuaries, do not correspond well with the values reported by Witzel and MacCrimmon (1983) (Figure 6). Thus, we conclude that the optimal mean water column velocity values of 0.12 ft/sec to 1.11 ft/sec reported by Reiser and Wesche (1977) are the most-appropriate values to use for assessing the brook trout spawning velocity conditions of the model reach.

Transect mean water column velocity values recorded in the model reach by PFBC staff between 2008 and 2011 ranged from 0.45 to 1.15 ft/sec, with a mean value of 0.72 ft/sec. The mean water column velocity conditions documented in the model reach are well within the optimal range reported in Reiser and Wesche (1977) for spawning brook trout. Raleigh et al. (1984) and PCWA (2010) reported optimal ranges of mean water column velocity values for rainbow trout that ranged from 0.60 ft/sec to 2.30 ft/sec. In general, the mean water column velocity conditions documented in the model reach are also within the optimal range for spawning rainbow trout (Figure 7).

Water Depth

Thalweg

Raleigh (1982) reported a minimum optimal thalweg depth value of 1.38 ft for adult brook trout. Raleigh et al. (1984) reported a minimum optimal thalweg depth value of 1.48 ft for adult rainbow trout (Table 36). Thalweg depth values recorded in the model reach by PFBC staff between 2008 and 2011 ranged from 1.28 ft to 2.18 ft, with a mean value of 1.76 ft. Thalweg depth conditions documented in the model reach were well within the optimal ranges reported for both adult brook trout and adult rainbow trout (Figure 8).

Water Column – Adults

Baker and Coon (1995) and SRBC (1998) reported optimal water column depth values for adult brook trout that ranged from 0.89 ft to 2.63 ft. PCWA (2010) reported a minimum water column depth of 2.20 ft as optimal for adult rainbow trout, and Pert and Erman (1994) observed a statistically significant preference of adult rainbow trout for water column depths over 3.15 ft (Table 36). The optimal depth values mentioned above for adult brook and rainbow trout suggest that adult rainbow trout prefer deeper water than adult brook trout. This conclusion is supported by the findings of Magoulick and Wilzback (1997) who reported both brook and rainbow trout being found significantly more often in deep water microhabitats than would be expected based on habitat availability in a small Pennsylvania stream, and that adult rainbow trout were found in significantly deeper water than adult brook trout.

Transect mean water column depth values recorded in the model reach by PFBC staff between 2008 and 2011 ranged from 0.69 ft to 1.45 ft, with a mean value of 1.12 ft. Transect mean water column depth values were generated by dividing the wetted channel area by the wetted width of each transect. The mean water column depth conditions documented in the model reach were within the optimal ranges reported in Baker and Coon (1995) and SRBC

(1998) for adult brook trout, but well below the optimal depth minimum of 2.20 ft reported in PCWA (2010) for adult rainbow trout (Figure 9).

Water Column – Juveniles

Baker and Coon (1995) and SRBC (1998) reported optimal water column depth values for juvenile brook trout that ranged from 0.49 ft to 1.88 ft. PCWA (2010) reported optimal water column depth values for juvenile rainbow trout that ranged from 1.00 ft to 2.20 ft. In general, the mean water column depth conditions documented in the model reach were within the optimal ranges reported for both juvenile brook trout and juvenile rainbow trout (Figure 10).

Spawning

Reiser and Wesche (1997) reported a minimum criterion of 0.20 ft depth for brook trout spawning, and SRBC (1998) reported optimal water depth values for brook trout spawning that ranged from 0.38 ft to 1.38 ft. PCWA (2010) reported optimal water column depth values for spawning rainbow trout that ranged from 0.60 ft to 1.50 ft. After comparing these reported optimal water depth values for brook and rainbow trout spawning to the water depth values recorded at a combined total of 85 redds (of unknown species origin) in Big Spring Creek by Snyder and Carline (2003) and PFBC staff between 2001 and 2011, we concluded that the optimal depth values reported by SRBC (1998) for spawning brook trout and PCWA (2010) for spawning rainbow trout were appropriate for use on Big Spring Creek. Water depth values recorded at the 85 redds (of unknown species origin) in Big Spring Creek by Snyder and Carline (2003) and PFBC staff ranged from 0.46 ft to 1.75 ft, with a mean value of 1.04 ft (Figure 11).

Substrate Particle Size

Stoneman and Jones (2000) reported coarse gravel (47 mm) as the mean substrate particle associated with brook trout in southern Ontario streams, and that in streams where brook trout coexisted with other trout species, substrate materials tended to be smaller (D90<26.5 mm) than those of allopatric brook trout streams. Stoneman and Jones (2000) also reported that rainbow trout were typically associated with streams with a mean substrate particle size of 99 mm (cobble), substrate materials coarser than those associated with brook trout (Table 36). Substrate data collected in the model reach by PFBC staff in 2009 and 2011 indicate that substrate composition of the model reach corresponded very well with the description of the substrate conditions Stoneman and Jones (2000) associated with brook trout. Furthermore, based on the findings of Stoneman and Jones (2000), the model reach substrate was better suited for brook trout than rainbow trout, especially when taking into consideration the sympatric nature of the Big Spring Creek trout fishery. Model reach substrate data pertinent to the findings of Stoneman and Jones are summarized in Table 37.

Raleigh (1982) and Raleigh et al. (1984) reported minimum criteria of 8% and 10% cobble and larger substrate materials (100 – 400 mm) as optimal escape cover for juvenile brook and rainbow trout, respectively (Table 36). Percent cobble or larger substrate values recorded in the model reach by PFBC staff in 2009 and 2011 ranged from 14.3% to 15.6%, indicating optimal escape cover conditions for both juvenile brook and rainbow trout (Table 38).

Reiser and Wesche (1997), Raleigh (1982), and SRBC (1998) reported optimal substrate particle size range for brook trout spawning that ranged from 3 to 64 mm (fine and coarse gravel). Raleigh et al. (1984) and PCWA (2010) reported a somewhat larger optimal substrate particle size range for rainbow trout spawning that ranged from 5 mm to 100 mm (fine gravel to small cobble). In general, these ranges of optimal substrate materials for brook and rainbow trout spawning were supported by the observations made at Big Spring Creek redds by PFBC staff in 2007 and 2011. For example, coarse gravel (16 – 64 mm) was the predominant substrate at 60% of the Big Spring Creek redds located within the optimal velocity and depth ranges for brook trout discussed above, with fine gravel (2 – 16 mm) the predominant substrate at the remaining 40% of the redds. In contrast, coarse gravel (16 – 64 mm) was the predominant substrate at 74% of the Big Spring Creek redds located within the optimal velocity and depth ranges for rainbow trout discussed above, with fine gravel (2 – 16 mm) the predominant substrate at the remaining 26% of the redds (Figure 12). Substrate composition data recorded in the model reach by PFBC staff in 2009 and 2011 indicated that the model reach consists of approximately 27% fine gravel (2 – 16 mm) and 21% coarse gravel (16 – 64 mm) with fine gravel as the median particle size (Table 38). With nearly 50% of the substrate in the model reach consisting of either fine or coarse gravel, substrate conditions in the model reach were well-suited for both brook and rainbow trout spawning.

Percent Fish Cover

Between 2008 and 2011, PFBC staff quantified fish cover using the method summarized in Simonson et al. (1993) for use in Wisconsin and nearby states. Using this method, fish cover is defined as shelter for a fish that is at least 200 mm (8 in) in total length, and cover features must be at least 1.0 ft long, 1.0 ft wide, and 1.0 ft high, and in water at least 1.0 ft deep (Simonson et al. 1993). Using the method of Simonson et al. (1993), the amount of fish cover in a given stream reach is hard to quantify, since percent fish cover values are strongly influenced by stream discharge and stage conditions, and in the case of Big Spring Creek, seasonal and annual fluctuations in aquatic macrophyte productivity. Simonson et al. (1993) reported a minimum value of 12% fish cover as optimal for lotic systems 10 to 50 m wide (model reach mean width = 14.7 m) (Table 36).

PFBC staff recorded percent cover values in the model reach for adult fish (fish at least 200 mm in length) that ranged from 7.7% to 20.4%, with a mean value of 12.3% (Table 39). Based on the methods of Simonson et al. (1993) used by PFBC staff, and the minimum value of 12% fish cover as optimal for fish at least 200 mm in length, the mean percent fish cover value of 12.3% documented in the model reach indicated that fish cover conditions in the model reach were generally within the optimal range for brook trout at least 200 mm in length. However, percent adult fish cover conditions observed in the model reach were quite variable, and two out of the three years we monitored, these values were substantially below the minimum criterion of 12% for optimal adult fish cover.

During the fish cover surveys conducted by PFBC staff discussed above, PFBC staff also documented the amount of cover available for juvenile fish in the model reach. In general, juvenile fish cover features were defined as shelter at least 0.5 ft long and 0.5 ft wide, with no minimum depth or velocity criteria. Although no optimal cover criteria for juvenile brook or rainbow trout reported in the literature matched the methods used by PFBC staff exactly, the minimum value of 14% cover reported by Raleigh (1982) for juvenile brook trout, and Raleigh et al. (1984) for juvenile rainbow trout, appear to be a reasonable estimates for this parameter (Table 36). Their 14% minimum criterion is based on fish cover in water at least 0.5 ft deep with a velocity of less than 0.5 ft/sec. Between 2008 and 2011, PFBC staff recorded percent cover values for juvenile fish in the model reach that ranged from 25.5% to 32.6%, with a mean value of 30.0% (Table 39). Based on Raleigh (1982) and Raleigh et al. (1984) minimum criteria of 14% cover as optimal for juvenile brook and rainbow trout, fish cover conditions in the model reach were well within the optimal range for both juvenile brook and rainbow trout.

Pre- and Post-2010 Habitat Project and Willow Tree Site Conditions

Water Column Velocity

Adults

Before construction of the 2010 project, transect mean water column velocity values observed in the project area were significantly higher than those of the model reach (Mann-Whitney test p=0.0018 and p=0.0056 in 2008 and 2009, respectively), and generally near or above the upper limit of the optimal velocity range of adult brook trout (Table 40; Figure 13). During June 2011 approximately nine months after construction of the 2010 project, there was no significant difference in the transect mean water column velocity values observed in the model and treatment reaches (Mann-Whitney test p=0.2902), and the range of velocity values recorded in the treatment reach showed a shift toward the center of the optimal velocity range of adult brook trout. Thus, the project successfully attained the objective of reducing the velocity of the waters in the project area to values similar to those of the model reach. However, in both the model and treatment reaches, both before and after the implementation of the 2010 project, mean water column velocity values were well within the optimal range of adult rainbow trout.

No statistical analysis was conducted between the velocity data collected at the model and Willow Tree (RM 3.88) reaches in 2011 because these data were collected under different stream discharge conditions. However, transect mean water column velocity values observed in the Willow Tree reach during 2011 at 30 cfs were substantially lower and less diverse than those observed in the model reach in 2009 when the creek was flowing at a discharge of 32 cfs. In addition, the velocity values recorded in the Willow Tree reach in 2011 were well within the optimal range of adult brook trout, and generally below the minimum optimal range of rainbow trout.

Juveniles

Before construction of the 2010 project, transect mean water column velocity values observed in the project area were generally just below the upper limit of the optimal velocity range of juvenile brook trout and just above the upper limit of juvenile rainbow trout (Table 40; Figure 14). Although the reduction in velocity observed in the treatment reach after the implementation of the 2010 project shifted velocity values toward the center of the optimal velocity range of juvenile brook trout, it also shifted more of these values into the optimal velocity range of rainbow trout.   Velocity values recorded in the Willow Tree reach in 2011 were well within the optimal velocity ranges for both juvenile brook and rainbow trout.

Spawning

Velocity values recorded in both the model and treatment reaches, both before and after the implementation of the 2010 project, were generally within the optimal spawning velocity range of brook trout, and just above the minimum limit of optimal spawning velocity of rainbow trout. The velocity values recorded in the Willow Tree reach in 2011 were generally below the minimum optimal range of rainbow trout (Table 40; Figure 15).

Some project stakeholders have suggested that future habitat enhancement efforts proposed in the Willow Tree reach (RM 3.88) should include reducing stream velocity values to values even lower than those observed in the model reach (RM 4.82). This suggestion is supported by the information presented above, and could be accomplished by maintaining, or slightly reducing, the velocity conditions observed in the Willow Tree reach in 2011. The velocity conditions observed in the Willow Tree reach in 2011 were well within the optimal ranges of adult, juvenile, and spawning brook trout, while being below the minimum optimal range of adult and spawning rainbow trout.

Water Depth

Thalweg

Before the construction of the 2010 project, thalweg depth values recorded in the project area were significantly lower than those of the model reach (Mann-Whitney test $p=0.0000$ in 2008 and 2009), and generally below the optimal ranges of adult brook and rainbow trout. In 2011, after construction of the 2010 project, thalweg depth values recorded in the treatment reach were significantly greater than those of the model reach (Mann-Whitney test $p=0.0109$), and above the minimum optimal thalweg depth of both brook and rainbow trout (Table 41; Figure 16).   Thus, the project exceeded the objective of increasing thalweg depth values of the project area to values similar to those of the model reach.

No statistical analysis was conducted between the 2011thalweg depth data collected at the model and Willow Tree reaches because these data were collected under different stream discharge conditions. However, thalweg depth values observed in the Willow Tree reach during 2011 at 30 cfs were similar to those observed in the model reach in 2009 at a discharge of 32 cfs, and were generally just above the minimum optimal thalweg depth of both brook and rainbow trout (Table 41; Figure 16)   An objective of future habitat enhancement work in the Willow Tree reach should be to reduce thalweg depth conditions in this reach to just below the lower limit of the optimal range for adult rainbow trout.

Water Column – Adults

Prior to constructing the 2010 project, transect mean depth values observed in the project area were significantly lower than those of the model reach (Mann-Whitney test p=0.0000 in 2008 and 2009), and generally below the minimum optimal range of adult brook trout. After construction of the 2010 project, mean depth values observed in the treatment reach were within the optimal range of adult brook trout, and significantly greater than those of the model reach (Mann-Whitney test p=0.0082) (Table 42; Figure 17). Thus, the project exceeded the objective of increasing the mean depth of the project area to values similar to those of the model reach.

In both the model and treatment reaches, before and after the implementation of the 2010 project, mean water column depth values were well below the minimum optimal range value of 2.20 ft for adult rainbow trout reported in PCWA (2010). However, in hind-sight, this minimum value of 2.20 ft may not be appropriate for use on Big Spring Creek. For example, the minimum optimal value reported for adult rainbow trout thalweg depth of 1.48 ft reported in Raleigh (1982) is considerably less than the 2.20 value reported by PCWA (2010) for mean depth, and there is no obvious explanation for why this should be. Furthermore, the large number of adult rainbow trout (622 fish >175 mm per km) documented in the treatment reach after the implementation of the 2010 project, suggests that the mean water column depth conditions in that reach, at that time (mean=1.27 ft, s.d.=0.17), should have been within, or very close to, the optimal range for adult rainbow trout.

No statistical comparison was made between the 2011 transect mean depth data collected at the model and Willow Tree reaches because these data were collected under different stream discharge conditions. However, transect mean depth values observed in the Willow Tree reach in 2011 at 30 cfs were substantially lower than those observed in the model reach in 2009 when discharge was 32 cfs. Mean water column depth values recorded in the Willow Tree reach were generally centered on the lower limit of optimal depth for adult brook trout and suboptimal for rainbow trout.

Water Column – Juveniles

In both the model and treatment reaches, both before and after the implementation of the 2010 project, mean water column depth values were within the optimal range of juvenile brook trout. Model reach mean water column depth values, both before and after the implementation of the 2010 project, were also within the optimal range of juvenile rainbow trout as well. However, treatment reach depth values were below the optimal range of rainbow trout before the implementation of the 2010 project, and within the optimal range of juvenile rainbow trout after the implementation of the project (Figure 18). Mean water column depth values recorded in the Willow Tree reach in 2011were within the optimal range of juvenile brook trout, and generally just below the optimal range of juvenile rainbow trout.

Spawning

Mean water column depth values recorded in the model and treatment reaches, both before and after the implementation of the 2010 project, and in the Willow Tree reach in 2011, were within the optimal range of both spawning brook and rainbow trout. However, the increase in depth in the treatment reach after the implementation of the 2010 project shifted the depth values of this reach toward the upper limit of the optimal range of spawning brook trout depth (Figure 19).

Wetted width/Depth Ratio

Prior to constructing the 2010 project, transect wetted width/depth ratio values observed in the project area were significantly greater than those of the model reach (p=0.0003 and p=0.0004 in 2008 and 2009, respectively). In 2011, after construction of the 2010 project, there was no significant difference in transect wetted width/depth ratio values observed in the model and treatment reaches (Mann-Whitney test p=0.1770) (Table 43; Figure 20). Thus, the project successfully attained the objective of replicating the general channel morphology characteristics of the model reach in the 2010 project area.

No statistical analysis was performed on the 2011 transect wetted width/depth ratio data collected at the model and Willow Tree reaches because these data were collected under different stream discharge conditions. However, transect wetted width/depth ratio values observed in the Willow Tree reach in 2011 at 30 cfs were substantially higher than those observed in the model reach in 2009 when discharge was 32 cfs (Figure 20). In general, the Willow Tree reach is substantially wider (mean width=77.7, s.d. =14.0) than the model reach (mean width=48.4, s.d. =13.3) and the treatment reach after the implementation of the 2010 project (mean width=45.8, s.d. =10.5). An objective of future habitat enhancement work in the Willow Tree reach will be to decrease wetted width/depth ratio conditions in this reach to more closely resemble the general channel morphology conditions of the model reach. This objective is likely readily attainable using construction techniques similar to those employed in the 2010 project, and may result in improved water temperature and dissolved oxygen conditions in the Willow Tree and downstream reaches of Big Spring Creek.

Substrate Particle Size

Substrate composition of the model, treatment, and Willow Tree reaches are very similar, and correspond well with the substrate characteristics Stoneman and Jones (2000) describe for brook trout streams. The median particle size category in all reaches consists of fine gravel (2 – 16 mm). Coarse gravel or smaller substrate (<64 mm) accounted for at least 80% of the substrate in all reaches across all monitoring events. Cobble substrate, which Stoneman and Jones (2000) reported as being the mean particle size associated with rainbow trout, accounted for 13.0% of the substrate composition of the model reach, and increased in the treatment reach from 5.4% before the implementation of the 2010 project to 11.2% after. No cobble substrate was documented in the willow tree reach (Table 44).

Based on the minimum criteria of 10% and 12% cobble and larger substrate materials (100 – 400 mm) as optimal escape cover for juvenile brook and rainbow trout, respectively (Raleigh 1982; Raleigh et al 1984), the percent cobble and larger materials values recorded in all reaches, across all years, were within the optimal range for both juvenile brook and rainbow trout. However, it should be noted that the percent cobble and larger substrate values recorded in the treatment reach changed from 10.3% before the implementation of the 2010 project to 16.5% after implementation. This change was primarily due to the addition of cobble and boulder material used as fill in the project (see Table 44).

With respect to fine and coarse gravel composition, and the potential implications of these components to brook and rainbow trout spawning conditions in the model, treatment, and Willow Tree reaches, fine and coarse gravel accounted for at least 40% of the substrate in all reaches, across all monitoring events. However, coarse gravel accounted for a larger percentage of the substrate than fine gravel in the treatment reach, while the opposite was observed in both the model and Willow Tree reaches (Table 44). Thus, based on the assumption that brook trout tend to use finer substrate materials for spawning than rainbow trout, the substrate conditions in the model and Willow Tree reaches may be better suited for brook trout spawning than the treatment reach. Also, it should be noted that coarse gravel appears to be rather limited in the Willow Tree reach (based on the single substrate composition sample available for this reach), and this may be having a negative effect on rainbow trout spawning activity in this reach.

Fish Cover

Between 2008 and 2011, PFBC staff quantified cover conditions for adult fish (at least 200 mm in length) in the model, treatment, and Willow Tree reaches using the methods described in Simonson et al. (1993) discussed above. Prior to implementation of the 2010 project, percent adult fish cover values recorded in the model reach were quite variable and ranged from 7.7% to 20.4% (mean = 14.0%). During this same timeframe, percent adult fish cover values recorded in the treatment reach ranged from 2.7% to 3.0% (mean = 2.8%), and were well below the minimum criterion of 12% for optimal adult fish cover. After the implementation of the 2010 project, the percent adult fish cover value recorded in the treatment reach increased dramatically to 19.9%, while only a slight increase in percent adult fish cover was recorded in the model reach from 2009 to 2011 (Table 45; Figure 21).

The combined effects of somewhat elevated stream discharge and high aquatic macrophyte production in 2008 substantially influenced water depth conditions and percent fish cover values recorded in the model reach in 2008, relative to the percent fish cover value observed in this same reach in 2009 and 2011. The influence of aquatic macrophyte productivity on percent fish cover values is clearly evident when comparing fish cover values recorded in the model reach in 2008 when the creek was flowing at 36 cfs and under high aquatic macrophyte production versus the values recorded in 2011 at a discharge of 41 cfs and low aquatic macrophyte production.

In spite of these complicating factors, the percent adult fish cover values recorded at the model and treatment reaches before and after the construction of the 2010 project clearly show that the project resulted in a substantial increase in the amount of adult fish cover in the project reach, especially cover other than that provided by aquatic macrophytes and available to fish throughout the year and during periods when aquatic macrophyte production is low (Table 45).

In 2011, the percent adult fish cover value recorded in the Willow Tree reach exceeded the minimum criterion of 12% for optimal adult fish cover. However, cover other than that provided by aquatic macrophytes is very limited in the Willow Tree reach, suggesting that fish cover may be limited during periods of low aquatic macrophyte productivity (Table 45; Figure 22). Future habitat enhancement work in the Willow Tree reach should include an objective of increasing adult fish cover provided by objects other than aquatic macrophytes, if the fish cover conditions of the Willow Tree reach are to more closely resemble those of the model reach. This objective should be readily attainable using construction techniques similar to those used in the 2010 project.

Between 2008 and 2011, PFBC staff quantified cover conditions for juvenile brook and rainbow trout (less than 200 mm in length) in the model, treatment, and willow tree reaches. Prior to implementation of the 2010 project, percent juvenile fish cover values recorded in the model reach ranged from 25.5% to 32.6% (mean = 29.0%). During this same timeframe, percent juvenile fish cover values recorded in the treatment reach ranged from 25.0% to 34.1% (mean = 29.6%), and were well above the minimum criterion of 14% for optimal juvenile fish cover. After the implementation of the 2010 project, percent juvenile fish cover values of 31.9% and 33.7% were recorded in the model and treatment reaches, respectively. Both values were well above the minimum criterion of 14% for optimal juvenile fish cover (Table 45; Figure 23). In 2011, a percent juvenile fish cover value of 53.0% was recorded in the willow tree reach. This value dramatically exceeded the minimum optimal criterion of 14% for juvenile fish cover.

In addition to the percent adult and juvenile fish cover data discussed above, PFBC staff documented the distance from the wetted channel mid-point of each monitoring transect to the closest adult fish cover. Distance to closest fish cover (DCFC) values reflect the amount and distribution of fish cover within the channel. For example, when comparing two stream reaches with similar percent fish cover values, but substantially different distance to closest fish cover (DCFC) characteristics, one could conclude that fish cover in the reach with the higher DCFC values would be less evenly distributed throughout the channel. Conversely, fish cover in the reach with the lower DCFC values would be more evenly distributed throughout the reach, which is the preferred condition.

Prior to constructing the 2010 project, DCFC values observed in the project area were significantly greater than those of the model reach (Mann-Whitney test p=0.0093 and p=0.0149 in 2008 and 2009, respectively). In 2011, there was no significant difference in the DCFC values observed in the model and treatment reaches after construction of the project (Mann-Whitney test p=0.0949) (Table 46; Figure 24).

Although no statistical analysis was performed on the 2011 DCFC data collected at the model and Willow Tree reaches, the DCFC values observed in the willow tree reach in 2011 at 30 cfs were substantially greater, and much more variable, than the values recorded in the model reach in 2009 at 32 cfs (Table 46; Figure 24).

Based on the adult fish cover data presented above and electrofishing survey results conducted in the model, treatment, and Willow Tree reaches in 2009 and 2011, immediately before and after the implementation of the 2010 project (Table 47), percent adult fish cover provided by objects other than aquatic macrophytes and the mean distance to closest adult fish cover appear to be the most important fish cover features influencing the abundance of adult trout (>175 mm) in these segments of Big Spring Creek (Figure 25; Figure 26). Additional analysis of physical habitat and fishery data from Big Spring Creek may provide further insight into the specific physical habitat variables that most strongly influence the trout fishery of the creek. Ideally, critical physical habitat/fishery relationships will be revealed and incorporated into the design of the proposed Pennsylvania Turnpike Commission-funded Phase 2 habitat enhancement project downstream of the 2010 project.

Pre- and post-implementation physical habitat monitoring data clearly show that the 2010 habitat enhancement project objectives of creating velocity, depth, and fish cover conditions similar to those observed in the model reach were successfully attained within one year of completion of the project. In addition, wetland and channel stability monitoring activities required by the PADEP and the U.S. Army Corps of Engineers indicated that the constructed wetlands are developing in accordance with conditions outlined in the permits issued by these agencies, and the constructed channel was stable with no signs of instability or channel erosion.

Water Temperature and Dissolved Oxygen

In general, water temperature and dissolved oxygen values recorded in the segment of Big Spring Creek immediately downstream from the model reach (RM 4.83) to the Stone Arch Bridge (RM 2.64), can fluctuate dramatically between late-afternoon and early-morning hours during the summer months, and the degree of daily fluctuation increases with increasing distance downstream from the spring source. For example, between late-afternoon on 30 June 2011 and early-morning on 1 July 2011, water temperature values fluctuated between 13.3 and 10.9°C (-2.4°C) at the downstream end of the 2010 project area (RM 4.31), and between 16.9 and 11.0°C (-5.9°C) approximately 1.7 miles downstream at the Stone Arch Bridge (RM 2.64) (Figure 27). Similarly, dissolved oxygen values fluctuated between 10.6 and 9.3 mg/l (-1.3 mg/l) and between 12.2 and 7.8 mg/l (-4.4 mg/l), at these same sites and times, respectively (Figure 28). Water temperature and dissolved oxygen data collected during June and July 2011 are summarized in Table 48.

Raleigh (1982) reported summer optimal water temperatures for brook trout range from 11 to 16°C, and Raleigh et al. (1984) reported optimal temperatures for rainbow trout range from 12 to 18°C. On the hot and clear afternoon of 30 June 2011, water temperature at the downstream end of the 2010 project reach (13.3°C) was within the optimal range for brook trout. However, water temperature increased downstream from the 2010 project, and at the downstream end of the proposed Phase 2 project reach (Willow Tree reach, RM 3.88), water temperature increased to 15.6° C and approached the upper limit of the optimal range of brook trout. Downstream of the Phase 2 project reach, a water temperature value of 16.9°C, just above upper limit of optimal temperature for brook trout, was recorded at both Nealy Road and the Stone Arch Bridge. All afternoon water temperature values recorded on 30 June 2011 were within the optimal range of rainbow trout (Figure 29).

The U.S. Environmental Protection Agency (U.S. EPA, 1986) reported a minimum water column dissolved oxygen concentration value of 8 mg/l as representing nearly maximal protection of salmonid fishery resources. Early-morning dissolved oxygen values recorded at the Stone Arch Bridge in June and July 2011 were consistently just below 8 mg/l. The lowest early-morning dissolved oxygen concentrations were observed on 29 July 2011 under foggy conditions, between the downstream end of the proposed Phase 2 project reach (Willow Tree Parking Lot, RM 3.88) downstream to the Stone Arch Bridge, with concentrations below the 8 mg/l criteria observed at both the Nealy Road Bridge and Stone Arch Bridge. Although no water temperature or dissolved oxygen data was collected prior to construction of the 2010 project, data collected by PFBC staff in the summer of 2011 indicate that the 2010 project may be having a positive effect on the dissolved oxygen conditions of Big Spring Creek. Early-morning dissolved oxygen concentration values recorded at the downstream end of the 2010 project site (RM 4.31) consistently exceeded the values recorded at all other sites (Figure 30). It appears that the localized areas of elevated turbulence associated with the water staging devices constructed during the 2010 project are aerating the creek's waters.

