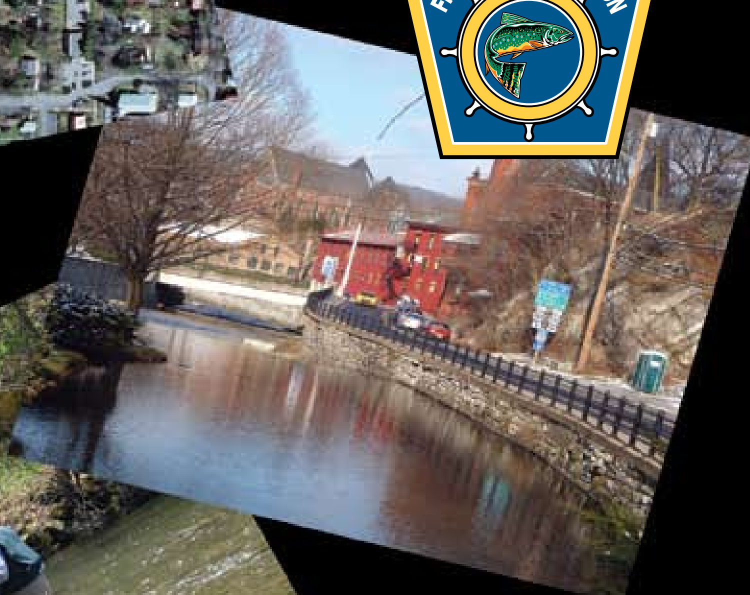
The Fishery of Spring Creek

A Watershed Under Siege



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Forward

A fishery consists of three elements: the animals that are being pursued, the habitat in which the animals live, and the people who are pursuing the animals for either sport or commercial purposes. Hence, in attempting to describe the historical and contemporary fishery of Spring Creek, we put considerable emphasis on habitat features, particularly water quality, while describing the trout populations and the anglers who were and are engaged in this fishery. We have written this bulletin with several audiences in mind: fisheries managers and researchers, regulatory agencies, municipal planners, elected officials, and anglers. We use metric units because much of our data were collected using that system, and it is preferred for scientific publications. We have included equivalent English units after the first use of a metric unit, except for flow, where we always give the English equivalents. The challenge of addressing audiences with such a broad range of interests is finding the right balance between technical detail and ease of comprehension. We leave it to the readers to tell us if we came close to that balance.

About the Authors

Dr. Robert Carline devoted his entire professional career to fisheries research. He began working with the Wisconsin Department of Natural Resources in 1967, then took a position with the U.S. Fish and Wildlife Service in 1976, and came to Pennsylvania in 1984, where he was Leader of the Pennsylvania Cooperative Fish and Wildlife Research Unit, U.S. Geological Survey, until his retirement in April 2007. He served as Adjunct Professor of Fisheries in the School of Forest Resources at The Pennsylvania State University (PSU), where the Unit is housed. He began his first research project on Spring Creek in 1985 and has been actively involved in a wide variety of projects in the watershed since then.

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Bruce A. Hollender began as a biologist with the Pennsylvania Fish and Boat Commission in 1971 and went on to become the Area Fisheries Manager for the northcentral region; he retired in 2007. During his tenure he surveyed and developed management plans for most of the streams, rivers, and lakes in the region. He earned B.S. and M.S. degrees in Natural Resources, majoring in Fisheries, from the University of Wisconsin-Stevens Point.

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Abstract

The Spring Creek watershed (378 km2; 146 mi2) has undergone substantial changes in land use since settlement in the late 1700s. Even though urbanization and population growth are increasing at a rapid pace, Spring Creek continues to support wild trout and a heavily-used sport fishery. The purpose of this bulletin is to trace the history of the Spring Creek fishery, attempt to relate changes in the fishery to human activities, and assess potential threats. The persistence of wild trout in Spring Creek is linked to the karst geology, which is characterized by many limestone springs throughout the watershed. These springs provide adequate year-round stream flow, and they moderate water temperatures in summer and winter.

While these springs have long benefited water quality, raw sewage from population centers in the early 1900s probably polluted certain stream reaches. Between 1913 and 1968, five wastewater treatment plants were constructed in the watershed, but discharges from several of these plants often degraded water quality. In addition, Spring Creek was subjected to numerous toxic spills, some of