The combined influence of temperature and dissolved oxygen concentration, expressed as dissolved oxygen percent saturation, is probably of greater importance to the overall health of the trout fishery between the Willow Tree reach and the Stone Arch Bridge, than the individual water temperature and dissolved oxygen concentration values discussed above. Davis (1975) developed a multi-tiered system of dissolved oxygen percent saturation criteria for protecting freshwater salmonids in water temperatures that ranged from 0 to 25°C. Based on the water temperature values recorded on Big Spring Creek in the early-morning hours in the summer of 2011, dissolved oxygen percent saturation values of >76% represent optimal conditions for salmonids (Davis, 1975). Interestingly, using Davis' criteria to assess the percent dissolved oxygen saturation conditions of Big Spring Creek in the summer of 2011, yields the same general results discussed above regarding dissolved oxygen concentration data expressed as mg/l. Early-morning dissolved oxygen values recorded at the Stone Arch Bridge in June and July 2011 were consistently just below the 76% saturation criteria. The lowest early-morning dissolved oxygen percent saturation values were observed on 29 July 2011 under foggy conditions, between the downstream end of the proposed Phase 2 project reach (Willow Tree Parking Lot, RM 3.88) downstream to the Stone Arch Bridge (RM 2.64), with percent saturation values below the 76% criteria observed at both the Nealy Road Bridge (RM 3.47) and Stone Arch Bridge (Figure 31).

In addition to the minimum dissolved oxygen percent saturation criteria developed by Davis (1975), the U.S. EPA (1986) reported a maximum criterion of 110% saturation for total dissolved gases for the protection of freshwater and marine aquatic life. This criterion is for the total of all dissolved gases (nitrogen, oxygen, and argon), not just dissolved oxygen. Thus, it cannot be readily assumed that the dissolved oxygen percent saturation values recorded between the Willow Tree site and the Stone Arch Bridge on the afternoon of 30 June 2011, that ranged from 114% to 131%, exceeded the total dissolved gases maximum criterion of 110% (Figure 32). However, taking into consideration the findings of Snyder and Carline (2003), who recorded a total dissolved gases % saturation value of 114.8% at the spring source of Big Spring Creek in February of 2002, and that the dissolved oxygen component of this value was only 89% saturation, it would be reasonable to conclude that total dissolved gases, between the downstream end of the Willow Tree reach and the Stone Arch Bridge, may be having a negative impact on the aquatic living resources of this segment of the creek. Snyder and Carline (2003) concluded the following, based on their single total dissolved gases sample collected at the spring source:

"… total dissolved gas concentrations at BS0 (spring source) are acutely lethal for most species of salmonids and would be expected to limit the ability of trout to reproduce in close proximity to the Big Spring. Additional measurements of total dissolved gases should be taken to determine whether gas supersaturation is a constant problem at the spring source and to document the distance that this condition persists downstream from the spring."

In order to reduce the potential negative effects of total dissolved gases from approximately the Willow Tree reach downstream, efforts should be initiated to prevent supersaturated dissolved oxygen levels and the warming of the creek's waters as they move downstream from the source springs. Progress could be made toward the attainment of both of these objectives by narrowing the over-widened areas of the creek, whereby reducing: (1) the amount of water surface area exposed to solar radiation, (2) aquatic macrophyte photosynthesis levels, (3) the rate at which the creek's waters warm as they flow downstream, and (4) dissolved oxygen and total dissolved gases percent saturation values. Objectives of future habitat enhancement work in the Willow Tree reach will be to decrease wetted width/depth ratio conditions in this reach to more closely resemble the general channel morphology conditions of the model reach, and to increase turbulence and aeration of the creek's waters. These objectives could be attained by using construction techniques similar to those employed in the 2010 project.

Summary of Results of the 2010 Project

The 2010 project reduced the velocity of the waters in the project area to values similar to those of the model reach and within the optimal range of adult, juvenile, and spawning brook trout. However, in both the model and treatment reaches, both before and after the implementation of the 2010 project, mean water column velocity values were also within the optimal range of adult, juvenile, and spawning rainbow trout. It is possible that additional benefit to brook trout over rainbow trout could have been realized if velocity values in the project area (mean = 0.75 ft/sec) were reduced to values slightly lower than those of the model reach (<0.60 ft/sec), creating velocity conditions optimal for all life stages of brook trout, while being below the optimal range for rainbow trout spawning.

Before the construction of the 2010 project, thalweg and mean water column depth values recorded in the project area were significantly lower than those of the model reach, and generally below the optimal ranges of adult brook and rainbow trout. After construction of the 2010 project, thalweg and mean water column depth values recorded in the treatment reach were significantly greater than those of the model reach, and within the optimal thalweg depth ranges of both adult brook and rainbow trout and the optimal mean water column depth range of adult brook trout. Thus, the project exceeded the objective of increasing thalweg and water column depth values of the project area to values similar to those of the model reach. It is possible that additional benefit to adult brook trout over adult rainbow trout could have been realized if the thalweg and mean water column depth conditions created in the project area were similar to those observed in the model reach, not deeper than those of the model reach.

In both the model and treatment reaches, both before and after the implementation of the 2010 project, mean water column depth values were within the optimal range of both spawning brook and rainbow trout and juvenile brook trout. However, the construction of the 2010 project resulted in a shift of mean water column depth conditions for juvenile rainbow trout from suboptimal to optimal conditions.

Prior to constructing the 2010 project, transect wetted width/depth ratio values observed in the project area were significantly greater than those of the model reach. After construction of the 2010 project, there was no significant difference in transect wetted width/depth ratio values observed in the model and treatment reaches.

Substrate composition of the model and treatment reaches were very similar, and corresponded well with the substrate characteristics described in the literature for brook trout streams. The median particle size category in both reaches both before and after the construction of the 2010 project consisted of fine gravel (2 – 16 mm). The most dramatic change in substrate conditions associated with construction of the 2010 project was an increase in the percent cobble (64 – 250 mm) substrate. Percent cobble substrate increased in the treatment reach from 5.4% before the implementation of the 2010 project to 11.2% after.

With respect to fine and coarse gravel composition, and the potential implications of these components to brook and rainbow trout spawning conditions in the model and 2010 project treatment reaches, fine and coarse gravel accounted for at least 40% of the substrate in both the model and treatment reaches, both before and after construction of the 2010 project. However, coarse gravel accounted for a larger percentage of the substrate than fine gravel in the treatment reach, both before and after the construction of the 2010 project, while the opposite was observed in the model reach. Furthermore, coarse gravel was required to be added to the treatment reach during the construction of the 2010 project in order to prevent scouring under the log water staging devices constructed in the project. Because rainbow trout tend to use coarser substrate materials for spawning than brook trout (although there is much overlap in habitat suitability between the two species for spawning substrate), and the relatively high abundance of coarse gravel in the treatment reach, both before and after the construction of the 2010 project, substrate conditions suitable for rainbow trout spawning are more readily available in the treatment reach than the model reach.

After the implementation of the 2010 project, the percent adult fish (fish at least 200 mm in length) cover value recorded in the treatment reach increased dramatically from an average of 2.8% to 19.9%, while only a slight increase in the value was recorded in the model reach. The percent adult fish cover values recorded before and after the construction of the 2010 project clearly show that the project resulted in a substantial increase in the amount of adult fish cover in the project reach, especially cover other than that provided by aquatic macrophytes and available to fish throughout the year and during periods when aquatic macrophyte production is low. Thus, the 2010 project resulted in an increase in cover for adult brook and rainbow trout that exceeded the minimum criterion of 12% for optimal adult fish cover, and exceeded the amount of adult fish cover observed in the model reach.

Distance to closest fish cover (DCFC) values reflect the amount and distribution of fish cover within the channel. Prior to constructing the 2010 project, DCFC values observed in the project area were significantly greater than those of the model reach. In 2011, there was no significant difference in the DCFC values observed in the model and treatment reaches after construction of the project.

Early-morning dissolved oxygen concentration values recorded at the downstream end of the 2010 project site consistently exceeded the values recorded at all other sites. It appears the localized areas of elevated turbulence associated with the water staging devices constructed during the 2010 project are aerating the creek's waters, and having a positive effect on the early-morning dissolved oxygen conditions in this segment of the creek.

Summary of Existing Conditions in the Proposed Phase 2 Project Reach

The following summary of recommendations for the proposed Phase 2 project to be constructed with PTC funds in the Willow Tree reach are based on the assumption that the wild trout fishery in this reach will be a sympatric brook-rainbow trout fishery, in spite of any efforts that may be conducted to eradicate rainbow and brown trout from this reach. However, the fishery will be managed to optimize the brook trout fishery.

Transect mean water column velocity values observed in the Willow Tree reach during 2011 at 30 cfs were substantially lower and less diverse than those observed in the model reach in 2009 when the creek was flowing at a discharge of 32 cfs. However, the average mean water column velocity value of 0.46 ft/sec recorded in the Willow Tree reach in 2011 was well within the optimal range of adult, juvenile, and spawning brook trout. In contrast to brook trout, the velocity values recorded in the Willow Tree reach in 2011 were within the optimal velocity range for juvenile rainbow trout, but generally below the minimum optimal range of adult and spawning rainbow trout. In general, maintaining the existing mean water column velocity conditions in the Willow Tree reach during future habitat enhancement activities should provide optimal velocity conditions for all life stages of brook trout, and sub-optimal conditions for adult and spawning rainbow trout.

Based on the affinity of rainbow trout for deep water, an objective of future habitat enhancement work in the Willow Tree reach should be to reduce the thalweg depth conditions in this reach to just below the lower limit of the optimal range for adult rainbow trout (1.48 ft). Future habitat enhancement work in the willow tree reach should increase mean water column depth conditions in this reach slightly, to conditions similar to those of the model reach (mean = 1.10 ft) which are within the optimal range for all life-stages of brook trout, and generally suboptimal mean water column depth conditions for adult rainbow trout.

Transect wetted width/depth ratio values observed in the Willow Tree reach are substantially higher than those observed in the model. In general, the Willow Tree reach is substantially wider (mean width=77.7 ft) than the model reach (mean width=48.4). Future habitat enhancement work in the Willow Tree reach should decrease the wetted width/depth ratio conditions in this reach to more closely resemble the general channel morphology conditions of the model reach.

In general, substrate composition of the Willow Tree reach was similar to that of the model reach, and corresponded well with the substrate characteristics described in the literature for brook trout streams. The median particle size category in both reaches consists of fine gravel (2 – 16 mm). With respect to fine and coarse gravel composition, and the potential implications of these components to brook and rainbow trout spawning conditions in the Willow Tree reach, fine and coarse gravel accounted for at least 40% of the substrate in this reach. However, fine gravel accounted for a larger percentage (30.6%) of the substrate than coarse gravel (10.2%) in the Willow Tree reach. Coarse gravel appears to be rather limited in the Willow Tree reach, and this may be having a negative effect on rainbow trout spawning activity in this reach. Future habitat enhancement work in the Willow Tree reach should focus on maintaining or increasing the percent composition of fine gravel substrate (2 – 16 mm) in this reach.

In 2011, the percent adult fish cover value recorded in the Willow Tree reach exceeded the minimum criterion of 12% for optimal adult fish cover, as well as, the percent adult fish cover value recorded in the model reach. However, cover other than that provided by aquatic macrophytes is very limited in the Willow Tree reach, suggesting that fish cover may be limited during periods of low aquatic macrophyte productivity. Future habitat enhancement work in the willow tree reach should include an objective of increasing adult fish cover provided by objects other than aquatic macrophytes, if the fish cover conditions of the Willow Tree reach are to more closely resemble those of the model reach.

DCFC values observed in the Willow Tree reach in 2011 were substantially greater (mean = 13.4 ft), and much more variable than the values recorded in the model reach. Between 2008 and 2011, the mean DCFC value recorded in the model reach was 6.1 ft. Thus, in general, adult trout in the Willow Tree reach have to travel twice as far from the mid-point of the wetted channel to reach cover, than fish in the model reach. In addition to increasing adult fish cover provided by objects other than aquatic macrophytes, future habitat enhancement work in the Willow Tree reach should include an objective of reducing the DCFC conditions to those similar to the model reach.

Based on the fish cover and electrofishing data collected in the model, treatment, and Willow Tree reaches in 2009 and 2011, immediately before and after the implementation of the 2010 project, percent adult fish cover provided by objects other than aquatic macrophytes and the mean distance to closest adult fish cover appeared to be the most important fish cover features influencing the abundance of adult fish in these segments of Big Spring Creek. Additional analysis of physical habitat and fishery data from Big Spring Creek may provide further insight into the specific physical habitat variables that most strongly influence the trout fishery of the creek. Additional analysis of the fishery, depth, velocity, fish cover, water temperature, and dissolved oxygen data collected between 2008 and 2012 will be conducted prior to developing the final design of the Phase 2 plan in an attempt to identify other critical relationships between the fishery and physical habitat data collected from Big Spring Creek, and these relationships will be incorporated into the final design of the proposed habitat enhancement project in the Willow Tree reach.

At the downstream end of the proposed Phase 2 Project reach (Willow Tree reach, RM 3.88), late-afternoon water temperatures approach the upper limit of the optimal range of brook trout. Downstream of the Phase 2 project reach, late-afternoon water temperature values exceed the upper limit of optimal temperature for brook trout. The lowest early-morning dissolved oxygen concentrations were observed between the downstream end of the proposed Phase 2 project reach downstream to the Stone Arch Bridge. However, dissolved oxygen percent saturation, is probably of greater importance to the overall health of the trout fishery between the Willow Tree reach and the Stone Arch Bridge. The lowest early-morning dissolved oxygen percent saturation values were observed between the downstream end of the proposed Phase 2 project reach downstream to the Stone Arch Bridge, with percent saturation values below the 76% criteria observed at both the Nealy Road Bridge and Stone Arch Bridge. Total dissolved gases, between the downstream end of the proposed Phase 2 project reach and the Stone Arch Bridge, may be having a negative impact on the aquatic living resources of this segment of the Big Spring Creek.

Big Spring Creek Management Options: Implications of Native versus Non-native Species

Option 1: Multi-species fishery with long-term optimization of the brook trout fishery

The goal pertaining to this management option is to continue to manage Big Spring Creek, sections 01 and 02, as a mixed brook, rainbow, and brown trout fishery and to manage the fishery preferentially for brook trout without initial removal of non-native salmonids. This mandates that any future habitat enhancement of Big Spring Creek preferentially be designed to favor brook trout. As such, the response of the brook trout fishery to habitat enhancement will measure success of existing and future projects. Objectives pertaining to this management option are: 1) achieve and maintain a total salmonid density comprised of brook, brown and rainbow trout of at least 90.00 kg/ha in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects; and 2) achieve and maintain a total salmonid species abundance composition of at least 70 percent brook trout to 30 percent rainbow and brown trout in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects. The biomass criterion pertaining to the first objective is based on brook and rainbow trout biomass estimates at long-term monitoring sites located at RM 4.77 and RM 4.29 and considers biomass estimates from 2005 through 2012, with the exception of 2010 as no surveys were completed during that year. Due to the small sample size and the presence of outlier values, nonparametric statistics were used to determine a median biomass value of 93.81 kg/ha, thus the 90.00 kg/ha goal. The abundance criterion pertaining to the second objective is based on abundance estimates at a long-term monitoring site located at RM 4.77, which was used as a model for the 2010 habitat enhancement project. During 2009, 2011 and 2012 brook trout comprised 72 percent, 71 percent and 82 percent (median = 72 percent), respectively, of the total estimated abundance of brook and rainbow trout at RM 4.77.

The brook trout was historically the only salmonid native to Pennsylvania and much of the eastern US; however, its historic range has been drastically reduced largely due to habitat degradation, as well as introduction and bioinvasion of non-native salmonids (i.e. brown trout and rainbow trout). The existence of non-native salmonids in most waterways can be attributed largely to stocking practices initiated during the 19th century (Benke 2002). Current brook trout distributions in Pennsylvania are often reduced to small, relatively high-elevation headwater streams, but were historically distributed throughout a much greater proportion of Pennsylvania's waters. Similar distribution patterns were described in the southern Appalachian Mountains (Flebbe 1994; Larson and Moore 1985).

A variety of biotic and abiotic factors such as interference competition (De Staso and Rahel 1994), adaptability or preference to different thermal (Paul and Post 2001) or pH (Kocovsky and Carline 2005) gradients, or condition-specific competition (Dunson and Travis 1991) may lead to non-native salmonids out competing brook trout in certain habitats. Regardless of the mechanism, arguments can be made for brook trout restoration; however, fisheries management agencies must not only consider ecological factors associated with native species management but also social and economic issues. To gain public support for restoration activities, it is critical to have an understanding of public values regarding brook trout and non-native species such as rainbow trout. Ethical values are based on the notion that organisms have intrinsic value and should be protected from negative impacts of human activities (Perring et al. 1992); however, the value society places on a particular species may be similar among salmonids (Quist and Hubert 2004). As such, any management activity that negatively impacts one species to benefit another may draw strong public opposition. Additionally, individuals may value the historic occurrence of a non-native species in a particular fishery.

Perhaps the most disparity among brook, rainbow and brown trout occurs with perceived differences among their recreational value. In many cases, replacement of brook trout with non-native rainbow or brown trout would likely have only a slight negative effect or even a positive effect on the recreational fishery. In the western US, angler preference among salmonids is minor or nonexistent and evidence suggests many anglers prefer non-native salmonids over natives due to their perceived superior sporting qualities (i.e. fighting ability, jumping ability, etc.) and their larger maximum total length (Quist and Huber 2004). Some anglers that frequently fish Big Spring Creek have reported preference for rainbow trout compared to brook trout to PFBC staff due to their larger body size (personal communications). As such, considering values when setting management policy governing native species management, ethical and historical values are likely unaffected by non-native salmonids, while recreational value could possibly increase in fisheries where brook trout have been replaced by non-native salmonids.

The economic issues associated with brook trout restoration are directly related to the previously described social issues. In the western US, Quist and Hubert (2004) asserted that the net economic benefit linked to replacement of cutthroat trout *Oncorhynchus clarki* by non-native salmonids depends on the values society attributes to a particular species, and this concept is likely applicable to native species management in Pennsylvania as well. Non-native salmonids are likely to be considered ecological and social substitutes for natives in most cases (Quist and Hubert 2004), thus their presence is likely to result in no net economic change to the value of the fishery; however, removal through either active or passive means would likely be ineffective and quite costly.

Genetic purity and diversity of candidate populations for native species restoration efforts should be considered when formulating management plans involving isolation management and removal of non-native species. National Park Service policy mandates that native species restoration efforts focus only on populations of genetically pure, native strains of brook trout in the Great Smoky Mountains National Park (Steve Moore, National Park Service, personal communications). Additionally, suitable sized stream reaches and effective population sizes (N_e) needed to maintain long-term population viability should be determined when formulating native species restoration plans (Hilderbrand and Kershner 2000). In such cases when stream sections are too small to maintain a minimum N_e required to preserve a viable native species population or when preservation efforts target genetically impure or naturalized hatchery-reared strains of salmonids, restoration efforts may be better focused on other waters. Applying this philosophy to Big Spring Creek would likely preclude Big Spring Creek from consideration for non-native removal management options as the genetics of the current brook trout population residing in Big Spring Creek likely more closely resemble that of the genetics of brook trout produced at the former BSFCS and Huntsdale State Fish Hatchery than that of the historic Big Spring Creek-Conodoguinet Creek Basin strain brook trout. Genetic testing would be required to understand the genetics of the current brook trout population if the goal of the restoration is to restore the historic Big Spring Creek-Conodoguinet Creek Basin strain brook trout.

Electrofishing surveys conducted in the 2010 project reach in 2009 and 2012 approximately one year before and two years after the construction of the 2010 project documented substantial increases in brook and rainbow trout abundance and biomass. Brook trout abundance increased in the 2010 project area from 199 to 697 fish/km, an increase of 250 percent (Table 20; Table 34). This increase in abundance coupled with the narrowing of the channel resulted in a total brook trout biomass increase from 5.24 to 40.93 kg/ha, an increase of 681 percent in the project area. During this same timeframe, brook trout abundance at sampling station 0102 located at RM 4.77, increased from 1,642 to 2,669 fish/km, an increase of 63 percent, and brook trout biomass increased from 63.59 to 90.34 kg/ha, an increase of 42 percent. Between 2009 and 2012, brook trout abundance and biomass increased in both the 2010 project and the upstream sampling station 0102; however, increases in these parameters in the 2010 project reach were more substantial than the increases documented in the control reach located at RM 4.77.

Rainbow trout abundance increased in the 2010 project area from 563 to 2,137 fish/km, an increase of 280 percent (Table 20; Table 30). This increase in abundance coupled with the narrowing of the channel resulted in a total rainbow trout biomass increase from 53.51 to 182.88 kg/ha, an increase of 242 percent. During this same timeframe, rainbow trout abundance at sampling station 0102 at RM 4.77 decreased from 654 to 588 fish/km, a decrease of 10 percent, and rainbow trout biomass increased from 35.44 to 68.00 kg/ha, an increase of 92 percent. Similar to the changes observed in the brook population discussed above, rainbow trout biomass increased in both the 2010 project area and sampling station 0102 between 2009 and 2011; however, rainbow trout abundance increased in the 2010 project area while decreasing in the control reach at RM 4.77. Increases in abundance and biomass in the 2010 project reach were more substantial than the changes documented in the control reach located at RM 4.77.

Electrofishing results at RM 3.88 in 2011 and 2012 indicate that this reach supports relatively low abundance and biomass of brook trout compared to the upstream reaches of Big Spring Creek, and were 73 fish/km and 3.23 kg/ha during 2011 and 49 fish/km and 1.87 kg/ha during 2012. Brook trout abundance and biomass values recorded at RM 3.88 in 2011 and 2012 were substantially lower than the values recorded in the 2010 project area during 2009 before construction of the project. The sampling station located at RM 3.88 also supported substantially fewer rainbow trout (427 fish/km, 16.75 kg/ha) during 2011than the upstream reaches of Big Spring Creek. However, during 2012 rainbow trout abundance and biomass substantially increased to 1,034 fish/km and 62.70 kg ha, respectively. During fall 2011, PFBC staff noted the presence of what appeared to be signs of trout spawning activity between the downstream limit of the 2010 habitat enhancement project and RM 3.88.

Although not clearly stated in the overall goal of the 2010 habitat enhancement project, it was assumed that the attainment of the goal be evaluated based on the response of the trout fishery in the project area, with emphasis on the response of the brook trout fishery. Therefore, to assess project success based on response of the fishery, additional fishery evaluations over a period of several years will be required (Platts and Nelson 1988; Bayley 2002; Roni et al. 2005). Examples of trout population monitoring studies conducted after the implementation of habitat enhancement activities include: Cox (2011), mixed brook and brown trout fishery in Vermont, four years; Hunt (1967), brook trout in Wisconsin, six years; and Wills and Dexter (2011), brown trout in Michigan, eight years. Other fishery professionals have reported a range of 5 to 10 years of post-implementation monitoring being needed to detect changes in fish abundance associated with habitat enhancement activities (Bayley 2002; Roni et al. 2005).

To adequately measure the response of the fishery to the 2010 habitat enhancement project, a period of at least seven years from completion will be required to pass before the success of the project can be determined. This proposed timeframe for evaluating project success is based on the recommendations of Roni et al. (2005) and the findings of Hunt (1976) and Willis and Dexter (2011). Roni et al. (2005) recommend five years of post-implementation monitoring to detect changes in fish abundance associated with habitat enhancement activities. Hunt (1976) monitored the response of the wild brook trout population in the spring-fed Lawrence Creek, Wisconsin, for a period of six years following intensive renovation of stream channel morphometry. He reported that brook trout abundance and biomass increased significantly during the first three years after construction of the project, but that the maximum abundance and biomass was not attained until five years after implementation of the project. Furthermore, he observed that the number of brook trout over 200 mm (8 inches) continued to increase throughout the entire six year post-implementation monitoring period. Interestingly, in the acknowledgement section of Hunt (1976), he writes: “The idea for modifying long-term research projects to include a waiting period between treatment and post-treatment phases evolved out of a discussion with Robert F. Carline, a fellow biologist in the Cold Water Group. I am grateful for his suggestion.” Wills and Dexter (2011) monitored wild brown trout in Michigan for a period of eight years after the implementation of a habitat enhancement project. They reported that the most dramatic increase in the density of 8 to 12 inch brown trout did not occur until five years after the implementation of the project.

The segment of Big Spring Creek from the downstream portion of the 2010 habitat enhancement project downstream to RM 3.88 is an excellent candidate for future habitat enhancement activity. The existing physical habitat and fish cover conditions, the presence of low-density brook and rainbow trout populations, and the presence of trout spawning areas in this reach provide an excellent foundation for future habitat enhancement efforts with a high probability of successfully increasing brook and rainbow trout abundance and biomass.

As previously stated, Big Spring Creek, sections 01 and 02, are currently managed with Catch-and-Release Fly-Fishing only regulations. During the period of 1976 through the spring of 1995, Big Spring Creek, sections 01 and 02, were managed with special regulations that allowed for the harvest of two trout per day greater than or equal to 15 inches. This special regulation was intended to encourage harvest of rainbow and brown trout and to protect the majority of the brook trout population (Greene 2002). In the spirit of preferential management for brook trout, staff recommend removal of the current Catch-and-Release Fly-Fishing Only Regulations (58 PA Code §65.14) in favor of Miscellaneous Special Regulations (58 PA Code §65.24) at Big Spring Creek, sections 01 and 02, beginning January 2014. If adopted by the Board of Commissioners, this regulation will restrict gear to fly-fishing tackle only and catch-and-release of brook trout year-round, but permit harvest of five rainbow and brown trout per day greater than or equal to seven inches from 8 a.m. on the opening day of trout season through Labor Day. From the day after Labor Day through the last day of February, Extended Season Regulations will apply (daily harvest of three rainbow and brown trout in combination greater than or equal to seven inches), and harvest of any trout, regardless of species, will be prohibited from March 1 through 8 a.m. on the opening day of trout season. This special regulation is intended to encourage harvest of rainbow and brown trout while protecting the brook trout population. It is not anticipated that harvest of rainbow and brown trout from this portion of Big Spring Creek will be substantial; however, it would provide fly-fishing anglers the opportunity harvest fish if they so choose and would further aide in maintaining and promoting a wild trout community dominated by brook trout.

Under this multi-species management option, Big Spring Creek, sections 01 and 02, would be managed as a mixed brook, rainbow, and brown trout fishery, using the habitat and fisheries management recommendations described below.

Option 1 Recommendations

1) Manage Big Spring Creek, sections 01 and 02, as a mixed brook, rainbow, and brown trout fishery. Future fisheries management and habitat enhancement will be tailored to favor brook trout to the greatest extent possible.
2) Conduct a public meeting to inform the public of the PFBC's fisheries management and habitat management plans.
3) Implement Miscellaneous Special Regulations at Big Spring Creek, sections 01 and 02, beginning January 2014. This regulation will restrict gear to fly-fishing tackle only and catch-and-release of brook trout, but permit harvest of five rainbow and brown trout per day greater than or equal to seven inches.
4) Design future habitat enhancement projects based on the physical habitat and fish cover characteristics of the model reach used in the 2010 habitat enhancement project, with modifications as needed based on the response of the fishery to the 2010 habitat enhancement project and available published literature. These habitat modifications will be designed to provide brook trout with optimal lotic habitat conditions.
5) Immediately proceed with the proposed Pennsylvania Turnpike Commission (PTC)-funded habitat enhancement project in the segment of Big Spring Creek immediately downstream from the 2010 habitat enhancement project. Project modifications compared to the 2010 project will include the addition of fine gravel fill material placed upstream of any log water staging devices constructed, decreasing thalweg depth to just below the lower limit of the optimal range for adult rainbow trout, increasing mean water column

depth to conditions similar to the model reach and maintaining velocity conditions to those below the conditions of the model reach, where possible. In addition, the proposed PTC-funded project will preserve the existing physical habitat conditions in areas known to be, or suspected to be, spawning areas for trout.

6) Continue to monitor the fishery of Big Spring Creek, sections 01 and 02, to track the response of the brook, rainbow, and brown trout populations to the 2010 habitat enhancement project and any future projects. The objectives pertaining to this management option are to: 1) achieve and maintain a total salmonid density comprised of brook, rainbow, and brown trout greater than or equal to 90.00 kg/ha in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects; and 2) achieve and maintain a total salmonid species abundance composition of at least 70 percent brook trout to 30 percent rainbow and brown trout in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects. Should these objectives not be attained seven years post-completion of any habitat enhancement efforts, staff will re-evaluate means to achieve previously stated objectives including a one-time removal of non-native salmonids.

Option 2: Accelerated optimization of the brook trout fishery

The goal pertaining to this option is to manage the Big Spring Creek salmonid fishery preferentially for brook trout with removal of non-native salmonids. Objectives pertaining to this management option are: 1) achieve and maintain a total salmonid density comprised of brook, rainbow, and brown trout of at least 90.00 kg/ha in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects; and 2) achieve and maintain a total salmonid species abundance composition of at least 90 percent brook trout to 10 percent rainbow and brown trout in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects. The rationale for the biomass criterion pertaining to the first object is explained in *Option 1* above. The abundance criterion pertaining to the second objective was developed to provide brook trout with a greater advantage than provided for in *Option 1*, but acknowledges that it is unlikely that all non-native salmonids will be completely eradicated from Big Spring Creek during removal efforts.

Anthropogenic activities have resulted in drastically altered natural systems in Pennsylvania and throughout the US leading to declines of native fish fauna. Additionally, bioinvasion of non-natives fishes is a leading cause attributed to negative impacts to native fishes, and limits effectiveness of native species conservation (Miller et al. 1989; Quist and Hubert 2004). In the southern Appalachian Mountains, introduction of rainbow trout has frequently been attributed to declines in brook trout populations throughout their native range (Moore et al. 1983; Larson and Moore 1985; Kulp and Moore 2000).

To eliminate or reduce encroachment of non-native fish species, natural resource agencies throughout the US have utilized a variety of techniques to remove non-native species. These include electrofishing removal, chemical renovation, and isolation management through the use of barriers to prevent re-invasion of non-native species (Moore et al. 1983; Larson and Moore 1985; Thompson and Rahel 1996; Kulp and Moore 2000; Avenetti et al. 2006; Meyer et al. 2006; Carmona-Catot et al. 2010). Chemical renovation (i.e. antimycin-A; rotenone) has commonly been used during native fish restoration efforts in the western US; however, the use of piscicides has not been widely accepted in the eastern US due to more abundant nongame fish communities and public opposition to the associated fish mortality (Kulp and Moore 2000). More commonly, natural resource agencies mechanically remove non-native species by electrofishing upstream from natural or manmade barriers to prevent re-colonization. Electrofishing removals have resulted in varied success, are labor intensive over a relatively long time period, and can be quite costly (Moore et al. 1983; Larson and Moore 1985; Thompson and Rahel 1996; Kulp and Moore 2000; Qusit and Hubert 2004; Avenetti et al.; 2006; Meyer et al. 2006; Carmona-Catot et al. 2010).

Based on the ecology of sympatric brook and rainbow trout populations, published literature describing native species restoration efforts, and trout population trends in Big Spring Creek, removal of rainbow trout would likely result in the greatest benefit to the Big Spring Creek brook trout fishery and optimize their potential for expansion. Chemical renovation through the use of toxicants is not the preferred removal option due to potential negative impacts to the nongame fish community and the likelihood of public opposition to mortality of rainbow and brown trout. Therefore, multiple electrofishing removals of rainbow and brown trout are recommended.

Kulp and Moore (2000) described a multiple removal effort that was successful in eliminating rainbow trout from a small southern Appalachian stream. Other removal efforts have not effectively eliminated non-native bioinvasives from study waters due to reduced electrofishing effort, reduced electrofishing efficiency due to habitat complexity, or failure to prevent emigration or reintroduction following removal (Moore et al. 1983; Thompson and Rahel 1996, 1998; Kulp and Moore 2000; Avenetti et al. 2006; Meyer et al. 2006).

Removal Logistics

Natural resource agencies throughout the US have utilized isolation management as a means to protect and restore native species from adverse interactions with non-native species (Thompson and Rahel 1998; Kruse et al. 2001; Novinger and Rahel 2003). Typically, isolation management entails the use of an existing barrier or construction of one if none exists, mechanical or chemical removal of fish upstream from the barrier, and re-introduction of native species upstream from the barrier (Avenetti et al. 2006). Despite the common use of barriers as a component of isolation management for native species restoration, there is a lack of information in the published literature evaluating their success preventing re-colonization from non-native fishes. (Thompson and Rahel 1998; Kruse et al. 2001; Novinger and Rahel 2003; Avenetti et al. 2006). Of those reported, all failed to prevent reinvasion of non-natives (Avenetti et al. 2006).

Despite this, a barrier to prevent re-establishment of removed rainbow and brown trout is needed to successfully eliminate non-native trout from the treatment reach of Big Spring Creek. In this regard, there are two options for meeting the previously stated objectives of attaining and maintaining a total salmonid biomass of greater than or equal to 90.00 kg/ha with a species abundance composition of at least 90 percent brook trout to 10 percent rainbow and brown trout in Big Spring Creek, sections 01 and 02: 1) install a barrier in the vicinity of Nealy Road (downstream limit of Section 02), or 2) utilize the existing Laughlin Mill Dam at the downstream limit of Section 04 as a barrier to upstream fish passage. Each of the two options is presented below.

Isolation management was utilized by the PFBC in the past in an attempt to protect the Big Spring Creek brook trout population from competition with non-native salmonids. In 1977, the PFBC constructed a fish passage barrier at RM 4.47 (downstream limit of current Section 01), and electrofishing efforts were used to remove rainbow and brown trout upstream from the barrier annually through 1993. By 1993, the barrier had deteriorated and its efficacy to prevent upstream migration of salmonids was lost (Greene 2002). Additionally, evidence suggests that anglers frequently captured rainbow and brown trout downstream from the barrier, and relocated them to upstream areas of Big Spring Creek (Dave Miko, PFBC, personal communication). These factors, coupled with frequent (daily) escapement of hatchery-reared rainbow and brown trout from the BSFCS, precluded efforts to manage for an allopatric brook trout population in the upstream-most 0.59 river-miles of Big Spring Creek. In 1994, the barrier was dismantled and efforts to remove rainbow and brown trout from this portion of stream were discontinued.

Based on the current status of the Big Spring Creek trout fishery, salmonid composition and abundance dynamics, and marked differences in physical habitat along its length, the appropriate location for a barrier to be constructed is in the vicinity of Nealy Road. Streams represent a linear continuum of heterogeneous habitats in which movements by stream fishes among spatially distinct habitats are often needed to complete different life stages (Schlosser 1991, 1995; Fausch et al. 2002; Kuhn et al. 2008). The spatial distribution of habitats needed to complete different life stages is intimately tied to the movement patterns of stream fishes (Dunning et al. 1992; Gown et al. 1994; Schrank and Rahel 2004; Kuhn et al. 2008). The highest density of wild trout reside in the portion of Big Spring Creek upstream from Nealy Road (Miko and Kuhn 2011). Additionally, it is likely that the majority, if not all spawning activities occur upstream of this point as well (personal observations). Therefore, to reduce the risk of fragmenting an already spatially limited brook trout population the barrier should be placed in the vicinity of Nealy Road and not at the previous location at RM 4.47.

Two barrier designs have been considered: 1) a barrier constructed from gabions commonly used by the Wyoming Game and Fish Department (WGFD), and 2) an electronic fish screen manufactured by Hydrolox. The WGFD gabion barrier design is likely the less costly of the two options; however, a small impoundment would be required upstream from the barrier to facilitate sufficient elevation drop necessary to prevent upstream fish passage. Conversely, the Hydrolox electronic fish screen would likely not create an upstream-impounded area and the rotating screen would pass drifting aquatic vegetation and other debris. This option is more costly, however, and would require a constant power source. A more detailed review of available options and permitting implications is needed to determine feasibility and most appropriate design for potential use at Big Spring Creek; however, recent correspondence with PADEP staff indicated that they would be reluctant to permit a fish passage barrier at Big Spring Creek unless impacts to the regimen and ecology of the stream are avoided and minimized to the greatest extent practicable and a need for the project is demonstrated. Additionally, PADEP staff indicated that it would be difficult to justify the need for a new barrier when an existing one currently exists at the Laughlin Mill Dam (John Chripczuk, PADEP, personal communications).

Assuming barrier placement at Nealy Road, rainbow and brown trout would be mechanically removed through towboat electrofishing from Nealy Road upstream to the spring source (sections 01 and 02), a distance of 1.52 river-miles. Kulp and Moore (2000) determined that five, three-pass depletion removal efforts over a period of two years were required to eliminate rainbow trout from Mannis Branch, a small southern Appalachian stream (858 m length of stream; 3.1 m mean wetted width). Other published research suggested reduced effort will likely fail to extirpate non-native trout from the treatment reach (Moore et al. 1983; Larson and Moore 1985; Thompson and Rahel 1996; Meyer et al. 2010).

Failure to fully eliminate non-native trout from the treatment reach would likely result in the need for prolonged and intensive electrofishing removals due to potential compensatory responses from remaining non-natives (Avenetti et al. 2006; Meyer et al. 2006). Most removal efforts documented in the published literature were conducted on small, headwater streams and the treatment reaches were substantially shorter in length and narrower than Big Spring Creek. Therefore, staff recommend that rainbow and brown trout currently residing in Big Spring Creek, sections 01 and 02, be removed via towboat electrofishing conducted for a period of three years with three, three-pass depletion efforts per year. Electrofishing efforts will begin at Nealy Road and progress upstream to the spring source. The treatment reach will consist of six sub-sections (electrofishing stations), and a minimum crew of eight Bureau of Fisheries staff will conduct the removals at a rate of one site per day. Thus, the removal will require six workdays to complete. Additionally, one hatchery truck and one Fish Culturist will be required to transport removed rainbow and brown trout to a predetermined receiving water.

Further investigation is needed to determine appropriate receiving waters for rainbow and brown trout salvaged from Big Spring Creek, sections 01 and 02. One option is to relocate salvaged fish to sections 03 and 04 of Big Spring Creek immediately downstream from the potential barrier; however, several factors would likely preclude attainment of the stated objectives upstream from the barrier. Additionally, it is unlikely that a self-sustaining sympatric population of rainbow and brown trout would develop downstream from the barrier. Low density of wild trout reside in this portion of the creek and physical habitat is markedly different from the upstream treatment reach (sections 01 and 02) (Miko and Kuhn 2011). Additionally, little to no habitat suitable for successful spawning activities occurs downstream from Section 02 primarily due to extreme sedimentation of substrates. As such, it is likely that rainbow and brown trout relocated to this portion of Big Spring Creek would not successfully reproduce and consequently would only persist in this stream reach over the short term.

Big Spring Creek, sections 03 and 04, are managed in the PFBCs ATW program and regulated with Commonwealth Inland Water regulations. Therefore, wild rainbow and brown trout relocated to this portion of Big Spring Creek would be subject to angler harvest and likely experience high fishing mortality. Staff do not recommend imposing restrictive regulations to protect relocated trout due to high use from anglers targeting stocked brook trout.

Finally, the immediate juxtaposition of the proposed restoration reach to the mixed rainbow and brown trout population downstream from the barrier would likely result in anglers catching rainbow and brown trout downstream from the barrier and transporting them upstream from the barrier, thus compromising the native species restoration effort. Anecdotal evidence suggests that anglers and guide services that currently fish Big Spring Creek do not specifically target brook trout, but rather prefer to catch rainbow trout due to their larger total length.

To avoid these potential problems, fish salvaged from Big Spring Creek, sections 01 and 02, could be relocated to Section 05 of Big Spring Creek downstream from the Laughlin Mill Dam. Big Spring Creek, Section 05, is 100 percent private, closed to fishing; therefore, angling opportunities for relocated rainbow and brown trout would be limited to landowners along this stream reach and their guests. PFBC policy regarding allocation of adult stocked trout mandates that stream sections have no more than 25 percent of the section length closed to angling (posted) in order to be included in the adult trout-stocking program. Although relocated trout are not PFBC hatchery-reared fish, this rationale should be considered when choosing receiving waters for fish salvaged from the upstream portions of Big Spring Creek. Additionally, the Laughlin Mill Dam is a top-spill structure impounding Big Spring Creek and creates a large and shallow pool upstream from the dam. Given this, it is likely that the thermal regime of Big Spring creek, Section 05, experiences seasonally elevated water temperatures unfavorable to salmonids.

Finally, fish salvaged from Big Spring Creek could be relocated to waters other than Big Spring Creek. To reduce expenditures and maximize efficiency, receiving waters should be in relative close proximity to Big Spring Creek. Staff do not recommend stocking salvaged fish into Class A designated stream sections or waters managed with special angling regulations. The intent is to stock fish salvaged from Big Spring Creek into nearby stream sections to provide local anglers with immediate recreational angling opportunities, and not to supplement existing Class A trout populations or establish new self sustaining populations. The vast majority of fish salvaged would be rainbow trout. Relative to wild brown trout or brook trout streams, there are very few wild rainbow trout fisheries in Pennsylvania other than in limestone spring streams. Based on existing information pertaining to wild rainbow trout fisheries in Pennsylvania, there is low potential to develop other wild rainbow trout fisheries than what currently exist. Additionally, stocking wild brown trout or brook trout fisheries with salvaged rainbow trout would increase competition for limited resources and likely have a negative impact on existing wild trout populations with low potential for stocked rainbow trout to establish self-sustaining populations. As such, potential receiving waters include Green Spring Creek (7B), Section 03, Middle Spring Creek (7B), Section 02, Rowe Run (7B), Section 02, Children’s Lake (7E), Fuller Lake (7E), and Yellow Breeches Creek (7E) Section 02. These waters are local ATWs, are limestone spring influenced with suitable water quality for rainbow trout, and are characterized by no or low density of wild trout.

An alternate barrier location is the Laughlin Mill Dam. Presently, the only remaining mill dam impounding Big Spring Creek is the Laughlin Mill Dam located at the downstream portion of Section 04 in the Town of Newville. The Laughlin Mill Dam is located at RM 1.27; 3.79 river-miles downstream from the spring source; therefore rainbow and brown trout would have to be removed from the upper 3.79 river-miles of Big Spring.

Utilizing the existing Laughlin Mill Dam as a barrier, removal of rainbow and brown trout from Big Spring Creek, sections 01 and 02, would follow procedures described above; however, fish should also be removed from sections 03 and 04. Low densities of rainbow and brown trout occur in Big Spring Creek, sections 03 and 04 (Miko and Kuhn 2011). Additionally, physical habitat characteristics of this portion of Big Spring Creek are markedly different from those described in sections 01 and 02. The physical habitat of Big Spring Creek, sections 03 and 04, is characterized by relatively long and deep pools with thick layers of sediment that cover substrates. Several methodologies are considered below to address the removal of the wild rainbow and brown trout from sections 03 and 04.

Toxicants could be used to remove rainbow and brown trout from sections 03 and 04. Given the habitat characteristics of these sections, electrofishing removal would likely fail to eradicate rainbow and brown trout from this portion of Big Spring Creek, leading to potential re-colonization of section 01 and 02 by the remaining trout; however, the use of toxicants also has limitations in this setting. Numerous spring sources entering this portion of the stream would dilute concentrations of toxicants, thus resulting in failure to eradicate all rainbow and brown trout. Additionally, fish toxicants are not species specific and high mortality of non-target species would occur. Finally, strong public opposition to the use of toxicants is likely.

Alternatively electrofishing could be utilized to remove rainbow and brown trout from sections 03 and 04. Success relative to the use of toxicants would likely be lower due to a variety of challenges presented by the physical habitat within these sections. As previously stated, physical habitat characteristics of the downstream portions of Big Spring Creek differ markedly from upstream reaches of the stream. In numerous locations along this reach of Big Spring Creek, water depth, heavy sedimentation of stream substrates, and instream woody debris preclude efficient electrofishing removal efforts. The removal of several large blockages caused by downed trees may be required to improve the capture rate of trout and allow for the effective and safe use of the sampling gear. Should woody debris removal occur where needed, rainbow and brown trout removal efforts would utilize a combination of towboat and small johnboat electrofishing techniques. Due to low densities of wild trout known to reside in this portion of Big Spring Creek relative to upstream reaches and adverse conditions for safe and efficient electrofishing, staff recommend one single-pass electrofishing removal during mid-summer of the first year of electrofishing removal efforts to coincide with removal efforts conducted upstream from Nealy Road (downstream limit of Section 02). This effort would likely not need to be repeated during the subsequent two years of removal efforts in upstream sections 01 and 02 due to the low density of wild trout residing in this portion of the stream. However, this single-pass effort could be repeated, if needed, during future electrofishing removal efforts should the wild trout population exceed the target abundance species composition of 90 percent brook trout to 10 percent rainbow and brown trout. It is likely, however, that a portion of the non-native salmonid populations will remain following removal efforts in sections 03 and 04, and individuals will likely re-colonize the upstream portions of the stream.

To facilitate removal by electrofishing, the treatment reach of sections 03 and 04 will consist of four sub-sections (electrofishing stations), and a minimum crew of five Bureau of Fisheries staff will conduct the removals at a rate of one site per day. Thus, the removal will require four workdays to complete. Additionally, one hatchery truck and one Fish Culturist will be required to transport removed rainbow and brown trout to a predetermined receiving water.

Alternatively, a final option is to make no effort dedicated solely to remove brown and rainbow trout from sections 03 and 04, but rather rely on routine electrofishing efforts in sections

01 and 02 to remove brown and rainbow trout from Big Spring Creek that have moved upstream. This approach recognizes that there will always be a component of wild rainbow and brown trout that exist throughout Big Spring Creek. It also recognizes that periodic efforts to remove wild rainbow and brown trout from Big Spring Creek will likely need to be conducted for the foreseeable future in order to maintain the target of a 90 percent brook trout and 10 percent other non-native wild trout species mix.

As outlined in the multi-species fishery option (*Option 1)*, staff recommend imposing a Miscellaneous Special Regulation at Big Spring Creek, section 01 and 02, beginning January 2014. This proposed regulation at Big Spring Creek, sections 01 and 02, would continue to restrict gear to fly-fishing tackle only and catch-and-release of brook trout, but permit harvest of five rainbow and brown trout per day greater than or equal to seven inches. It is unlikely that harvest of rainbow and brown trout in this portion of Big Spring Creek would be substantial; however, it would provide fly-fishing anglers the opportunity to harvest fish if they so choose and would further aide in maintaining a wild trout population dominated by brook trout.

Option 2 Recommendations

1) Manage Big Spring Creek, sections 01 and 02, primarily as a brook trout fishery but at an accelerated pace compared to Option 1. Future fisheries management and habitat enhancement will be tailored to optimize the potential of the brook trout fishery to the greatest extent possible; including mechanical removal of non-native salmonids. The objectives pertaining to this management option are to: 1) achieve and maintain a total salmonid density comprised of brook, rainbow, and brown trout greater than or equal to 90.00 kg/ha in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects; and 2) achieve and maintain a total salmonid species abundance composition of at least 90 percent brook trout to 10 percent rainbow and brown trout in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects.
2) Conduct a public meeting to inform the public of the PFBC's intent to manage Big Spring Creek, sections 01 an 02, to optimize the brook trout fishery, and to implement recommendations presented below.
3) Implement Miscellaneous Special Regulations at Big Spring Creek, sections 01 and 02, beginning January 2014. This regulation will restrict gear to fly-fishing tackle only and catch-and-release of brook trout, but permit harvest of five rainbow and brown trout per day greater than or equal to seven inches.
4) Design future habitat enhancement projects based on the physical habitat and fish cover characteristics of the model reach used in the 2010 habitat enhancement project, with modifications as needed based on the response of the fishery to the 2010 habitat enhancement project and available published literature. These habitat modifications will be designed to provide brook trout with optimal lotic habitat conditions.
5) Immediately proceed with the proposed Pennsylvania Turnpike Commission (PTC)-funded habitat enhancement project in the segment of Big Spring Creek immediately downstream from the 2010 habitat enhancement project. Project modifications compared to the 2010 project will include the addition of fine gravel fill material placed upstream of any log water staging devices constructed, decreasing thalweg depth to just below the

lower limit of the optimal range for adult rainbow trout, increasing mean water column depth to conditions similar to the model reach and maintaining velocity conditions to those below the conditions of the model reach, where possible. In addition, the proposed PTC-funded project will preserve the existing physical habitat conditions in areas known to be, or suspected to be, spawning areas for trout.

6) Utilizing the existing Laughlin Mill Dam located at the downstream limit of Section 04 at RM 1.27 as a barrier preventing upstream fish movement, remove rainbow and brown trout beginning 2014 from Big Spring Creek, sections 01 through 04, utilizing the previously described electrofishing methodologies. Rainbow and brown trout residing in Big Spring Creek, sections 01 and 02, will be removed via towboat electrofishing conducted for a period of three years with three, three-pass depletion efforts per year. Additionally, rainbow and brown trout residing in sections 03 and 04 will be removed with one single-pass electrofishing effort during the first year of removals. Removal efforts will begin prior to future habitat enhancement in Section 02.
7) Relocate rainbow and brown trout salvaged from Big Spring Creek to waters in relative close proximity. Potential receiving waters include Green Spring Creek (7B), Section 03, Middle Spring Creek (7B), Section 02, Rowe Run (7B), Section 02, Children's Lake (7E), Fuller Lake (7E), and Yellow Breeches Creek (7E) Section 02.
8) Conduct monitoring of the Big Spring Creek salmonid fishery at historic sampling stations located in sections 01 and 02 at RM 4.96, RM 4.77, RM 4.47, RM 4.29, and RM 3.88. If the estimated abundance (number per kilometer) of brook trout determined during monitoring falls below 90 percent of the total salmonid abundance composition, staff will again remove non-native salmonids during the following year.

Conclusion and Final Recommendations

Non-native fishes that become naturalized are frequently attributed to declines of native fish populations and substantially limit success of native fish species restoration efforts (Wilcove et al. 1998; Ritchter et al. 1997; Miller et al. 1989; Sheldon 1988). However, naturalized non-native species can provide valuable sport fisheries and are commonly stocked in waters outside their native range, providing local and regional recreational and economic benefit. Due to habitat degradation and declining native fish assemblages, fisheries management agencies must decide among tradeoffs regarding game, non-game, native, and non-native species management (Beamesderfer 2000). Fisheries management agencies must also decide whether non-native game fish management is compatible with native fish restoration efforts, and formulate appropriate policy. Restoration of native fishes depends on an understanding of the ecological systems and processes, as well as social and economic issues (Quist and Hubert 2004).

The PFBC recognizes the history and unique nature of Big Spring Creek's brook trout fishery, and is committed to managing this resource preferentially for brook trout. However, the genetic composition of the brook trout residing in Big Spring Creek is not known, and is likely more similar to brook trout that were produced at the former BSFCS than that of the historic Big Spring Creek strain of brook trout. We also recognize the social and economic value of the rainbow and brown trout component of the Big Spring Creek salmonid fishery. As previously stated, the upstream portion of Big Spring Creek currently supports the highest density of wild rainbow trout in Pennsylvania, and many anglers who fish the stream value this component of the fishery. Due to the high density of rainbow trout known to occur in Big Spring Creek, as well as complexity of habitat characterizing the stream, removal efforts would be quite costly, require substantial staff time and effort, and would likely be ineffective over the long-term.

For these reasons and others presented in this document, staff recommend the follow course of action for the future management of the Big Spring trout fishery:

1) Manage Big Spring Creek, sections 01 and 02, under Option 1. Future fisheries management and habitat enhancement will be tailored to favor brook trout to the greatest extent possible.
2) Conduct a public meeting to inform the public of the PFBC's intent to continue the current strategy of managing Big Spring Creek, sections 01 and 02, as a multi-species trout fishery.
3) Implement Miscellaneous Special Regulations at Big Spring Creek, sections 01 and 02, beginning January 2014. This regulation will restrict gear to fly-fishing tackle only and catch-and-release of brook trout, but permit harvest of five rainbow and brown trout per day greater than or equal to seven inches.
4) Design future habitat enhancement projects based on the physical habitat and fish cover characteristics of the model reach used in the 2010 habitat enhancement project, with modifications as needed based on the response of the fishery to the 2010 habitat enhancement project and available published literature. These habitat modifications will be designed to provide brook trout with optimal lotic habitat conditions.
5) Immediately proceed with the proposed Pennsylvania Turnpike Commission (PTC)-funded habitat enhancement project in the segment of Big Spring Creek immediately downstream from the 2010 habitat enhancement project. Project modifications compared to the 2010 project will include the addition of fine gravel fill material placed upstream of any log water staging devices constructed, decreasing thalweg depth to just below the lower limit of the optimal range for adult rainbow trout, increasing mean water column depth to conditions similar to the model reach and maintaining velocity conditions to those below the conditions of the model reach, where possible. In addition, the proposed PTC-funded project will preserve the existing physical habitat conditions in areas known to be, or suspected to be, spawning areas for trout. .
6) Continue to monitor the fishery of Big Spring Creek, sections 01 and 02, to track the response of the brook, rainbow, and brown trout populations to the 2010 habitat enhancement project and any future projects. The objectives pertaining to this management option are to: 1) achieve and maintain a total salmonid density comprised of brook, rainbow, and brown trout greater than or equal to 90.00 kg/ha in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects; and 2) achieve and maintain a total salmonid species abundance composition of at least 70 percent brook trout to 30 percent rainbow and brown trout in Big Spring Creek, sections 01 and 02, within seven years of completed habitat enhancement projects. Should these objectives not be attained seven years post-completion of any habitat enhancement efforts, staff will re-evaluate means to achieve previously stated objectives including a one-time removal of non-native salmonids.

Summary of Fishery and Habitat Management Recommendations

- Develop clearly-stated, measureable, time-bound objectives that will effectively and objectively assess the long-term success of the proposed Phase 2 project.
- It is possible that additional benefit to brook trout over rainbow trout could have been realized in the 2010 project area if velocity values were reduced to values slightly lower than those of the model reach, creating optimal velocity conditions for all life stages of brook trout, while being below the optimal range for rainbow trout spawning. In general, maintaining the existing mean water column velocity conditions in the Phase 2 project reach should provide optimal velocity conditions for all life stages of brook trout, and sub-optimal conditions for adult and spawning rainbow trout.
- The 2010 project exceeded the objective of increasing thalweg and water column depth values to values similar to those of the model reach. It is possible that additional benefit to adult brook trout over adult rainbow trout could have been realized in the 2010 project area, if the thalweg and mean water column depth conditions created in the project area were similar to those observed in the model reach. Based on the affinity of rainbow trout for deep water, the Phase 2 project will be designed to reduce the thalweg depth conditions in this reach to just below the lower limit of the optimal range for adult rainbow trout (1.48 ft), while slightly increasing mean water column depth to conditions similar to those of the model reach (mean = 1.10 ft) which are within the optimal range for all life-stages of brook trout, and suboptimal conditions for adult rainbow trout.
- During construction of the 2010 project, coarse gravel was required to be added to the treatment reach to prevent scouring under the log water staging devices. Rainbow trout tend to use coarser substrate materials for spawning than brook trout, and based on the very high abundance of young-of-the-year rainbow trout observed in the project area immediately after the construction of the project, the 2010 project most likely increased the amount of substrate suitable for rainbow trout spawning in the project area. Although future habitat enhancement work in the Phase 2 project reach may require the use of coarse gravel to stabilize some devices, the volume of coarse gravel used should be kept to a minimum, and fine gravel should be used where possible. In addition, more-detailed analysis should be performed during the design phase of the project, to create velocity, substrate, and depth conditions that are optimal for spawning brook trout, but suboptimal for spawning rainbow trout.
- After the implementation of the 2010 project, the percent adult fish cover value recorded in the treatment reach increased dramatically from an average of 2.8% to 19.9% (minimum optimal criterion of 12%). It is possible that additional benefit to brook trout over rainbow trout could have been realized in the 2010 project area, if fish cover conditions more closely resembling those of the model reach (i.e., less adult fish cover) were created in the project area. Fish cover other than that provided by aquatic macrophytes is very limited in the Phase 2 project reach, suggesting that fish cover may be limited during periods of low aquatic macrophyte productivity. Future habitat enhancement work in the Phase 2 project reach should focus on increasing adult fish cover provided by objects other than aquatic macrophytes, and creating percent adult fish cover and distance to closest adult fish cover conditions similar to those of the model reach.

- Two barrier designs were considered: 1) a barrier constructed from gabions commonly used by the Wyoming Game and Fish Department (WGFD), and 2) an electronic fish screen manufactured by Hydrolox. The WGFD gabion barrier design is likely the less costly of the two options. However, recent correspondence with PADEP staff indicated that PTC mitigation funds could not be used to cover the costs associated with constructing a barrier. Furthermore, they indicated they would be reluctant to permit a fish passage barrier on Big Spring Creek when a barrier currently exists at the Laughlin Mill Dam in Newville.
- Efforts must be incorporated into the management of both Sections 01 and 02 to reduce the percent composition of rainbow trout as staff do not believe it is possible to design a habitat enhancement project that will exclude rainbow trout, since there is significant overlap in most habitat suitability components of brook and rainbow trout. In fact, there were many rainbow trout in Big Spring Creek before the 2010 project was constructed and these fish are still present. One management option is to allow adequate time (a minimum of seven years from the completion of the project) for the fish community to respond to the habitat enhancement work conducted in 2010, and then determine if the long-term result of the project is a trout community comprised of 70% brook trout. This option is recommended by staff. Another option is immediate removal of as many rainbow trout as possible prior to construction of the Phase 2 project via a large scale electrofishing effort coupled with stocking the rainbow trout in nearby waters open to harvest. The objective under this option would be a trout community comprised of 90% brook trout. With both options, it is recommended that a regulation be developed to allow for the selective harvest of rainbow and brown trout from Big Spring.
- Objectives of future habitat enhancement work in the Willow Tree reach will include narrowing the over-widened areas of the creek, reducing: (1) the amount of water surface area exposed to solar radiation, (2) aquatic macrophyte photosynthesis levels, (3) the rate at which the creek's waters warm as they flow downstream, and (4) dissolved oxygen and total dissolved gases percent saturation values, and increasing water turbulence to aerate the creek's waters.

PFBC Division of Habitat Management staff will work closely with the project designer throughout the design of the Phase 2 project to insure that the approach outlined above will be incorporated into the Phase 2 plan. In addition, PFBC staff will conduct additional analyses of all physical habitat, fish cover, and electrofishing data collected in the model, 2010 project, and proposed phase 2 project reaches, in an attempt to identify the physical habitat and fish cover parameters that appear to be influencing the brook and rainbow trout fisheries in these segments of Big Spring Creek. If any relationships that appear to selectively provide brook trout with some benefit that is not advantageous to rainbow trout are identified, this information will be incorporated into the Phase 2 project design, in attempt to maximize the benefit of the project to brook trout.

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Table 1. Physical characteristics of Big Spring Creek (7B), sections 01 and 02, Cumberland County.

Physical characteristics	Section 01	Section 02
USGS quadrangles	Newville	Newville
upstream section limit	spring source; 40°07'42"/77°24'26"	former Piper Mill Dam; 40°08'11"/77°24'22"
downstream section limit	former Piper Mill Dam; 40°08'11"/77°24'22"	Nealy Road Bridge; 40°08'57"/77°24'24"
length (km)	0.95	1.50
mean Width (m)	15.57	16.53
area (ha)	1.48	2.48

Table 2. Sampling station locations, lengths and average widths for Section 01 and 02, Big Spring Creek (7B), Cumberland County, surveyed during August 2009, 2011 and 2012**.**

Section	Station river mile	Downstream limit	Length (m)	Mean width (m)
01	4.77	300 m downstream from the McCracken Mill Dam; 40°07'56"/77°24'27"	300	15.2
01	4.47	former Piper Milll Dam; 40°08'11"/77°24'22"	366	21.4
02	4.29	300 m downstream from the former Piper Milll Dam; 40°08'20"/77°24'24"	300	11.1
02	3.88	PFBC "Willow Tree" parking area; 40°08'40"/77°24'20"	325	23.3

Table 3. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2009 and was located at RM 4.77. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	26			57	0.14	87
75-99	257	193	349	564	3.37	857
100-124	55	34	96	121	1.65	183
125-149	10			22	0.54	33
150-174	21	13	35	46	1.89	70
175-199	28	19	45	61	3.93	93
200-224	18	10	36	39	3.65	60
225-249	25	16	43	55	7.17	83
250-274	13	8	24	29	5.10	43
275-299	9	5	19	20	4.47	30
300-324	11	6	22	24	7.43	37
325-349	7	3	18	15	6.11	23
350-374	8	4	18	18	8.74	27
375-399	4			9	7.15	13
400-424	1			2	2.25	3
Total	493			1082	63.59	1642

Table 4. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2011 and was located at RM 4.77. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	42	23	86	92	0.23	140
75-99	299	238	374	656	3.92	997
100-124	69	46	105	151	2.07	230
125-149	58	41	84	127	3.10	193
150-174	86	66	111	189	7.75	287
175-199	48	35	68	105	6.74	160
200-224	28	18	45	61	5.68	93
225-249	20	12	33	44	5.76	66
250-274	7	3	15	15	2.77	23
275-299	14	5	18	31	7.14	47
300-324	16	5	22	35	10.87	53
325-349	8	3	15	17	6.67	26
350-374	3			6	3.28	10
375-399	6	2	10	13	8.39	20
400-424	1			2	1.75	3
425-449	1			2	2.57	3
Total	706			1546	78.69	2351

Table 5. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2012 and was located at RM 4.77. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	160	83	337	351	0.86	533
75-99	306	220	439	671	4.01	1020
100-124	40	21	82	88	1.20	133
125-149	45	30	72	99	2.41	150
150-174	68	51	94	149	6.13	227
175-199	68	52	92	149	9.54	227
200-224	28	19	42	61	5.68	93
225-249	22	14	37	48	6.31	73
250-274	12	7	23	26	4.71	40
275-299	13	7	25	29	6.45	43
300-324	9	5	19	20	6.08	30
325-349	13	7	25	29	11.35	43
350-374	9	4	21	20	9.83	30
375-399	5	2	13	11	8.94	17
400-424	2			4	4.50	7
425-449	1			2	2.34	3
Total	801			1757	90.34	2669

Table 6. Estimated abundance and biomass of wild brook and rainbow trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2009, 2011 and 2012 and was located at RM 4.77.

	Brook trout						Rainbow trout					
	2009		2011		2012		2009		2011		2012	
Length group (mm)	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km
50-74	0.14	87	0.23	140	0.86	533						
75-99	3.37	857	3.92	997	4.01	1020					0.01	3
100-124	1.65	183	2.07	230	1.20	133	0.55	60	0.76	83	0.91	100
125-149	0.54	33	3.10	193	2.41	150	4.02	233	5.92	343	2.30	133
150-174	1.89	70	7.75	287	6.13	227	5.58	193	7.31	253	1.83	63
175-199	3.93	93	6.74	160	9.54	227	3.30	70	5.34	113	1.26	27
200-224	3.65	60	5.68	93	5.68	93	0.46	7	0.92	13	3.21	47
225-249	7.17	83	5.76	66	6.31	73	0.63	7	2.82	30	3.77	40
250-274	5.10	43	2.77	23	4.71	40	0.82	7	2.87	23	4.10	33
275-299	4.47	30	7.14	47	6.45	43	3.28	20	3.83	23	6.57	40
300-324	7.43	37	10.87	53	6.08	30	7.54	37	2.74	13	7.54	37
325-349	6.11	23	6.67	26	11.35	43	1.78	7	5.35	20	5.35	20
350-374	8.74	27	3.28	10	9.83	30	2.12	7	4.24	13	4.24	13
375-399	7.15	13	8.39	20	8.94	17					1.35	3
400-424	2.25	3	1.75	3	2.50	7			3.50	7	1.75	3
425-449			2.57	3	2.34	3					1.95	3
450-474							2.34	3	9.37	13	2.34	3
475-499							3.02	3			9.05	10
500-524											3.48	3
525-549									3.51	3	6.99	7
550-574												
575-599									4.28	3		
600-624									5.26	3		
625-649												
650-674												
675-699									6.36	3		
Total	63.59	1642	78.69	2351	90.34	2669	35.44	654	74.38	959	68.00	588

Table 7. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2009 and was located at RM 4.77. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
100-124	18	10	36	39	0.55	60
125-149	70	49	103	154	4.02	233
150-174	58	40	88	127	5.58	193
175-199	21	12	38	46	3.30	70
200-224	2			4	0.46	7
225-249	2			4	0.63	7
250-274	2			4	0.82	7
275-299	6	2	15	13	3.28	20
300-324	11	6	25	24	7.54	37
325-349	2			4	1.78	7
350-374	2			4	2.12	7
375-399						
400-424						
425-449						
450-474	1			2	2.34	3
475-499	1			2	3.02	3
Total	196			427	35.44	654

Table 8. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2011 and was located at RM 4.77. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
100-124	25	14	48	55	0.76	83
125-149	103	82	131	226	5.92	343
150-174	76	57	103	167	7.31	253
175-199	34	22	54	75	5.34	113
200-224	4	2	10	9	0.92	13
225-249	9	5	18	20	2.82	30
250-274	7	3	15	15	2.87	23
275-299	7	3	16	15	3.83	23
300-324	4	2	10	9	2.74	13
325-349	6	2	15	13	5.35	20
350-374	4	2	10	9	4.24	13
375-399						
400-424	2			4	3.50	7
425-449						
450-474	4			9	9.37	13
475-499						
500-524						
525-549	1			2	3.51	3
550-574						
575-599	1			2	4.28	3
600-624	1			2	5.26	3
625-649						
650-674						
675-699	1			2	6.36	3
Total	289			634	74.38	959

Table 9. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2012 and was located at RM 4.77. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	1			2	0.01	3
100-124	30	18	53	66	0.91	100
125-149	40	26	64	88	2.30	133
150-174	19	12	32	42	1.83	63
175-199	8	4	18	18	1.26	27
200-224	14	8	30	31	3.21	47
225-249	12	7	23	26	3.77	40
250-274	10	5	23	22	4.10	33
275-299	12	6	27	26	6.57	40
300-324	11	6	22	24	7.54	37
325-349	6	3	14	13	5.35	20
350-374	4	2	10	9	4.24	13
375-399	1			2	1.35	3
400-424	1			2	1.75	3
425-449	1			2	1.95	3
450-474	1			2	2.34	3
475-499	3			7	9.05	10
500-524	1			2	3.48	3
525-549	2			4	6.99	7
Total	177			388	68.00	588

Table 10. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2009 and was located at RM 4.47. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	5			6	0.02	14
75-99	74	46	126	94	0.57	202
100-124	17	9	33	22	0.30	46
125-149						
150-174						
175-199	4	2	10	5	0.33	11
200-224	11	6	23	14	1.3	30
225-249	13	6	28	17	2.17	36
250-274	9	4	23	11	2.06	25
275-299	1			1	0.29	3
300-324						
325-349	1			1	0.51	3
350-374	1			1	0.64	3
Total	136			172	8.19	373

Table 11. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2011 and was located at RM 4.47. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	1			2	0.00	3
75-99	102	53	214	207	1.24	279
100-124	9			18	0.25	25
125-149	2			4	0.10	5
150-174	15	8	31	30	1.25	41
175-199	44	28	72	89	5.72	120
200-224	39	25	61	79	7.33	107
225-249	43	29	65	87	11.44	117
250-274	18	10	30	37	6.57	49
275-299	10	2	13	20	4.78	28
300-324	5			10	3.17	14
325-349	5	2	13	10	3.84	14
350-374	5	2	10	10	5.06	14
375-399	3			6	3.35	8
Total	301			609	54.10	824

Table 12. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2012 and was located at RM 4.47. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	6			12	0.03	16
75-99	272	161	492	553	3.31	743
100-124	8			16	0.22	22
125-149	18	7	45	37	0.89	49
150-174	38	22	68	77	3.17	104
175-199	33	20	60	67	4.29	90
200-224	16	7	40	33	3.01	44
225-249	18	9	38	37	4.79	49
250-274	9	4	22	18	3.27	25
275-299	15	9	29	30	6.90	41
300-324	15	9	27	30	9.40	41
325-349	13	7	25	26	10.53	36
350-374	8	4	19	16	8.10	22
375-399	2			4	3.32	5
Total	471			956	61.23	1287

Table 13. Estimated abundance and biomass of wild brook and rainbow trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2009, 2011 and 2012, and was located at RM 4.47.

	Brook trout						Rainbow trout					
	2009		2011		2012		2009		2011		2012	
Length group (mm)	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km
50-74	0.02	14	0.00	3	0.03	16						
75-99	0.57	202	1.24	279	3.31	743			0.03	5	0.05	11
100-124	0.30	46	0.25	25	0.22	22	0.30	46	2.96	287	4.07	393
125-149			0.10	5	0.89	49	1.40	115	32.32	1658	11.09	568
150-174			1.25	41	3.17	104	1.85	90	12.67	388	5.63	172
175-199	0.33	11	5.72	120	4.29	90	1.65	49	15.29	287	3.06	57
200-224	1.30	30	7.33	107	3.01	44	0.40	8	5.73	74	9.98	128
225-249	2.17	36	11.44	117	4.79	49			1.45	14	19.78	186
250-274	2.06	25	6.57	49	3.27	25			4.19	30	25.87	186
275-299	0.29	3	4.78	28	6.90	41	0.32	3	6.59	36	22.32	120
300-324			3.17	14	9.40	41	0.40	3	10.80	46	10.17	44
325-349	0.51	3	3.84	14	10.53	36			6.61	22	8.26	27
350-374	0.64	3	5.06	14	8.10	22	0.62	3	6.88	19	5.90	16
375-399			3.35	8	3.32	5			2.50	5	2.50	5
400-424							2.04	5	3.25	5	6.50	11
425-449							1.14	3	10.84	16	1.81	3
450-474									10.86	14	8.69	11
475-499											13.98	14
500-524												
525-549									3.25	3	6.31	5
550-574											4.06	3
575-599											4.27	3
Total	8.19	373	54.10	824	61.23	1287	10.12	325	136.22	2909	174.30	1963

Table 14. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2009 and was located at RM 4.47. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
100-124	17	8	37	22	0.30	46
125-149	42	25	77	54	1.40	115
150-174	33	21	54	42	1.85	90
175-199	18	10	33	23	1.65	49
200-224	3			4	0.40	8
225-249						
250-274						
275-299	1			1	0.32	3
300-324	1			1	0.40	3
325-349						
350-374	1			1	0.62	3
375-399						
400-424	2			3	2.04	5
425-449	1			1	1.14	3
Total	119			152	10.12	325

Table 15. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2011 and was located at RM 4.47. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	2			4	0.03	5
100-124	105	73	158	213	2.96	287
125-149	607	516	714	1234	32.32	1658
150-174	142	114	176	289	12.67	388
175-199	105	77	145	213	15.29	287
200-224	27	15	52	55	5.73	74
225-249	5	2	13	10	1.45	14
250-274	11	5	25	22	4.19	30
275-299	13	7	25	26	6.59	36
300-324	17	10	29	35	10.80	46
325-349	8	4	17	16	6.61	22
350-374	7			14	6.88	19
375-399	2			4	2.50	5
400-424	2			4	3.25	5
425-449	6	2	15	12	10.84	16
450-474	5			10	10.86	14
475-499						
500-524						
525-549	1			2	3.25	3
Total	1065			2163	136.22	2909

Table 16. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 01, Cumberland County. Station was surveyed during August 2012 and was located at RM 4.47. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	4			8	0.05	11
100-124	144	105	203	293	4.07	393
125-149	208	167	258	423	11.09	568
150-174	63	45	93	128	5.63	172
175-199	21	12	36	43	3.06	57
200-224	47	34	68	96	9.98	128
225-249	68	52	93	138	19.78	186
250-274	68	51	93	138	25.87	186
275-299	44	31	65	89	22.32	120
300-324	16	8	34	33	10.17	44
325-349	10	5	21	20	8.26	27
350-374	6	2	15	12	5.90	16
375-399	2			4	2.50	5
400-424	4	2	10	8	6.50	11
425-449	1			2	1.81	3
450-474	4			8	8.69	11
475-499	5			10	13.98	14
500-524						
525-549	2			4	6.31	5
550-574	1			2	4.06	3
575-599	1			2	4.27	3
Total	719			1461	174.30	1963

Table 17. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2009 and was located at RM 4.29. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	1			3	0.02	3
100-124						
125-149						
150-174						
175-199	2			6	0.38	7
200-224	3			9	0.83	10
225-249						
250-274	2			6	1.07	7
Total	8			24	2.30	27

Table 18. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2011 and was located at RM 4.29. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	9			24	0.14	30
100-124	3			8	0.11	10
125-149						
150-174	1			3	0.11	3
175-199	6	3	15	16	1.01	20
200-224	6	2	15	16	1.46	20
225-249	6	3	15	16	2.06	20
250-274	7	3	18	18	3.29	23
275-299	1			3	0.59	3
300-324	2			5	1.62	7
325-349						
350-374	2			5	2.61	7
Total	43			114	13.00	143

Table 19. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2012 and was located at RM 4.29. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	1			3	0.01	3
75-99	7			18	0.11	23
100-124						
125-149						
150-174	6			16	0.65	20
175-199	1			3	0.17	3
200-224	2			5	0.49	7
225-249						
250-274	1			3	0.47	3
275-299						
300-324						
325-349	9	4	22	24	9.41	30
350-374	3			8	3.92	10
375-399						
400-424	2			5	5.38	7
Total	32			85	20.61	106

Table 20. Estimated abundance and biomass of wild brook and rainbow trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2009, 2011 and 2012, and was located at RM 4.29.

	Brook trout						Rainbow trout					
	2009		2011		2012		2009		2011		2012	
Length group (mm)	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km
50-74					0.01	3						
75-99	0.02	3	0.14	30	0.11	23			0.15	30	0.40	80
100-124			0.11	10			0.96	77	3.97	363	7.80	713
125-149							5.66	240	18.97	920	14.66	710
150-174			0.11	3	0.65	20	7.77	197	27.07	783	6.00	173
175-199	0.38	7	1.01	20	0.17	3	6.67	103	12.78	227	2.44	43
200-224	0.83	10	1.46	20	0.49	7	4.70	50	9.87	120	8.77	107
225-249			2.06	20			0.43	3	5.63	50	13.90	123
250-274	1.07	7	3.29	23	0.47	3			1.96	13	16.21	110
275-299			0.59	3			0.75	3	5.24	27	15.06	77
300-324			1.62	7			12.20	43	9.84	40	12.30	50
325-349					9.41	30	4.88	13	11.73	37	6.40	20
350-374			2.61	7	3.92	10	5.81	13	13.96	37	2.54	7
375-399							12.91	23	6.45	13	6.45	13
400-424					5.38	7	4.80	7	20.97	33	4.19	7
425-449							10.68	13	23.33	33	14.00	20
450-474							3.21	3	5.61	7	16.82	20
475-499									21.65	20	21.65	20
500-524							9.50	7	15.35	10	4.15	3
525-549											8.15	7
550-574							5.91	3	5.91	3	6.09	3
575-599									8.14	3	5.51	3
Total	2.30	27	13.00	143	20.61	106	96.84	798	228.58	2769	193.49	2309

Table 21. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2009 and was located at RM 4.29. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
100-124	23	9	56	69	0.96	77
125-149	72	47	115	216	5.66	240
150-174	59	41	90	177	7.77	197
175-199	31	17	62	93	6.67	103
200-224	15	8	32	45	4.70	50
225-249	1			3	0.43	3
250-274						
275-299	1			3	0.75	3
300-324	13	7	26	39	12.20	43
325-349	4			12	4.88	13
350-374	4	2	10	12	5.81	13
375-399	7	3	18	21	12.91	23
400-424	2			6	4.80	7
425-449	4	2	10	12	10.68	13
450-474	1			3	3.21	3
475-499						
500-524	2			6	9.50	7
525-549						
550-574	1			3	5.91	3
Total	240			720	96.84	798

Table 22. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2011 and was located at RM 4.29. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	9	4	22	24	0.15	30
100-124	109	81	152	286	3.97	363
125-149	276	234	327	724	18.97	920
150-174	235	192	288	617	27.07	783
175-199	68	45	106	178	12.78	227
200-224	36	22	64	94	9.87	120
225-249	15	9	29	39	5.63	50
250-274	4			10	1.96	13
275-299	8	4	18	21	5.24	27
300-324	12	5	30	31	9.84	40
325-349	11	6	22	29	11.73	37
350-374	11	6	22	29	13.96	37
375-399	4	2	10	10	6.45	13
400-424	10	4	24	26	20.97	33
425-449	10	5	23	26	23.33	33
450-474	2			5	5.61	7
475-499	6	3	14	16	21.65	20
500-524	3			8	15.35	10
525-549						
550-574	1			3	5.91	3
575-599	1			3	8.14	3
Total	831			2179	228.58	2769

Table 23. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2012 and was located at RM 4.29. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	24	10	60	63	0.40	80
100-124	214	128	378	562	7.80	713
125-149	213	142	335	559	14.66	710
150-174	52	29	99	136	6.00	173
175-199	13	6	28	34	2.44	43
200-224	32	17	65	84	8.77	107
225-249	37	24	59	97	13.90	123
250-274	33	21	55	87	16.21	110
275-299	23	14	39	60	15.06	77
300-324	15	8	31	39	12.30	50
325-349	6	3	15	16	6.40	20
350-374	2			5	2.54	7
375-399	4			10	6.45	13
400-424	2			5	4.19	7
425-449	6	3	16	16	14.00	20
450-474	6	3	15	16	16.82	20
475-499	6	2	15	16	21.65	20
500-524	1			3	4.15	3
525-549	2			5	8.15	7
550-574	1			3	6.09	3
575-599	1			3	5.51	3
Total	693			1819	193.49	2309

Table 24. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2011 and was located at RM 3.88. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	7			9	0.06	22
100-124	3			4	0.05	9
125-149						
150-174						
175-199						
200-224	3			4	0.37	9
225-249	6	3	15	8	1.04	18
250-274						
275-299	3			4	0.90	9
300-324	2			3	0.81	6
Total	24			32	3.23	73

Table 25. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2012 and was located at RM 3.88. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	7			9	0.06	22
100-124	1			1	0.02	3
125-149						
150-174	1			1	0.05	3
175-199	2			3	0.17	6
200-224	4	2	10	5	0.49	12
225-249						
250-274						
275-299						
300-324						
325-349						
350-374						
375-399	1			1	1.08	3
Total	16			20	1.87	49

Table 26. Estimated abundance and biomass of wild brook and rainbow trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2011 and 2012, and was located at RM 3.88.

	Brook trout				Rainbow trout			
	2011		2012		2011		2012	
Length group (mm)	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km
75-99	0.06	22	0.06	22				
100-124	0.05	9	0.02	3	0.26	43	0.15	25
125-149					1.70	151	5.06	449
150-174			0.05	3	2.09	111	4.87	258
175-199			0.17	6	1.23	40	1.70	55
200-224	0.37	9	0.49	12	1.79	40	1.24	28
225-249	1.04	18			0.38	6	1.89	31
250-274					0.49	6	1.24	15
275-299	0.90	9			0.33	3	4.61	43
300-324	0.81	6			0.41	3	4.95	37
325-349					2.15	12	2.68	15
350-374					0.64	3	3.19	15
375-399			1.08	3			3.24	12
400-424					2.11	6	5.28	15
425-449							3.52	9
450-474							4.23	9
475-499							3.63	6
500-524							4.79	6
525-549							3.14	3
550-574					3.17	3		
575-599							3.29	3
Total	3.23	73	1.87	49	16.75	427	62.70	1034

Table 27. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2011 and was located at RM 3.88. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
100-124	14	8	30	18	0.26	43
125-149	49	32	79	65	1.70	151
150-174	36	22	61	48	2.09	111
175-199	13	6	30	17	1.23	40
200-224	13	7	25	17	1.79	40
225-249	2			3	0.38	6
250-274	2			3	0.49	6
275-299	1			1	0.33	3
300-324	1			1	0.41	3
325-349	4			5	2.15	12
350-374	1			1	0.64	3
375-399						
400-424	2			3	2.11	6
425-449						
450-474						
475-499						
500-524						
525-549						
550-574	1			1	3.17	3
Total	139			183	16.75	427

Table 28. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), Section 02, Cumberland County. Station was surveyed during August 2012 and was located at RM 3.88. Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	Population estimate	Low 95 % CI	High 95% CI	Estimated number/ha	Estimated kg/ha	Estimated number/km
100-124	8			11	0.15	25
125-149	146	92	243	193	5.06	449
150-174	84	55	133	111	4.87	258
175-199	18	11	35	24	1.70	55
200-224	9	4	23	12	1.24	28
225-249	10	4	25	13	1.89	31
250-274	5	2	13	7	1.24	15
275-299	14	6	34	18	4.61	43
300-324	12	6	25	16	4.95	37
325-349	5			7	2.68	15
350-374	5			7	3.19	15
375-399	4			5	3.24	12
400-424	5	2	13	7	5.28	15
425-449	3			4	3.52	9
450-474	3			4	4.23	9
475-499	2			3	3.63	6
500-524	2			3	4.79	6
525-549	1			1	3.14	3
550-574						
575-599	1			1	3.29	3
Total	337			447	62.70	1034

Table 29. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), sections 01 and 02, Cumberland County. Stations were surveyed during August 2009 and were located at the habitat enhancement project site (sampling stations at RM 4.47 and RM 4.29 combined). Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	CPUE	Population estimate	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	1.63	3	3	0.01	7
75-99	15.15	38	49	0.30	103
100-124	4.07	9	11	0.15	23
125-149					
150-174					
175-199	2.25	3	6	0.36	9
200-224	5.21	7	12	1.06	20
225-249	3.66	7	8	1.08	18
250-274	3.07	6	9	1.56	16
275-299	0.41	1	1	0.14	1
300-324					
325-349	0.00	1	1	0.26	1
350-374	0.00	1	1	0.32	1
Total	35.45	76	101	5.24	199

Table 30. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), section 01 and 02, Cumberland County. Stations were surveyed during August 2011 and were located at the habitat enhancement project site (sampling stations at RM 4.47 and RM 4.29 combined). Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	CPUE	Population estimate	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	0.00	1	1	0.00	1
75-99	7.42	56	115	0.69	154
100-124	0.97	6	13	0.18	17
125-149	0.00	1	2	0.05	3
150-174	1.72	8	17	0.68	22
175-199	6.66	25	53	3.36	70
200-224	7.04	23	48	4.39	63
225-249	7.58	25	52	6.75	69
250-274	4.63	13	27	4.93	36
275-299	1.99	6	11	2.68	15
300-324	0.71	4	8	2.40	10
325-349	0.86	3	5	1.92	7
350-374	1.41	4	8	3.83	10
375-399	0.43	2	3	1.68	4
Total	41.42	177	363	33.54	481

Table 31. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), section 01 and 02, Cumberland County. Stations were surveyed during August 2012 and were located at the habitat enhancement project site (sampling stations at RM 4.47 and RM 4.29 combined). Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	CPUE	Population estimate	Estimated number/ha	Estimated kg/ha	Estimated number/km
50-74	0.78	4	7	0.02	10
75-99	14.79	140	286	1.71	383
100-124	0.98	4	8	0.11	11
125-149	1.56	9	18	0.45	25
150-174	6.45	22	47	1.91	62
175-199	4.81	17	35	2.23	47
200-224	1.70	9	19	1.75	25
225-249	2.14	9	18	2.40	25
250-274	1.12	5	10	1.87	14
275-299	2.73	8	15	3.45	20
300-324	2.34	8	15	4.70	20
325-349	4.48	11	25	9.97	33
350-374	2.17	6	12	6.01	16
375-399	0.39	1	2	1.66	3
400-424	0.34	1	3	2.69	3
Total	46.78	254	520	40.93	697

Table 32. Estimated abundance and biomass of wild brook trout from Big Spring Creek (7B), sections 01 and 02, Cumberland County. Stations were surveyed during August 2009, 2011 and 2012, and were located at the habitat enhancement project site (sampling stations at RM 4.47 and RM 4.29 combined).

	Brook trout						Rainbow trout					
	2009		2011		2012		2009		2011		2012	
Length group (mm)	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km	Estimated kg/ha	Estimated number/km
50-74	0.01	7	0.00	1	0.02	10						
75-99	0.30	103	0.69	154	1.71	383			0.09	18	0.23	45
100-124	0.15	23	0.18	17	0.11	11	0.63	62	3.46	325	5.93	553
125-149			0.05	3	0.45	25	3.53	177	25.64	1289	12.88	639
150-174			0.68	22	1.91	62	4.81	143	19.86	586	5.81	173
175-199	0.36	9	3.36	70	2.23	47	4.16	76	14.04	257	2.75	50
200-224	1.06	20	4.39	63	1.75	25	2.55	29	7.80	97	9.38	118
225-249	1.08	18	6.75	69	2.40	25	0.22	2	3.54	32	16.84	155
250-274	1.56	16	4.93	36	1.87	14			3.08	22	21.04	148
275-299	0.14	1	2.68	15	3.45	20	0.54	3	5.92	31	18.69	98
300-324			2.40	10	4.70	20	6.30	23	10.32	43	11.23	47
325-349	0.26	1	1.92	7	9.97	33	2.44	7	9.17	29	7.33	24
350-374	0.32	1	3.83	10	6.01	16	3.22	8	10.42	28	4.22	12
375-399			1.68	4	1.66	3	6.46	12	4.47	9	4.47	9
400-424					2.69	3	3.42	6	12.11	19	5.35	9
425-449							5.91	8	17.09	25	7.91	11
450-474							1.61	2	8.23	10	12.75	15
475-499									10.82	10	17.81	17
500-524							4.75	3	7.67	5	2.08	2
525-549									1.63	1	7.23	6
550-574							3.94	2	2.96	2	4.06	3
575-599									4.07	2	4.89	3
Total	5.24	199	33.54	481	40.93	697	54.49	563	182.39	2840	182.88	2137

Table 33. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), sections 01 and 02, Cumberland County. Stations were surveyed during August 2009 and were located at the habitat enhancement project site (sampling stations at RM 4.47 and RM 4.29 combined). Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	CPUE	Population estimate	Estimated number/ha	Estimated kg/ha	Estimated number/km
100-124	9.01	20	45	0.63	62
125-149	29.46	57	135	3.53	177
150-174	32.74	46	110	4.81	143
175-199	16.52	25	58	4.16	76
200-224	5.46	9	24	2.55	29
225-249	0.00	1	2	0.22	2
250-274					
275-299	0.92	1	2	0.54	3
300-324	6.08	7	20	6.30	23
325-349	2.06	2	6	2.44	7
350-374	1.95	3	7	3.22	8
375-399	2.06	4	11	6.46	12
400-424	1.85	2	4	3.42	6
425-449	1.95	3	7	5.91	8
450-474	0.52	1	2	1.61	2
475-499					
500-524	0.52	1	3	4.75	3
525-549					
550-574	0.52	1	2	3.94	2
Total	111.62	183	438	54.49	563

Table 34. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), sections 01 and 02, Cumberland County. Stations were surveyed during August 2011 and were located at the habitat enhancement project site (sampling stations at RM 4.47 and RM 4.29 combined). Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	CPUE	Population estimate	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	2.05	6	14	0.09	18
100-124	30.07	107	250	3.46	325
125-149	120.50	442	979	25.64	1289
150-174	57.71	189	453	19.86	586
175-199	26.06	87	196	14.04	257
200-224	9.01	32	75	7.80	97
225-249	4.65	10	25	3.54	32
250-274	2.31	8	16	3.08	22
275-299	4.04	11	24	5.92	31
300-324	6.41	15	33	10.32	43
325-349	3.93	10	23	9.17	29
350-374	3.72	9	22	10.42	28
375-399	1.24	3	7	4.47	9
400-424	2.32	6	15	12.11	19
425-449	2.81	8	19	17.09	25
450-474	1.19	4	8	8.23	10
475-499	1.35	3	8	10.82	10
500-524	0.54	2	4	7.67	5
525-549	0.22	1	1	1.63	1
550-574	0.27	1	1	2.96	2
575-599	0.27	1	1	4.07	2
Total	280.67	955	2174	182.39	2840

Table 35. Estimated abundance and biomass of wild rainbow trout from Big Spring Creek (7B), sections 01 and 02, Cumberland County. Stations were surveyed during August 2012 and were located at the habitat enhancement project site (sampling stations at RM 4.47 and RM 4.29 combined). Biomass was determined using the Chapman modification of the Petersen estimator.

Length group (mm)	CPUE	Population estimate	Estimated number/ha	Estimated kg/ha	Estimated number/km
75-99	2.53	14	36	0.23	45
100-124	29.40	179	427	5.93	553
125-149	49.85	211	491	12.88	639
150-174	15.81	58	132	5.81	173
175-199	5.31	17	38	2.75	50
200-224	12.62	40	90	9.38	118
225-249	17.15	53	118	16.84	155
250-274	19.51	51	112	21.04	148
275-299	13.2	34	75	18.69	98
300-324	6.34	16	36	11.23	47
325-349	2.89	8	18	7.33	24
350-374	0.92	4	9	4.22	12
375-399	1.06	3	7	4.47	9
400-424	1.25	3	7	5.35	9
425-449	1.34	4	9	7.91	11
450-474	1.86	5	12	12.75	15
475-499	2.64	6	13	17.81	17
500-524	0.34	1	1	2.08	2
525-549	0.53	2	5	7.23	6
550-574	0.20	1	2	4.06	3
575-599	0.20	1	2	4.89	3
Total	184.95	711	1640	182.88	2137

Table 36. Summary of brook and rainbow trout optimal habitat suitability values and observed ranges of use values from literature review.

Habitat Parameter	Species	Adult	Juvenile	Spawning
Mean Water Column Velocity (ft/sec)	Brook Trout	0.00 – 0.38 Optimal for fish at least 6” in length (SRBC, 1998)	0.00 – 0.88 Optimal for fish 2” – 6” in length (SRBC, 1998)	0.00 – 0.38 Optimal (SRBC, 1998)
Mean Water Column Velocity (ft/sec)	Brook Trout	0.20 – 0.89 Optimal for fish 3.5” – 8” in length (Baker and Coon, 1995)	0.20 – 0.98 Optimal for fish < 3.5” in length (Baker and Coon, 1995)	0.12 – 1.11 Optimal (Reiser & Wesche, 1977)
Mean Water Column Velocity (ft/sec)	Brook Trout			0.90 – 1.97 Optimal (Raleigh, 1982)
Velocity 10 cm Above Redds	Brook Trout			0.10 – 1.38 Observed range (Witzel & MacCrimmon, 1983)
Mean Water Column Velocity (ft/sec)	Rainbow Trout	0.50 – 1.20 Optimal for fish >6” in length (PCWA, 2010)	0.20 – 0.75 Optimal for fish 2” – 6” (PCWA, 2010)	0.60 – 2.00 Optimal (PCWA, 2010)
Mean Water Column Velocity (ft/sec)	Rainbow Trout	0.49 -0.98 Optimal for fish at least 8” in length (Pert & Erman, 1994)		0.98 – 2.30 Optimal (Raleigh et al., 1984)
Mean Depth (ft)	Brook Trout	0.89 – 1.80 Optimal for fish 3.5” – 8” in length (Baker & Coon, 1995)	0.49 – 1.12 Optimal for fish < 3.5” in length (Baker and Coon, 1995)	0.20 Minimum optimal (Reiser & Wesche, 1977)
Mean Depth (ft)	Brook Trout	1.13 – 2.63 Optimal for fish at least 6” in length (SRBC, 1998)	1.13 – 1.88 Optimal for fish 2” – 6” in length (SRBC, 1998)	0.38 – 1.38 Optimal (SRBC, 1998)
Mean Depth (ft)	Rainbow Trout	2.20 Minimum optimal for fish >6” in length (PCWA, 2010)	1.00 – 2.20 Optimal for fish 2” – 6” in length (PCWA, 2010)	0.60 – 1.50 Optimal (PCWA, 2010)
Mean Depth (ft)	Rainbow Trout	3.15 Minimum optimal for fish at least 8” in length (Pert & Erman, 1994)		
Average Thalweg Depth (ft)	Brook Trout	1.38 Minimum optimal (Raleigh, 1982)		
Average Thalweg Depth (ft)	Rainbow Trout	1.48 Minimum optimal (Raleigh et al., 1984)		

Table 36 (*continued*). Summary of brook and rainbow trout optimal habitat suitability values and observed ranges of use values from literature review.

Habitat Parameter	Species	Adult	Juvenile	Spawning
Substrate Composition	Brook Trout	D90 coarse gravel or smaller (D90 < 26.5 mm) for brook trout as a species when other trout species are present, and larger substrate for allopatric brook trout populations, mean particle size associated with brook trout as a species = 47 mm (coarse gravel) (Stoneman & Jones, 2000)	10% Minimum cobble and larger (100 – 400 mm) optimal for escape cover (Raleigh, 1982)	Fine and coarse gravel (3 – 50 mm) optimal (Reiser & Wesche, 1977); Fine and coarse gravel (3 – 64 mm) optimal (SRBC, 1998); Coarse gravel (28 – 62 mm) optimal (Raleigh, 1982)
Substrate Composition	Rainbow Trout	Mean particle size associated with rainbow trout as a species = 99 mm (cobble) (Stoneman & Jones, 2000)	12% Minimum cobble and larger (100 – 400 mm) optimal for escape cover (Raleigh et al., 1984)	Coarse gravel (16 – 60 mm) optimal for fish <20" in length, and coarse gravel to small cobble (16 - 100 mm) optimal for fish 20" or more in length (Raleigh et al., 1984); Fine gravel to small cobble (5 – 76 mm) optimal (PCWA, 2010)
% Cover in water at least 1 ft deep	Brook and Rainbow Trout	12% Minimum optimal for fish at least 8" in length (Simonson et al., 1993)		
% Cover in water at least 0.5 ft deep	Brook and Rainbow Trout		14% Minimum optimal (Raleigh ,1982; Raleigh et al., 1984)	

Table 37. Model reach general substrate characteristics pertinent to the findings of Stoneman and Jones (2000).

Parameter	Stoneman & Jones (2000) Observations	2009	2011
Median Particle Size Category		Fine Gravel (3 – 16 mm)	Fine Gravel (3 – 16 mm)
% Coarse Gravel or Smaller (<64 mm)	Mean particle size category associated with brook trout	85.7	84.4
% Coarse Gravel (16 - 64 mm)		20.8	22.1
% Cobble (64 – 250 mm)	Mean particle size category associated with rainbow trout	13.0	13.0

Table 38. Model reach juvenile cobble and larger substrate for escape cover and spawning gravel data.

Parameter	Brook Trout Optimal Condition	Rainbow Trout Optimal Condition	2009	2011
% Cobble or Larger Substrate (>64 mm) for Juvenile Escape Cover	10% Minimum	12% Minimum	14.3	15.6
% Fine Gravel (2 – 16 mm)			26.0	27.3
% Coarse Gravel (16 - 64 mm)		Coarse gravel for spawning	20.8	22.1
% Fine and Coarse Gravel (2 – 64 mm)	Mix of fine and coarse gravel for spawning		46.8	49.4

Table 39. Percent fish cover values from Big Spring Creek model reach (RM 4.82).

Year	Reach / 2010 Project Status	Cover Type	% Adult fish Cover Optimal Condition	% Adult fish Cover	% Juvenile Fish Cover Optimal Condition	% Juvenile Fish Cover
2008	Model / Before	Total Fish Cover	12% Min.	20.4	14% Min.	32.6
2008	Model / Before	Aquatic Macrophyte Cover		15.6		21.8
2008	Model / Before	Other Cover		4.7		10.8
2009	Model / Before	Total Fish Cover	12% Min.	7.7	14% Min.	25.5
2009	Model / Before	Aquatic Macrophyte Cover		4.1		11.4
2009	Model / Before	Other Cover		3.6		14.2
2011	Model / After	Total Fish Cover	12% Min.	8.7	14% Min.	31.9
2011	Model / After	Aquatic Macrophyte Cover		4.1		20.4
2011	Model / After	Other Cover		4.5		11.5
	Model Reach Mean	Total Fish Cover	12% Min.	12.3	14% Min.	30.0
	Model Reach Mean	Aquatic Macrophyte Cover		7.9		17.9
	Model Reach Mean	Other Cover		4.3		12.2

Table 40. Transect mean velocity values from Big Spring Creek Model (RM 4.82), Treatment (RM 4.47 and RM 4.29), and Willow Tree (RM 3.88) reaches.

Year	**USGS Gage Discharge (cfs)**	**Reach**	**n**	**Median (ft/sec)**	**Mean (ft/sec)**	**Std. Dev. (ft/sec)**	**Mann-Whitney Test Significance at 95% CL**
Optimal Ranges (ft/sec)		Adult	Juvenile		Spawning		
Brook Trout		0.00 – 0.89	0.00 – 0.98		0.12 – 1.11		
Rainbow Trout		0.49 – 0.98	0.20 – 0.75		0.60 – 2.30		
2008	36	Model	11	0.65	0.66	0.15	Treatment reach velocity higher than model reach (p=0.0018)
		Treatment (Pre-Implementation)	32	0.79	0.84	0.17	
2009	32	Model	11	0.66	0.68	0.15	Treatment reach velocity higher than model reach (p=0.0056)
		Treatment (Pre-Implementation)	32	0.87	0.89	0.20	
2011	41	Model	11	0.74	0.82	0.19	No difference between velocity of model and treatment reaches (p=0.2902)
		Treatment (Post-Implementation)	32	0.72	0.75	0.19	
	30	Willow Tree	21	0.43	0.46	0.09	Not Determined

Table 41. Thalweg depth values from Big Spring Creek Model (RM 4.82), Treatment (RM 4.47 and RM 4.29), and Willow Tree (RM 3.88) reaches.

Year	USGS Gage Discharge (cfs)	Reach	n	Median (ft)	Mean (ft)	Std. Dev. (ft)	Mann-Whitney Test Significance at 95% CL
Optimal Ranges (ft)		Adult					
Brook Trout		1.38 Minimum					
Rainbow Trout		1.48 Minimim					
2008	36	Model	11	1.90	1.91	0.17	Treatment reach maximum depth lower than model reach (p=0.0000)
		Treatment (Pre-Implementation)	32	1.25	1.32	0.27	
2009	32	Model	11	1.64	1.61	0.16	Treatment reach maximum depth lower than model reach (p=0.0000)
		Treatment (Pre-Implementation)	32	1.16	1.13	0.17	
2011	41	Model	11	1.78	1.77	0.18	Treatment reach maximum depth higher than model reach (p=0.0109)
		Treatment (Post-Implementation)	32	2.00	2.01	0.29	
	30	Willow Tree	21	1.62	1.55	0.29	Not Determined

Table 42. Transect mean depth values from Big Spring Creek Model (RM 4.82), Treatment (RM 4.47 and RM 4.29), and Willow Tree (RM 3.88) reaches.

Year	USGS Gage Discharge (cfs)	Reach	n	Median (ft)	Mean (ft)	Std. Dev. (ft)	Mann-Whitney Test Significance at 95% CL
Optimal Ranges (ft)		Adult	Juvenile		Spawning		
Brook Trout		0.89 – 2.63	0.49 – 1.88		0.38 – 1.38		
Rainbow Trout		2.20 Minimum	1.00 – 2.20		0.60 – 1.50		
2008	36	Model	11	1.21	1.23	0.16	Treatment reach mean depth lower than model reach (p=0.0000)
		Treatment (Pre-Implementation)	32	0.80	0.80	0.13	
2009	32	Model	11	1.03	1.03	0.17	Treatment reach mean depth lower than model reach (p=0.0000)
		Treatment (Pre-Implementation)	32	0.68	0.68	0.09	
2011	41	Model	11	1.14	1.10	0.14	Treatment reach mean depth higher than model reach (p=0.0082)
		Treatment (Post-Implementation)	32	1.31	1.27	0.17	
	30	Willow Tree	21	0.88	0.89	0.17	Not Determined

Table 43. Transect wetted width/depth ratio values from Big Spring Creek Model (RM 4.82), Treatment (RM 4.47 and RM 4.29), and Willow Tree (RM 3.88) reaches.

Year	USGS Gage Discharge (cfs)	Reach	n	Median	Mean	Std. Dev.	Mann-Whitney Test Significance at 95% CL
2008	36	Model	11	39.5	40.8	16.8	Treatment reach W/D ratio higher than model reach (p=0.0003)
		Treatment (Pre-Implementation)	32	72.2	74.9	25.2	
2009	32	Model	11	48.3	49.8	20.2	Treatment reach W/D ratio higher than model reach (p=0.0004)
		Treatment (Pre-Implementation)	32	88.3	86.2	28.5	
2011	41	Model	11	40.7	45.6	16.8	No difference between W/D ratio of model and treatment reaches (p=0.1770)
		Treatment (Post-Implementation)	32	36.6	37.1	11.3	
	30	Willow Tree	21	81.7	92.6	33.6	Not Determined

Table 44. Channel substrate composition information from Big Spring Creek Model (RM 4.82), Treatment (RM 4.47 and RM 4.29), and Willow Tree (RM 3.88) reaches.

Parameter	Optimal Conditions		Model Reach		Treatment Reach		Willow Tree Reach
	Brook Trout	Rainbow Trout	2009	2011	2009	2011	2011
Median Particle Size Category			Fine Gravel	Fine Gravel	Fine Gravel	Fine Gravel	Fine Gravel
% Sand or Finer (<2 mm)			38.9	35.0	45.9	42.4	44.9
% Fine Gravel (2-16 mm)			26.0	27.3	17.6	18.3	30.6
% Coarse Gravel (16-64 mm)		Optimal substrate for spawning	20.8	22.1	25.9	22.8	10.2
% Fine and Coarse Gavel (2-64 mm)	Optimal substrate for spawning		46.8	49.4	43.8	41.1	40.8
% Coarse Gravel or Smaller (<64 mm)	Substrate associated with brook trout		85.7	84.4	89.3	82.1	85.7
% Cobble (64-250 mm)		Substrate associated with rainbow trout	13.0	13.0	5.4	11.2	0.0
%Cobble or Larger (>64 mm)	10% Minimum for juvenile escape cover	12% Minimum for juvenile escape cover	14.3	15.6	10.3	16.5	14.3

Table 45. Percent fish cover values from Big Spring Creek Model (RM 4.82), Treatment (RM 4.47 and RM 4.29), and Willow Tree (RM 3.88) reaches.

Year	Reach Sample	Cover Type	% Adult fish Cover Optimal Condition	% Adult fish Cover	% Juvenile Fish Cover Optimal Condition	% Juvenile Fish Cover
2008	Model Before	Total Fish Cover	12% Min.	20.4	14% Min.	32.6
2008	Model Before	Aquatic Macrophyte Cover		15.6		21.8
2008	Model Before	Other Cover		4.7		10.8
2008	Treatment Before	Total Fish Cover	12% Min.	3.0	14% Min.	25.0
2008	Treatment Before	Aquatic Macrophyte Cover		2.0		17.3
2008	Treatment Before	Other Cover		1.0		7.7
2009	Model Before	Total Fish Cover	12% Min.	7.7	14% Min.	25.5
2009	Model Before	Aquatic Macrophyte Cover		4.1		11.4
2009	Model Before	Other Cover		3.6		14.2
2009	Treatment Before	Total Fish Cover	12% Min.	2.7	14% Min.	34.1
2009	Treatment Before	Aquatic Macrophyte Cover		2.1		23.1
2009	Treatment Before	Other Cover		0.6		11.0
2011	Model After	Total Fish Cover	12% Min.	8.7	14% Min.	31.9
2011	Model After	Aquatic Macrophyte Cover		4.1		20.4
2011	Model After	Other Cover		4.5		11.5
2011	Treatment After	Total Fish Cover	12% Min.	19.9	14% Min.	33.7
2011	Treatment After	Aquatic Macrophyte Cover		12.2		17.5
2011	Treatment After	Other Cover		7.7		16.2
2011	Willow Tree	Total Fish Cover	12% Min.	13.6	14% Min.	53.0
2011	Willow Tree	Aquatic Macrophyte Cover		12.1		43.4
2011	Willow Tree	Other Cover		1.5		9.7

Table 46. Distance to closest fish cover values from Big Spring Creek Model (RM 4.82), Treatment (RM 4.47 and RM 4.29), and Willow Tree (RM 3.88) reaches.

Year	USGS Gage Discharge (cfs)	Reach	n	Median (ft)	Mean (ft)	Std. Dev. (ft)	Mann-Whitney Test Significance at 95% CL
2008	36	Model	11	2.10	2.35	1.86	Treatment reach DCFC higher than model reach (p=0.0093)
		Treatment (Pre-Implementation)	32	12.40	13.79	14.11	
2009	32	Model	11	8.00	7.61	2.52	Treatment reach DCFC higher than model reach (p=0.0149)
		Treatment (Pre-Implementation)	32	13.80	21.19	20.70	
2011	41	Model	11	8.30	8.36	5.07	No difference between DCFC of model and treatment reaches (p=0.0949)
		Treatment (Post-Implementation)	32	5.60	6.04	4.15	
	30	Willow Tree	21	6.20	13.37	14.15	Not Determined

Table 47. Electrofishing results from the Big Spring Creek Control (RM 4.77), 2010 Project Treatment (RM 4.47 and RM 4.29), and Willow Tree (RM 3.88) sampling stations.

Year	Reach	Range of Total Length Values (mm)	#/Km	#/Km = or > 175 mm	% Change in #/Km	Kg/Ha	% Change in Kg/Ha
Brook Trout							
2009	Control	50 - 424	1642	412		63.59	
2011	Control	50 - 449	2351	504	143	78.69	124
2009	2010 Project Area Pre-Construction	50 – 374	199	66		5.24	
2011	2010 Project Area Post-Construction	50 -399	481	284	242	33.54	640
2011	Willow Tree	75 – 324	79	48		3.74	
Rainbow Trout							
2009	Control	100 – 499	654	168		35.44	
2011	Control	100 – 699	959	280	147	74.38	210
2009	2010 Project Area Pre-Construction	100 – 574	563	181		54.49	
2011	2010 Project Area Post-Construction	75 – 599	2840	622	504	182.39	335
2011	Willow Tree	100 - 574	427	122		16.74	

Table 48. Summer 2011 water temperature and dissolved oxygen data from the Big Spring Creek.

Site	River Mile	Date	Weather Conditions	Water Clarity	Time	Temp (C)	Dissolved Oxygen (mg/l)	Dissolved Oxygen Saturation (mg/l)	Dissolved Oxygen Percent Saturation
Immediately Downstream of Model Reach	4.83	6/17/2011	Mostly Cloudy	Clear	10:16 AM	11.3	10.0	10.60	94.4
Downstream End of 2010 Project	4.31	6/17/2011	Mostly Cloudy	Clear	9:00 AM	11.5	10.4	10.55	98.5
Willow Tree Parking Lot	3.88	6/17/2011	Mostly Cloudy	Clear	8:27 AM	11.6	9.4	10.53	89.3
Nealy Road Parking Lot	3.47	6/17/2011	Mostly Cloudy	Clear	7:58 AM	11.5	8.9	10.55	84.3
Stone Arch Bridge Parking Lot	2.64	6/17/2011	Mostly Cloudy	Clear	7:23 AM	11.6	7.4	10.53	70.3
Downstream End of 2010 Project	4.31	6/30/2011	Sunny	Clear	3:42 PM	13.3	10.6	10.16	104.4
Willow Tree Parking Lot	3.88	6/30/2011	Sunny	Clear	3:22 PM	15.6	11.0	9.64	114.0
Nealy Road Parking Lot	3.47	6/30/2011	Sunny	Clear	3:04 PM	16.9	12.3	9.36	131.5
Stone Arch Bridge Parking Lot	2.64	6/30/2011	Sunny	Clear	2:47 PM	16.9	12.2	9.36	130.4
Immediately Downstream of Model Reach	4.83	7/1/2011	Clear	Clear	7:25 AM	11.0	9.0	10.67	84.4
Downstream End of 2010 Project	4.31	7/1/2011	Clear	Clear	7:05 AM	10.9	9.3	10.69	87.0
Willow Tree Parking Lot	3.88	7/1/2011	Clear	Clear	6:46 AM	10.8	9.0	10.71	84.0
Nealy Road Parking Lot	3.47	7/1/2011	Clear	Clear	6:26 AM	10.8	8.4	10.71	78.4
Stone Arch Bridge Parking Lot	2.64	7/1/2011	Clear	Clear	6:06 AM	11.0	7.8	10.67	73.1
Immediately Downstream of Model Reach	4.83	7/28/2011	Light Rain	Clear	3:36 PM	11.3	8.8	10.60	83.0
Downstream End of 2010 Project	4.31	7/28/2011	Light Rain	Clear	3:50 PM	11.9	9.6	10.47	91.7
Willow Tree Parking Lot	3.88	7/28/2011	Light Rain	Clear	4:02 PM	12.6	10.0	10.31	97.0
Nealy Road Parking Lot	3.47	7/28/2011	Light Rain	Clear	4:20 PM	13.1	10.2	10.20	100.0
Stone Arch Bridge Parking Lot	2.64	7/28/2011	Light Rain	Clear	4:32 PM	14.0	10.5	10.00	105.0
Immediately Downstream of Model Reach	4.83	7/29/2011	Heavy Fog	Clear	5:54 AM	11.2	8.5	10.62	80.0
Downstream End of 2010 Project	4.31	7/29/2011	Heavy Fog	Clear	6:13 AM	11.2	8.7	10.62	81.9
Willow Tree Parking Lot	3.88	7/29/2011	Heavy Fog	Clear	6:19 AM	11.4	8.1	10.58	76.6
Nealy Road Parking Lot	3.47	7/29/2011	Heavy Fog	Clear	6:32 AM	11.6	7.6	10.53	72.2
Stone Arch Bridge Parking Lot	2.64	7/29/2011	Heavy Fog	Clear	6:43 AM	12.0	7.0	10.44	67.0

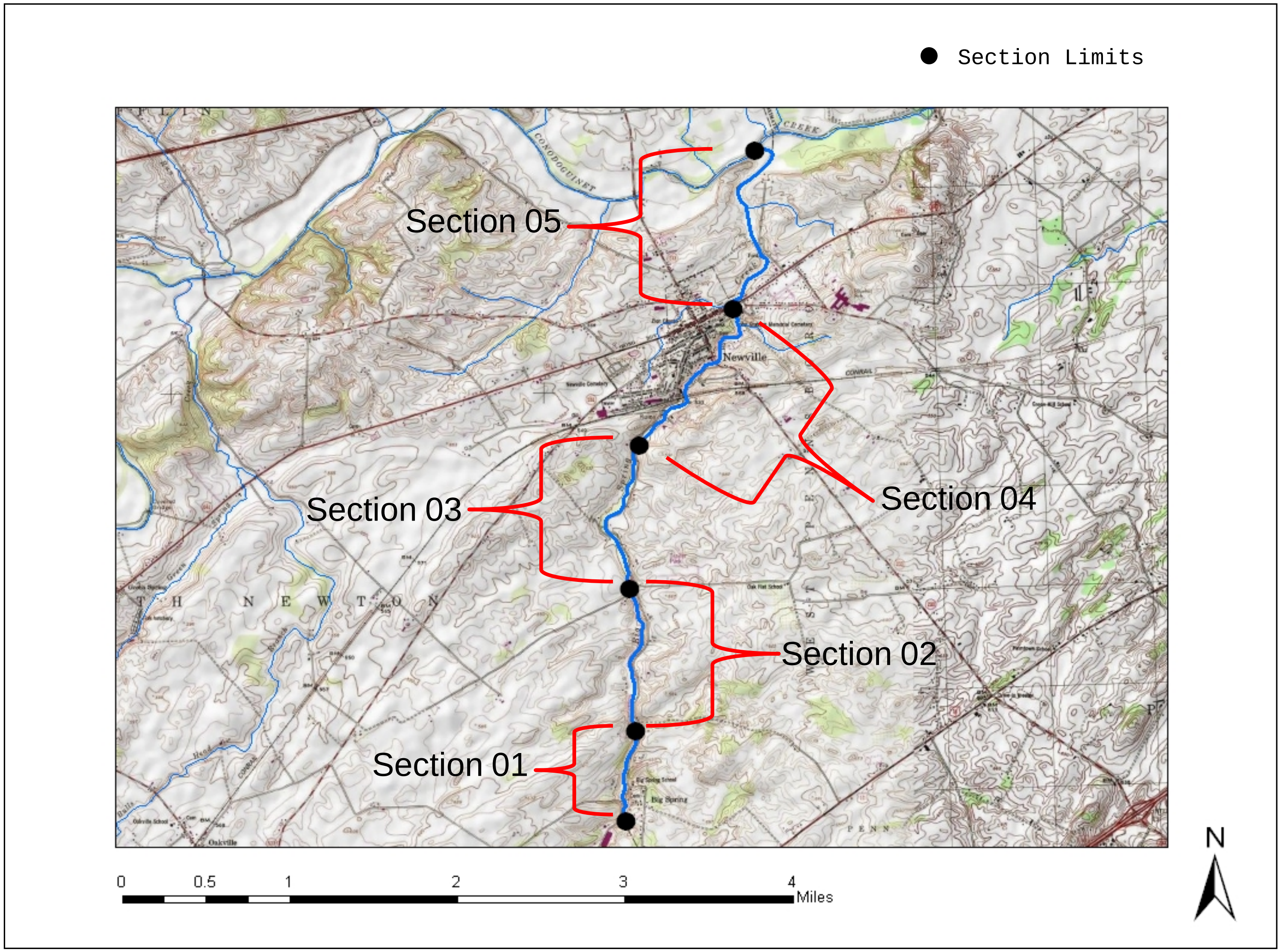

Figure 1. Location map of Big Spring Creek (7B), Cumberland County.

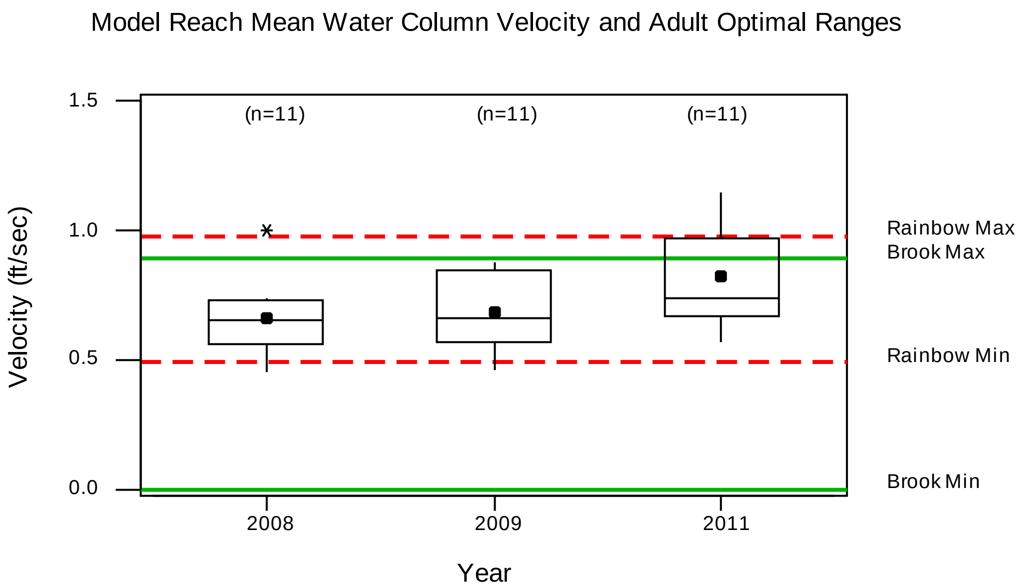

Figure 2. Big Spring Creek model reach transect mean water column velocity data and adult optimal velocity ranges for brook and rainbow trout.

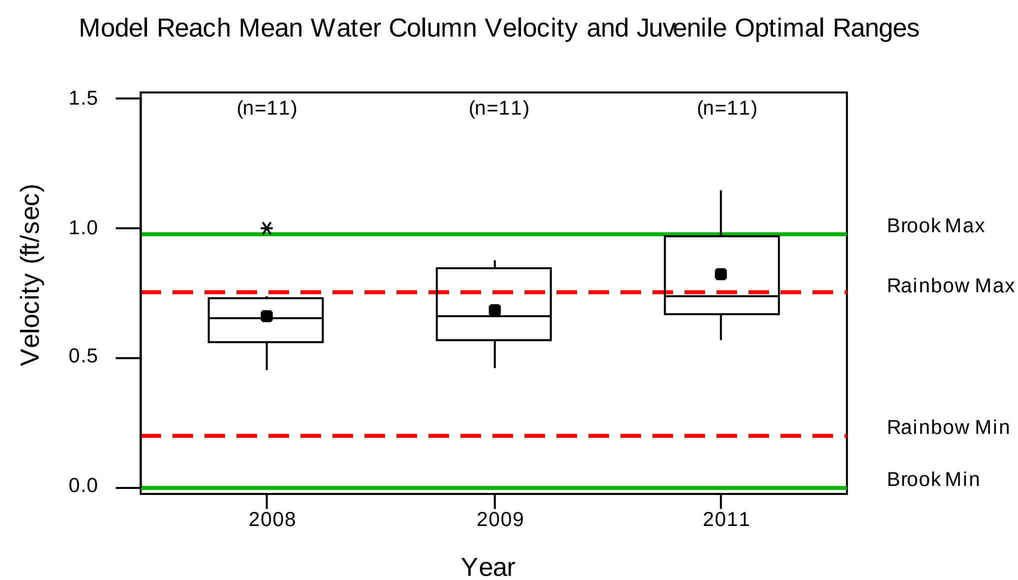

Figure 3. Big Spring Creek model reach transect mean water column velocity data and juvenile optimal velocity ranges for brook and rainbow trout.

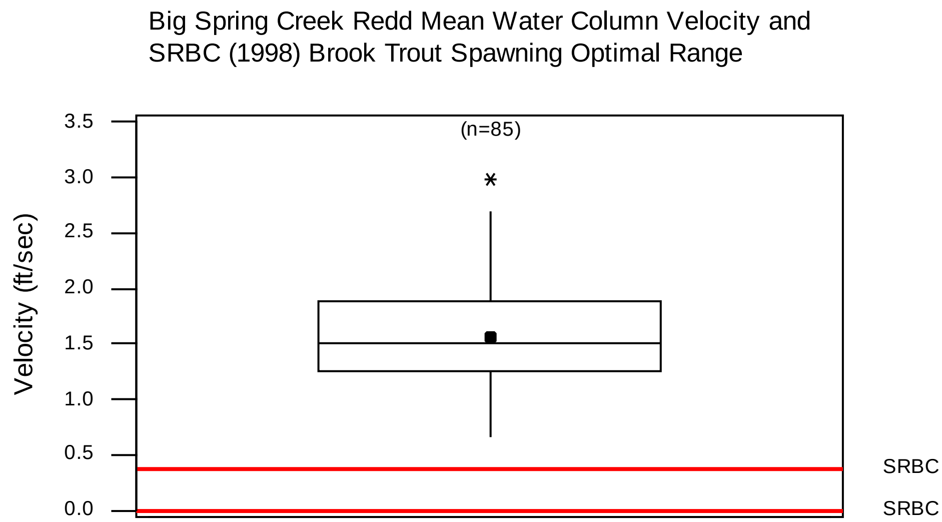

Figure 4. Big Spring Creek redd mean water column velocity data and spawning optimal velocity range for brook reported by SRBC (1998).

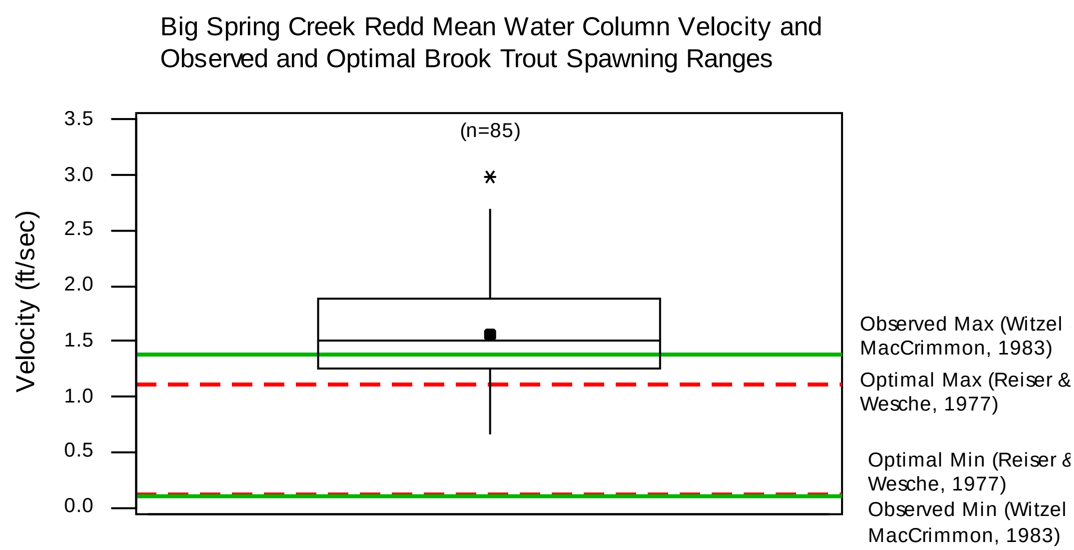

Figure 5. Big Spring Creek redd mean water column velocity data, range of brook trout redd velocity values reported by Witzel and MacCrimmon (1983), and spawning optimal velocity range for brook reported by Reiser and Wesche (1977).

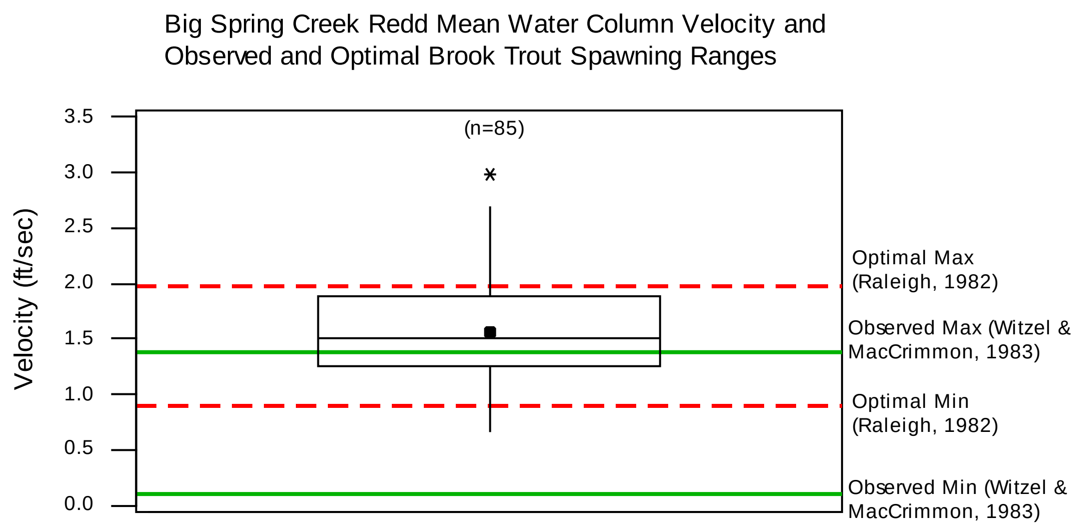

Figure 6. Big Spring Creek redd mean water column velocity data, range of brook trout redd velocity values reported by Witzel and MacCrimmon (1983), and spawning optimal velocity range for brook reported by Raleigh (1982).

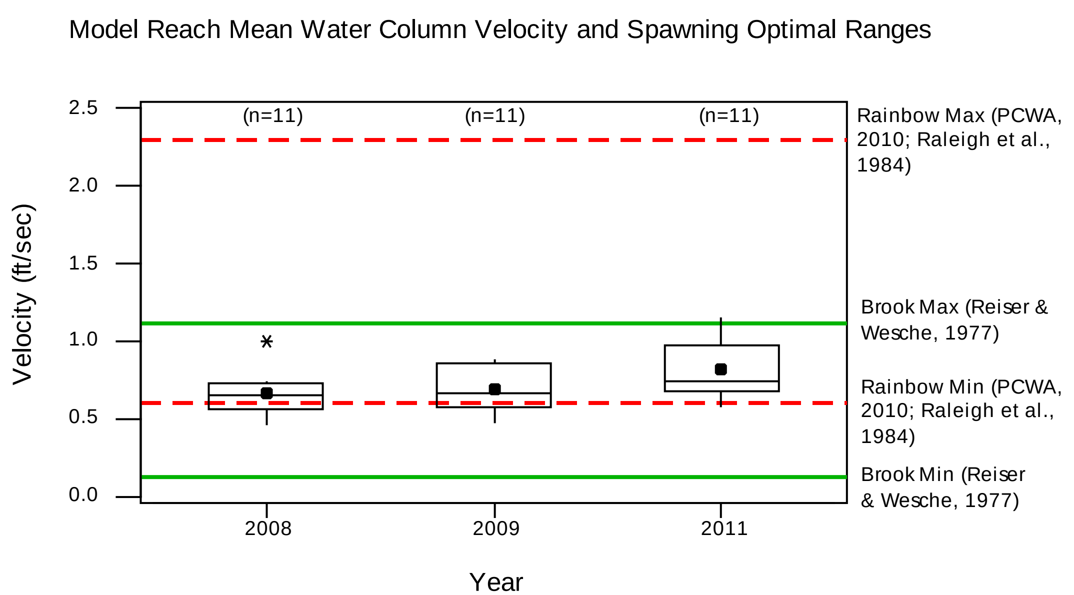

Figure 7. Big Spring Creek model reach transect mean water column velocity data and spawning optimal velocity ranges for brook and rainbow trout.

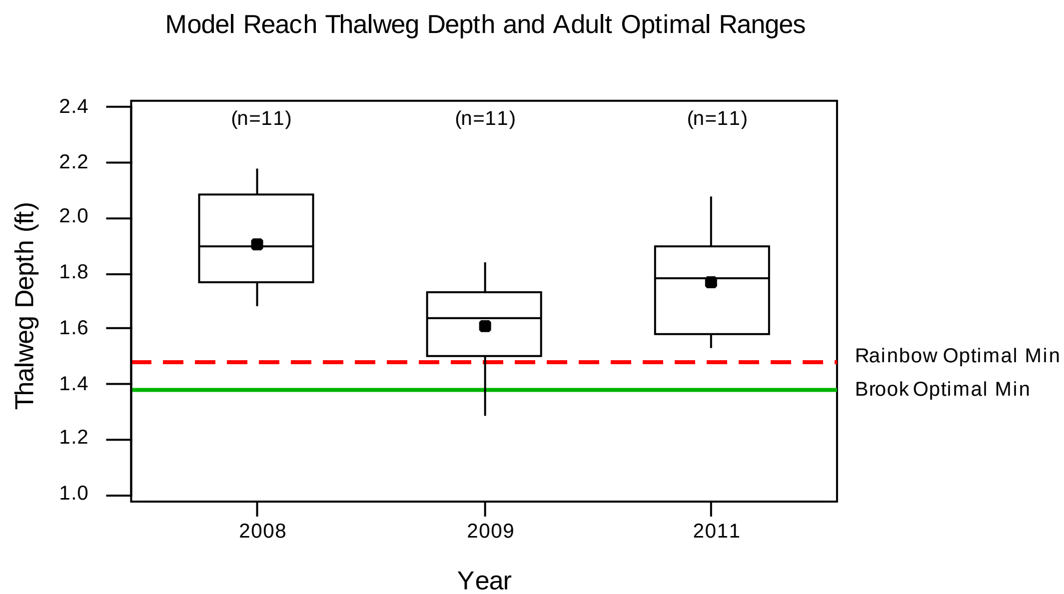

Figure 8. Big Spring Creek model reach thalweg depth data and adult optimal thalweg depth ranges for brook and rainbow trout.

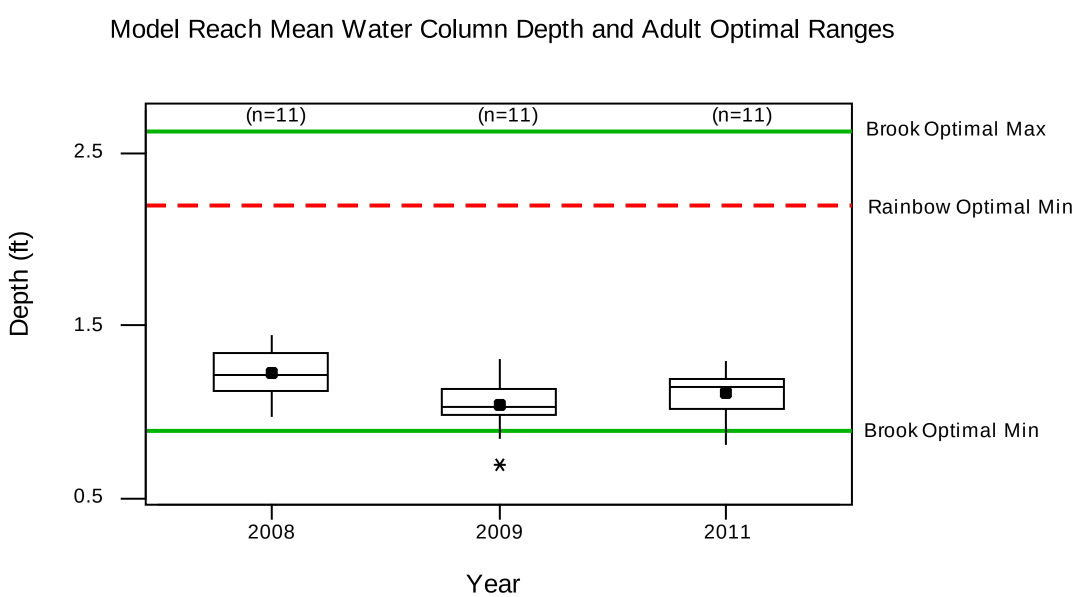

Figure 9. Big Spring Creek model reach mean water column depth data and adult optimal depth ranges for brook and rainbow trout.

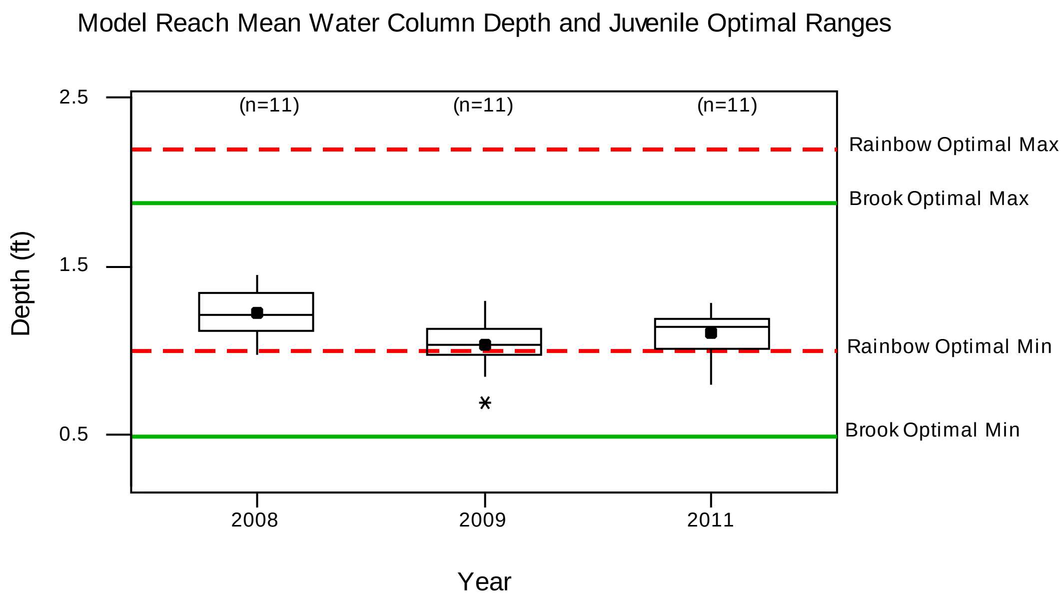

Figure 10. Big Spring Creek model reach mean water column depth data and juvenile optimal depth ranges for brook and rainbow trout.

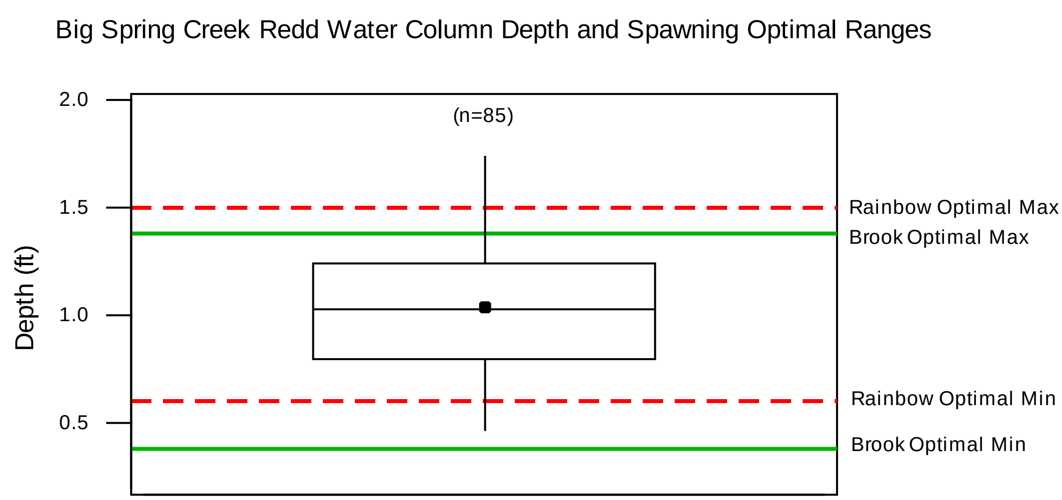

Figure 11. Big Spring Creek redd depth data and optimal spawning depth values reported for brook trout (SRBC, 1998) and rainbow trout (PCWA, 2010).

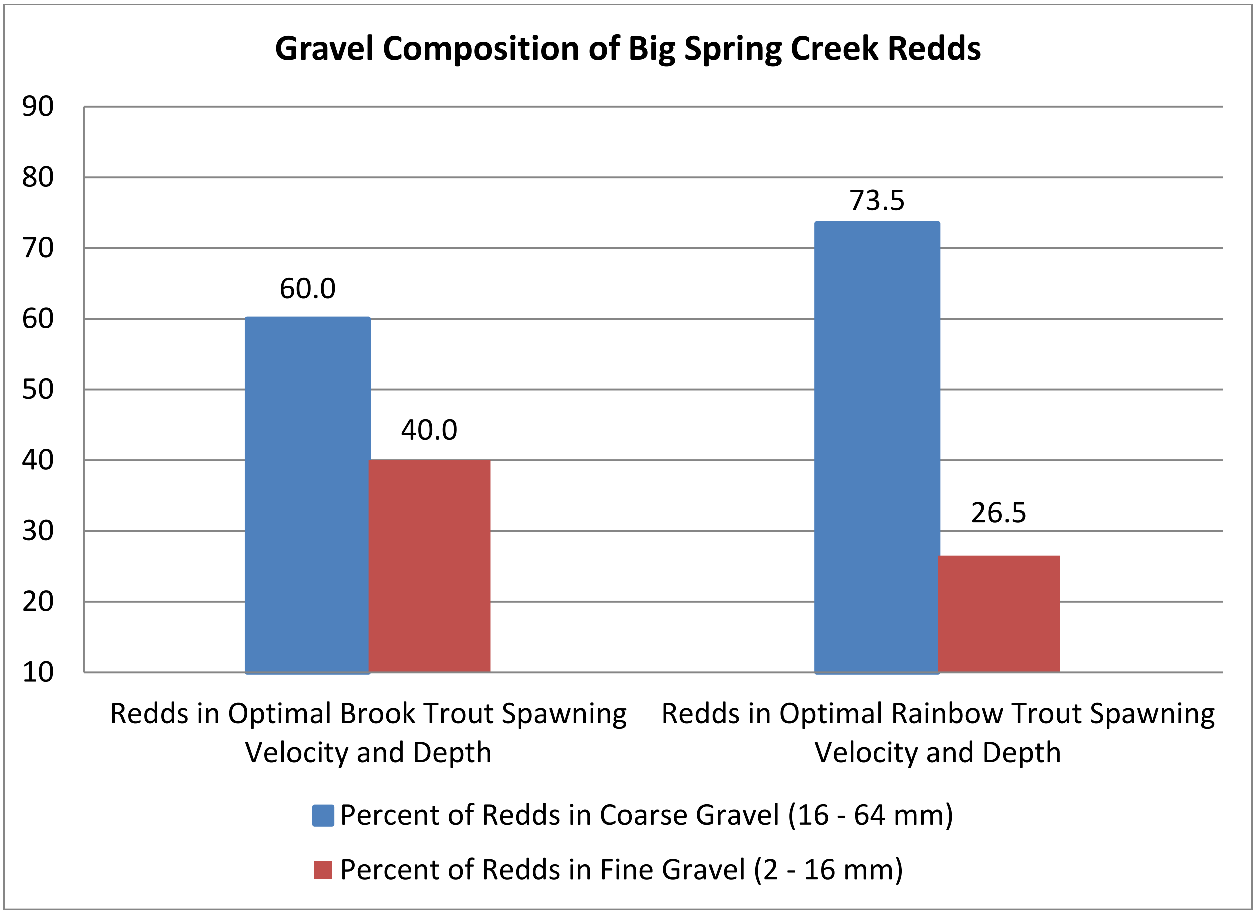

Figure 12. Gravel composition of Big Spring Creek redds located in optimal brook and rainbow trout spawning velocity and depth conditions.

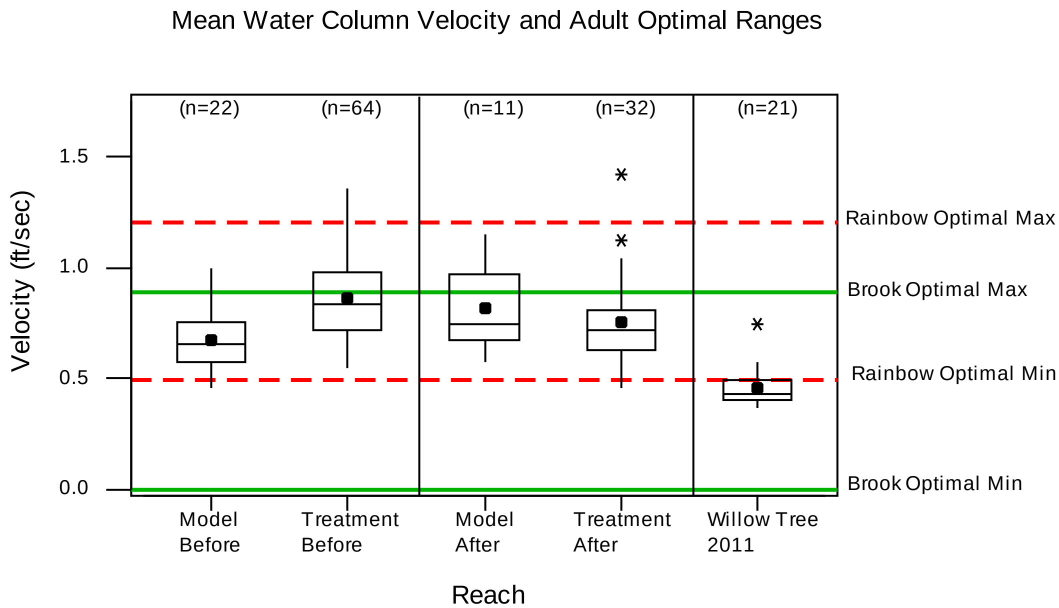

Figure 13. Adult brook and rainbow trout optimal velocity ranges and mean water column velocity data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

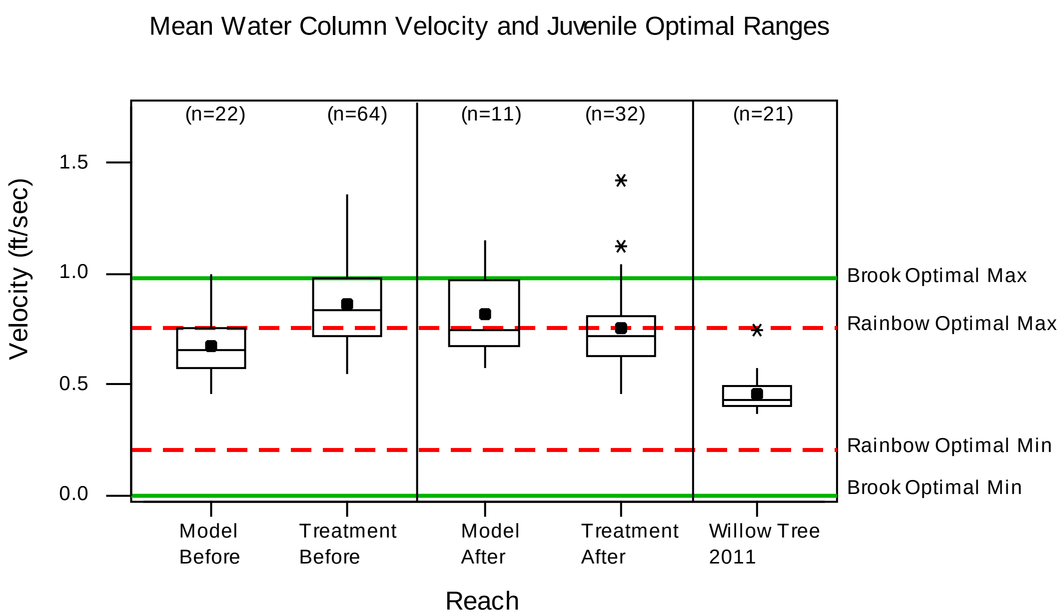

Figure 14. Juvenile brook and rainbow trout optimal velocity ranges and mean water column velocity data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

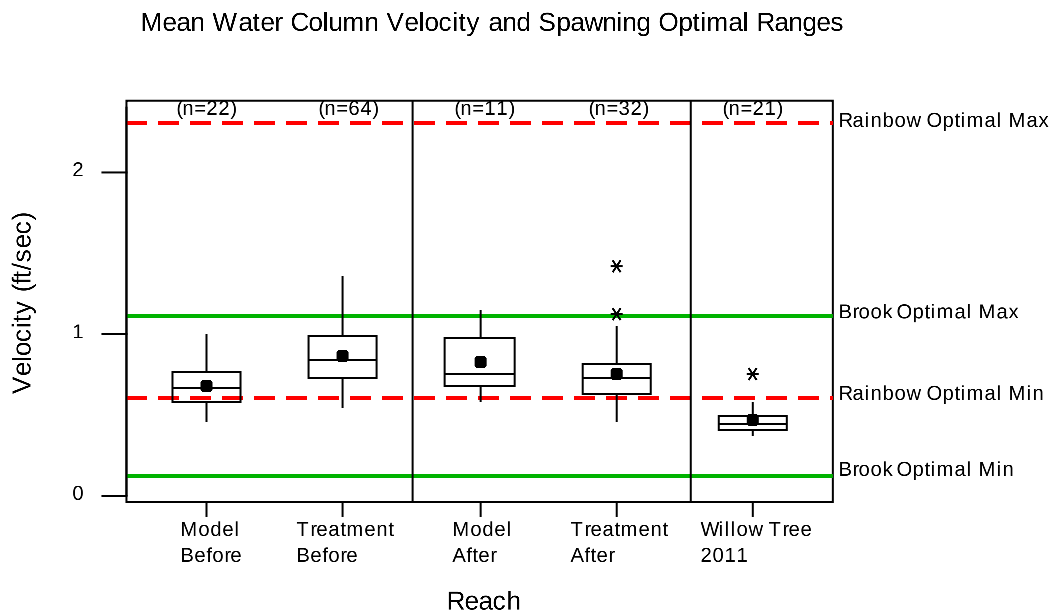

Figure 15. Spawning brook and rainbow trout optimal velocity ranges and mean water column velocity data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

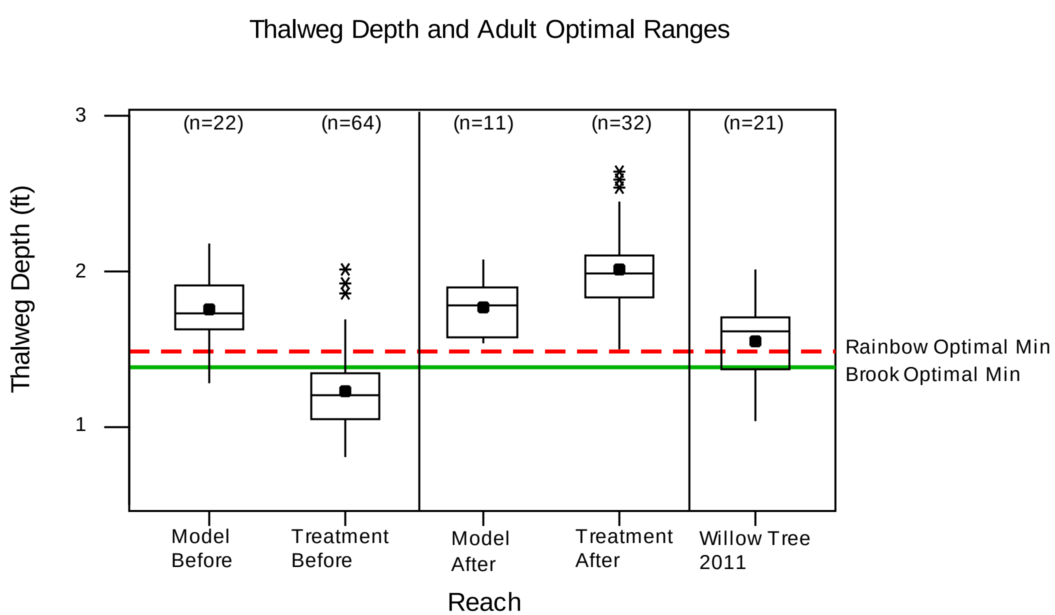

Figure 16. Adult brook and rainbow trout optimal thalweg depth ranges and mean water column depth data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

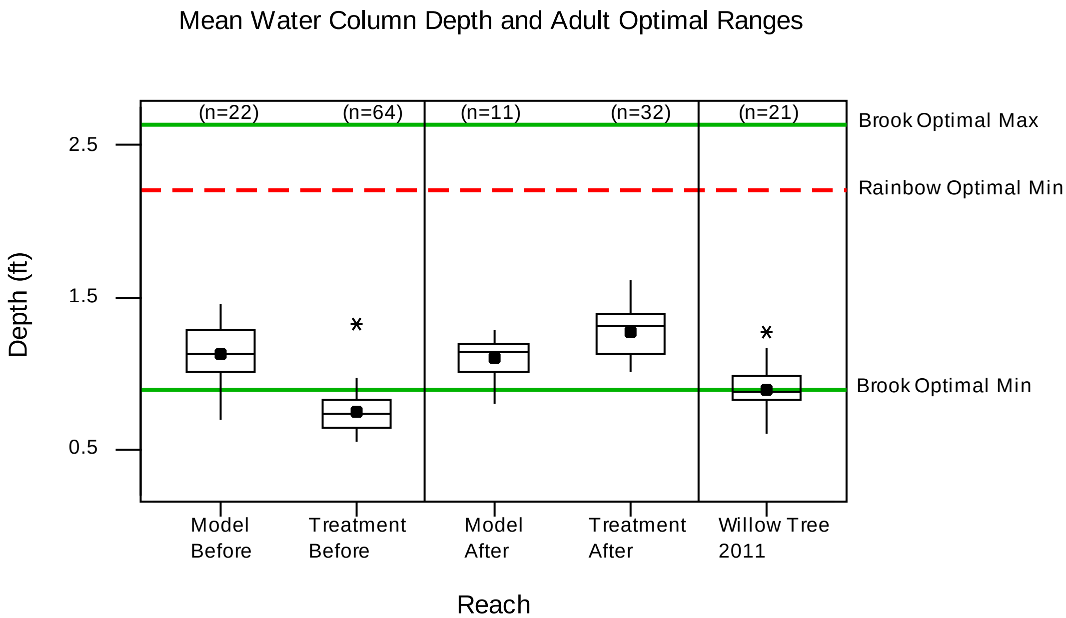

Figure 17. Adult brook and rainbow trout optimal depth ranges and mean water column depth data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

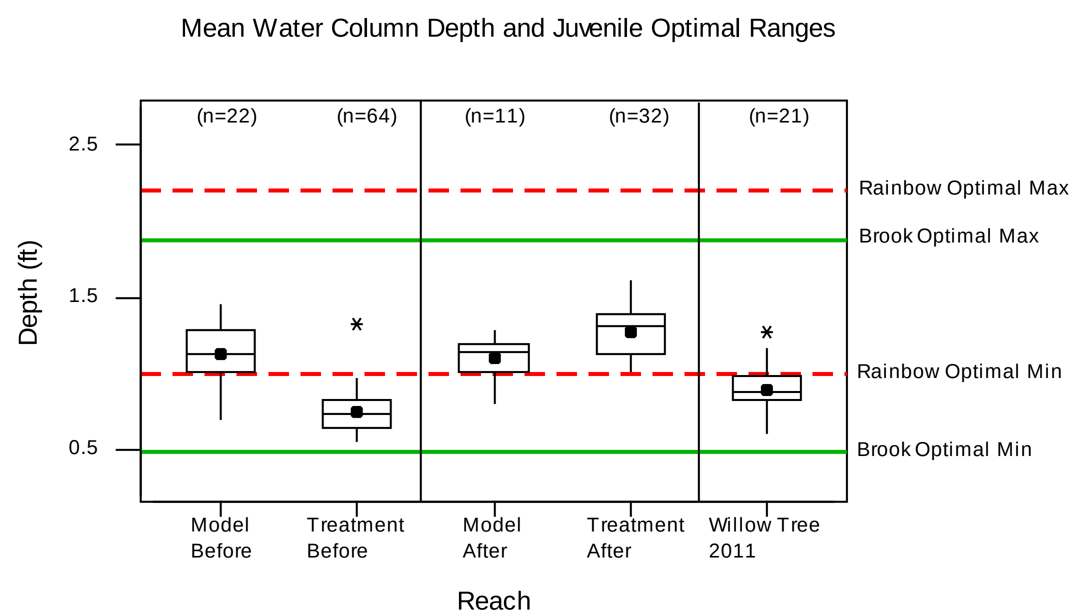

Figure 18. Juvenile brook and rainbow trout optimal depth ranges and mean water column depth data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

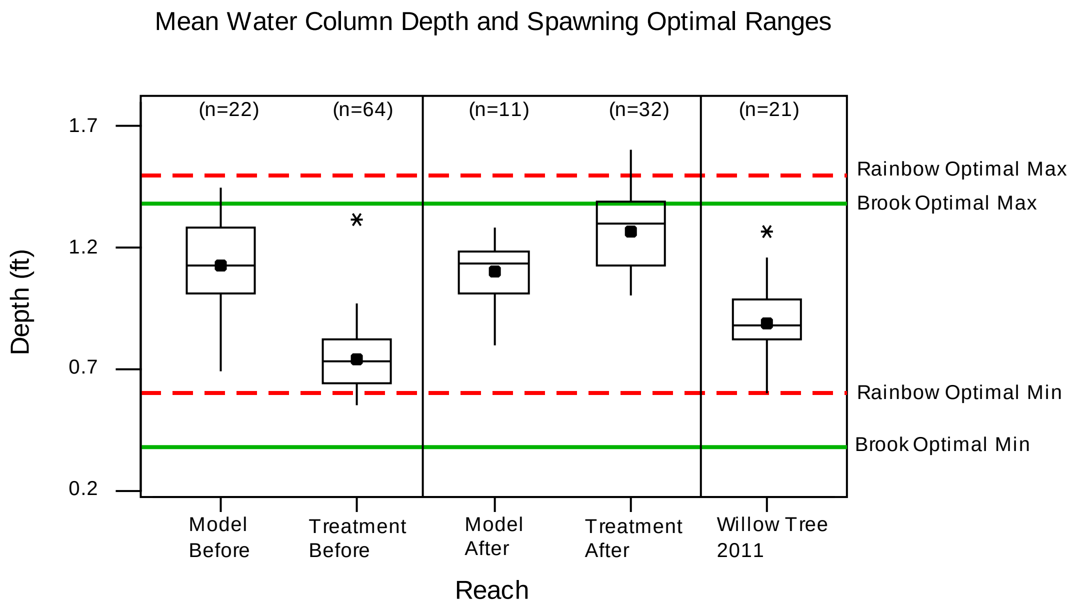

Figure 19. Spawning brook and rainbow trout optimal depth ranges and mean water column depth data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

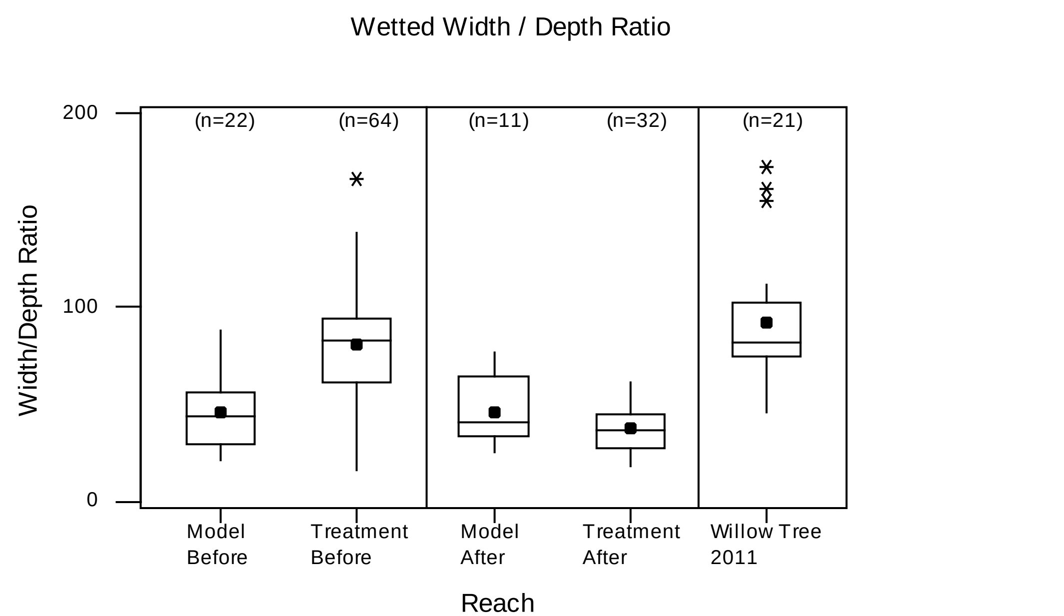

Figure 20. Wetted width / depth ratio data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

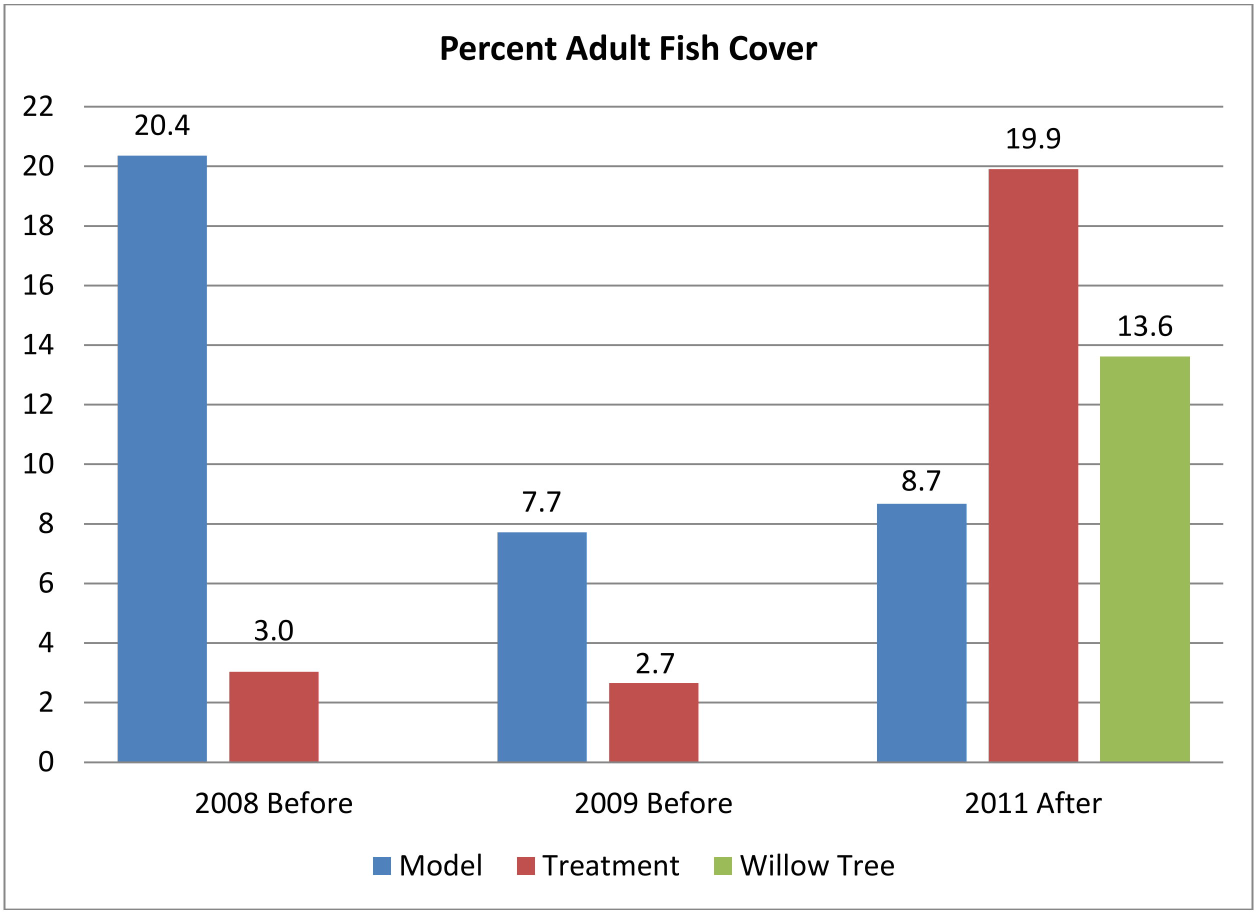

Figure 21. Percent adult fish cover data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

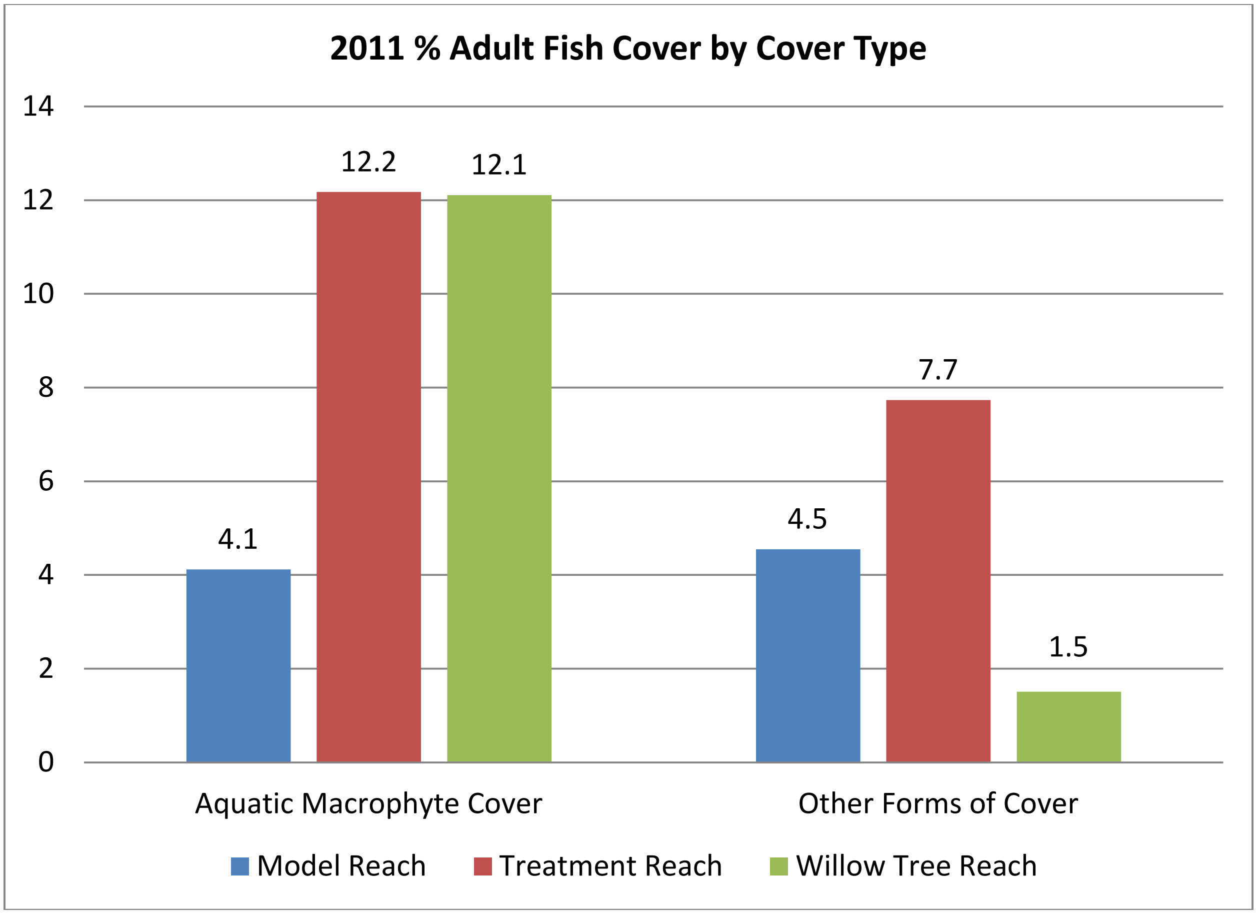

Figure 22. 2011 percent adult fish cover data from Big Spring Creek model, treatment, and willow tree reaches by cover type.

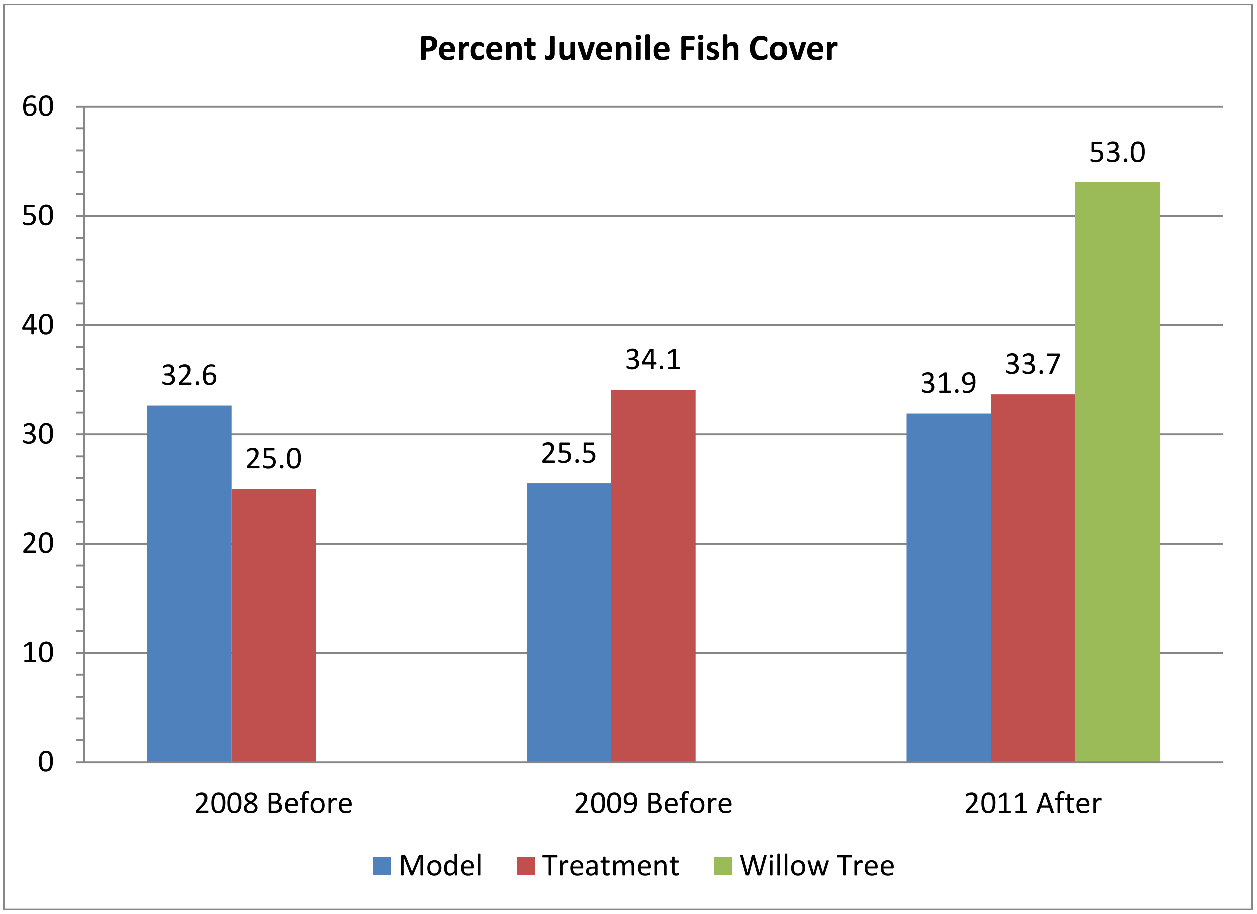

Figure 23. Percent juvenile fish cover data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

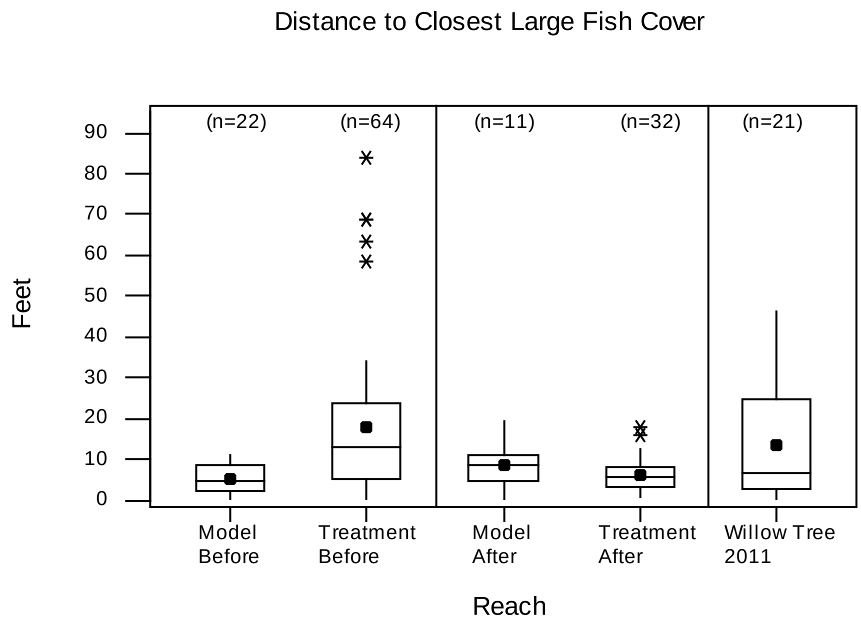

Figure 24. Distance to closest adult fish cover data from Big Spring Creek model and treatment reaches before and after the implementation of the 2010 habitat enhancement project, and the willow tree reach in 2011.

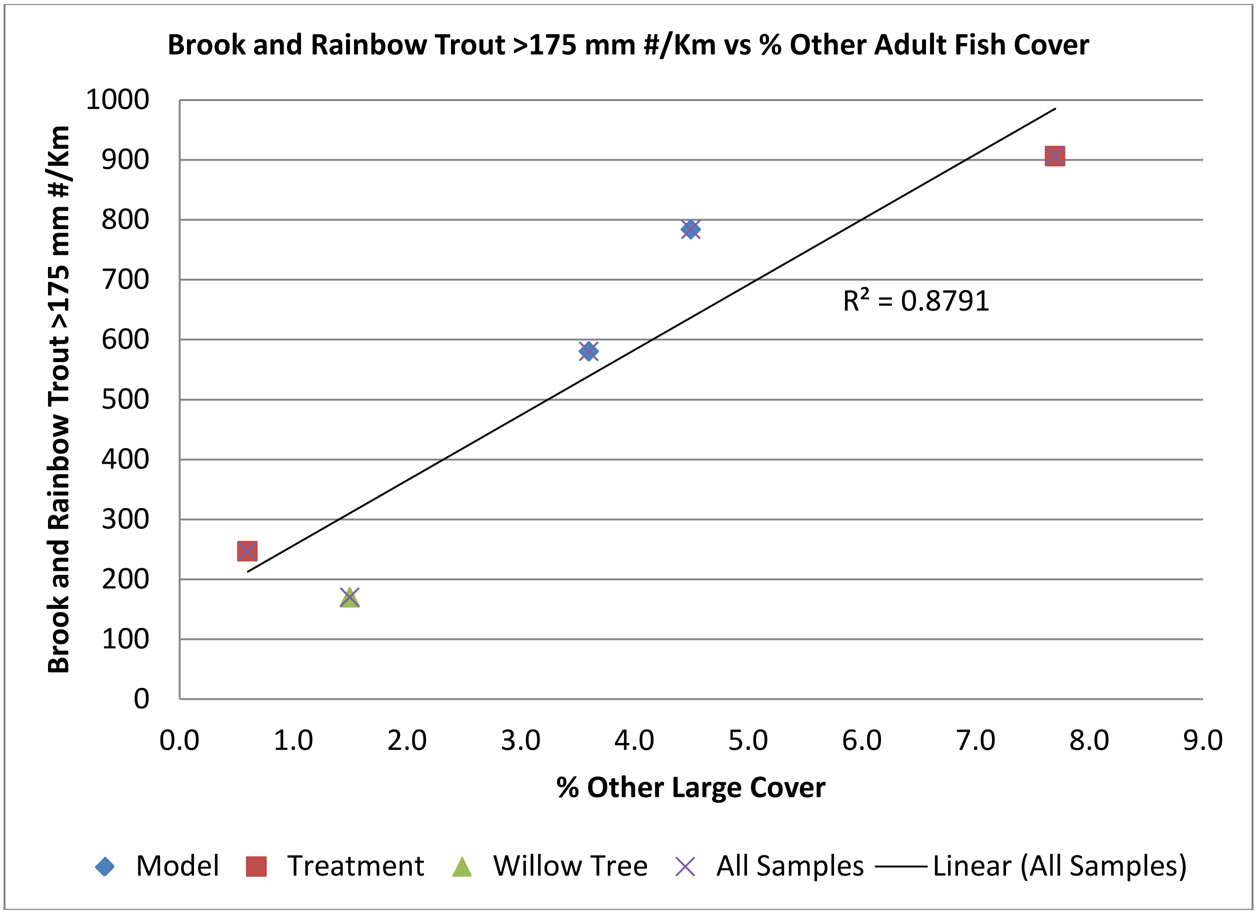

Figure 25. Brook and rainbow trout >175 mm in length number per km vs. percent adult fish cover other than aquatic macrophytes from Big Spring Creek model, treatment, and willow tree reaches from 2009 and 2011.

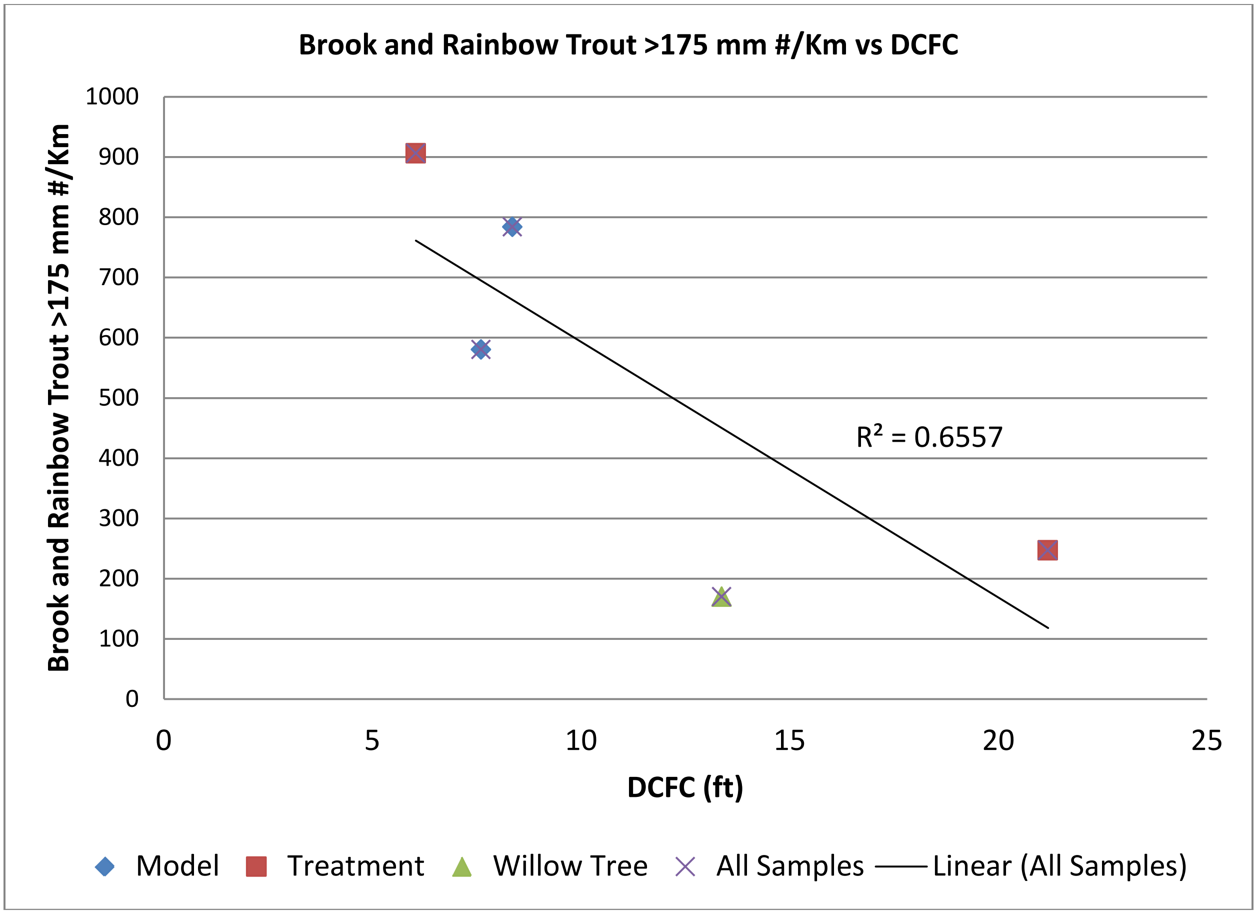

Figure 26. Brook and rainbow trout >175 mm in length number per km vs. distance to closest adult fish cover (DCFC) from Big Spring Creek model, treatment, and willow tree reaches from 2009 and 2011.

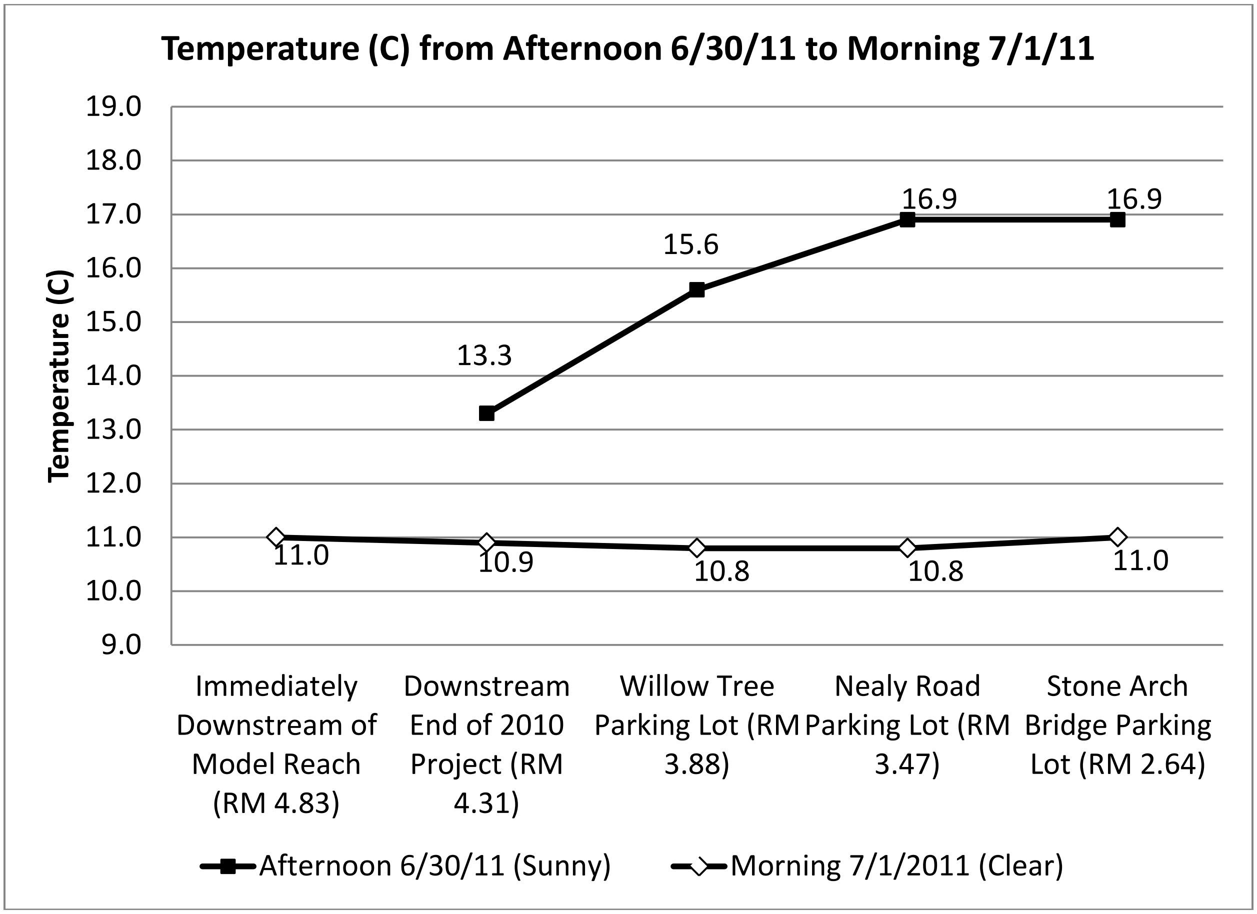

Figure 27. Late-afternoon (6/30/2011) and early-morning (7/1/2011) water temperature data from Big Spring Creek.

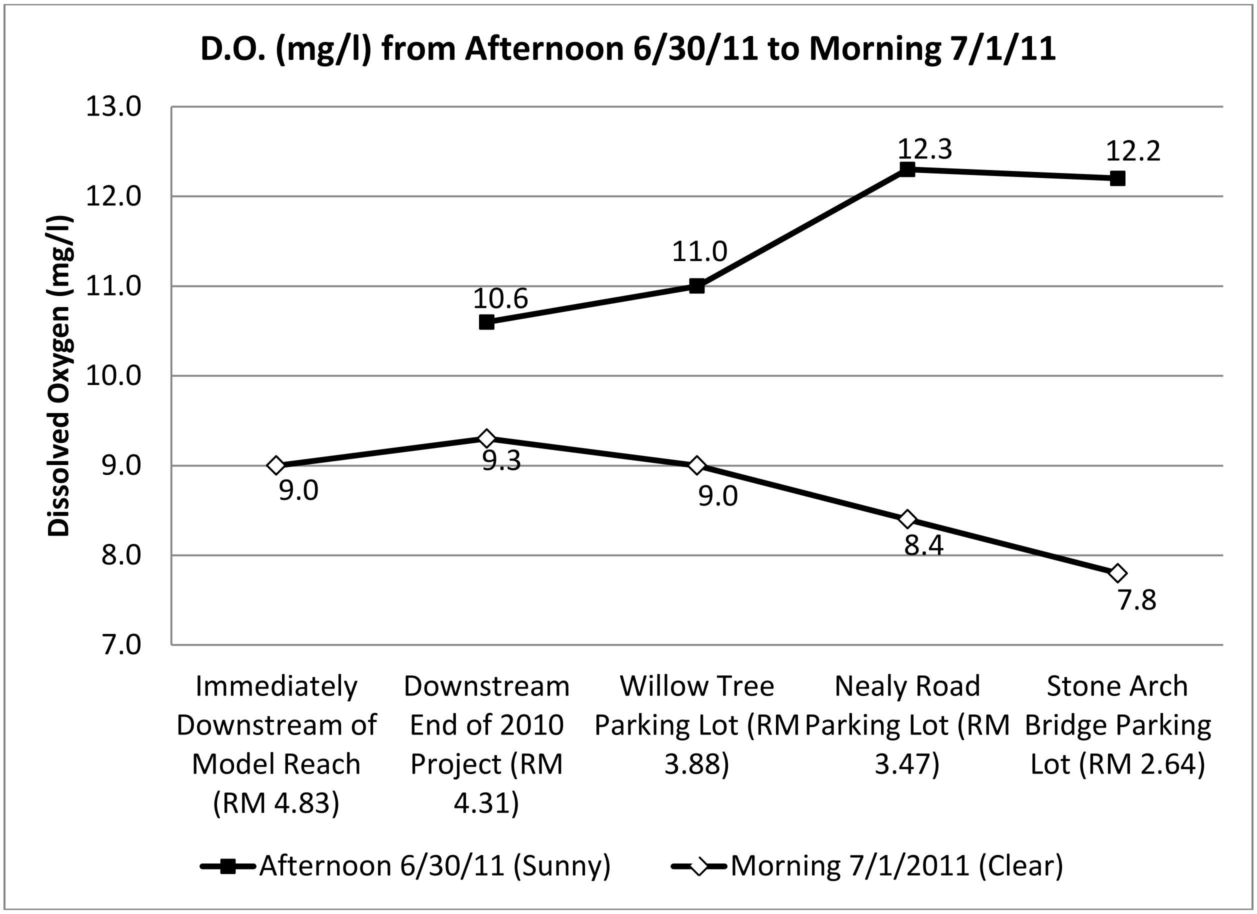

Figure 28. Late-afternoon (6/30/2011) and early-morning (7/1/2011) dissolved oxygen data from Big Spring Creek.

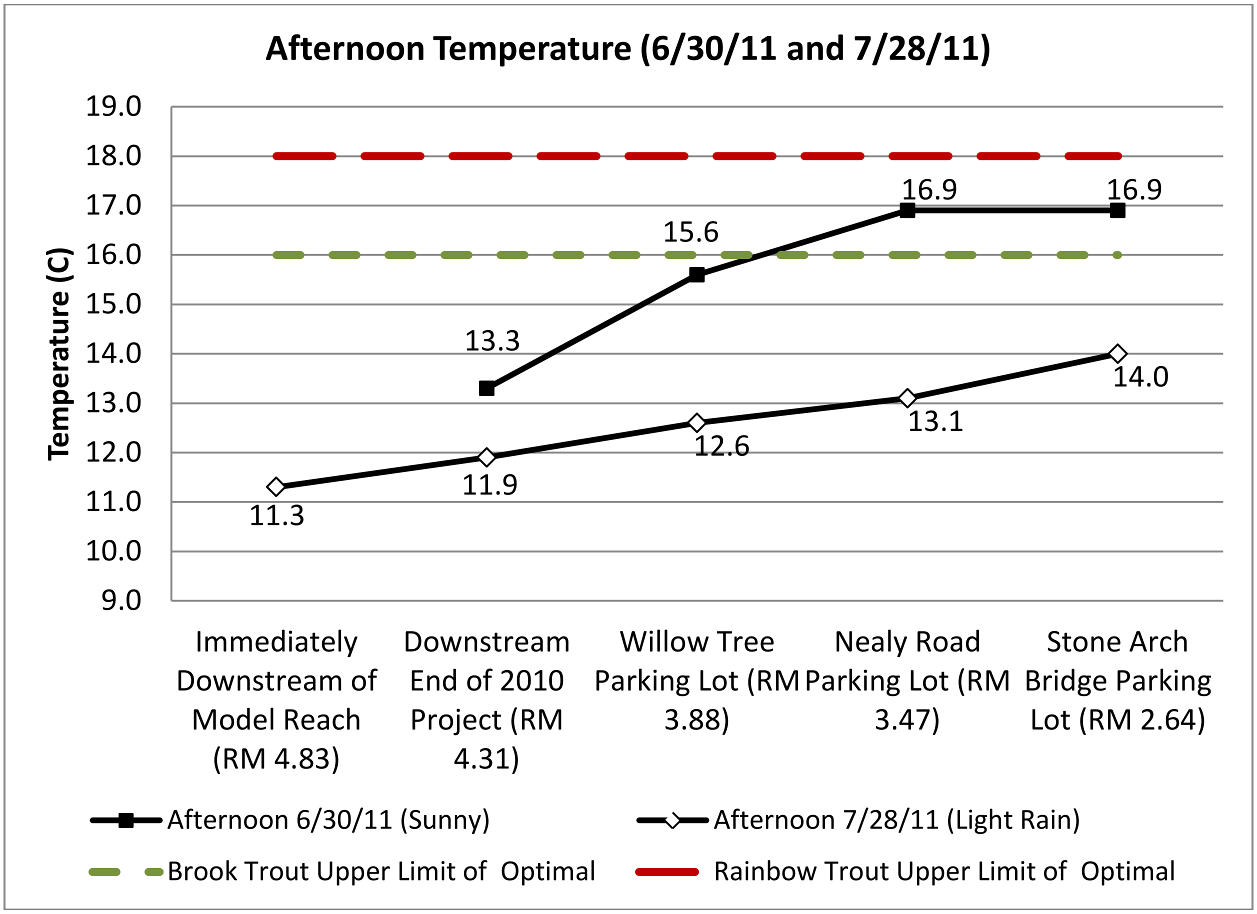

Figure 29. Late-afternoon water temperature data from Big Spring Creek.

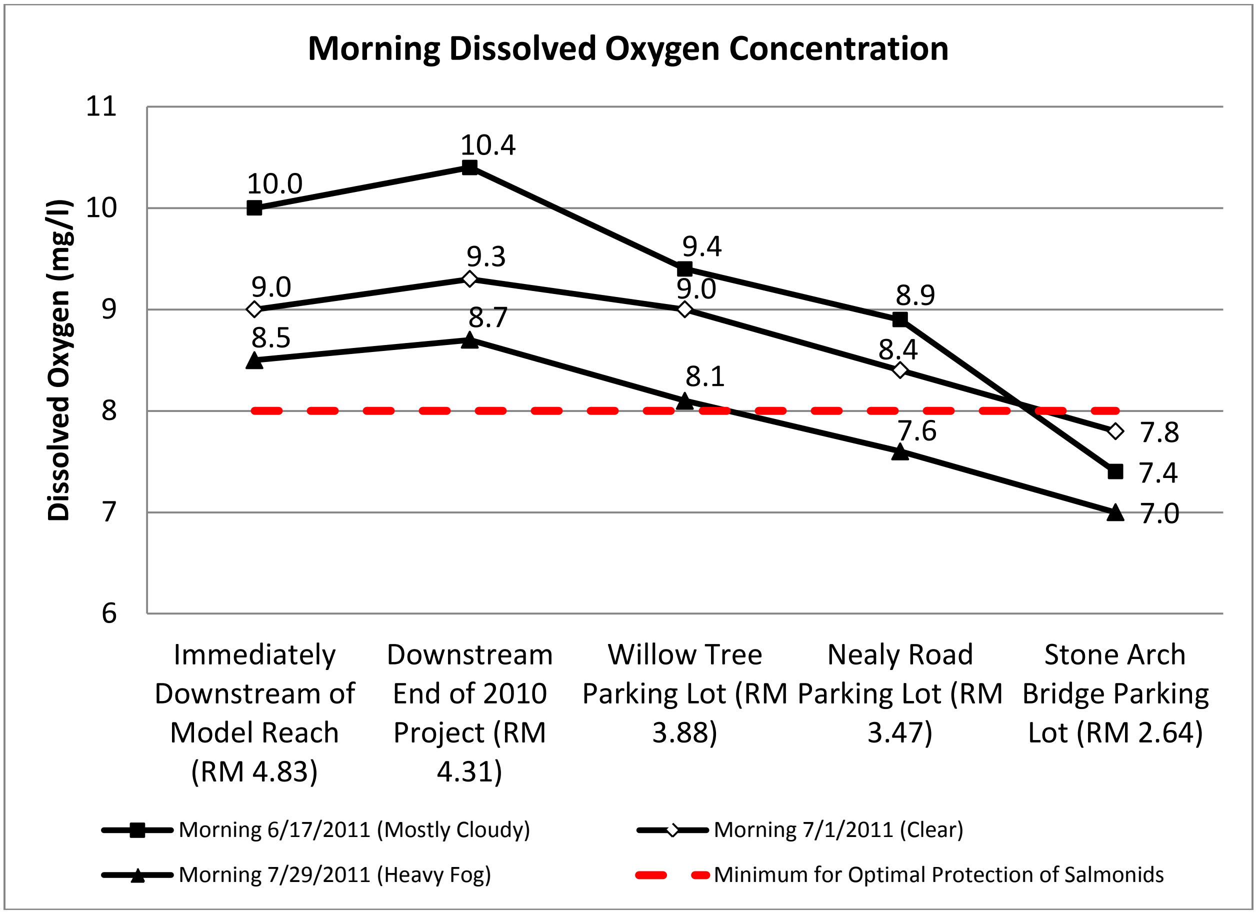

Figure 30. Early-morning dissolved oxygen data from Big Spring Creek.

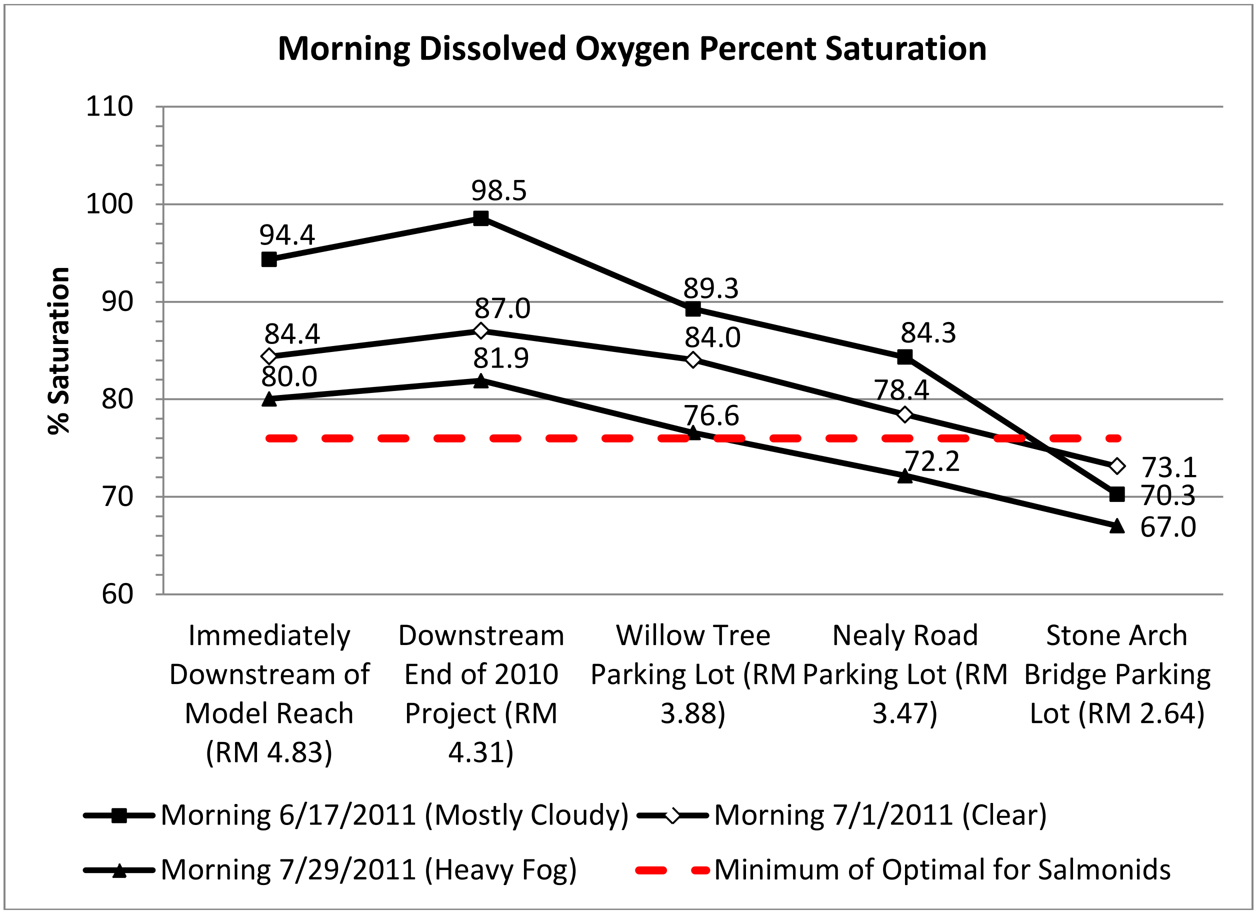

Figure 31. Early-morning dissolved oxygen percent saturation data from Big Spring Creek.

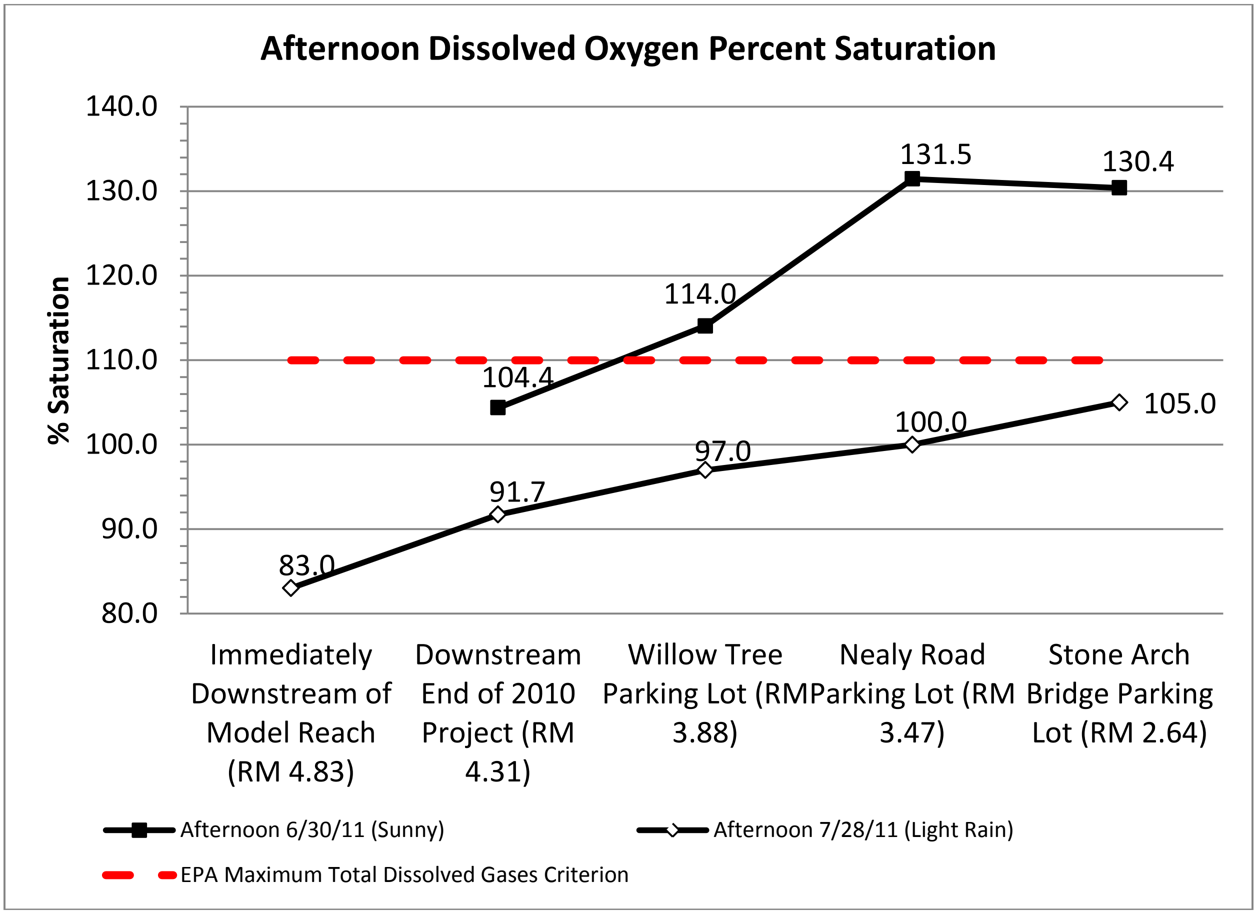

Figure 32. Late-afternoon dissolved oxygen percent saturation data from Big Spring Creek.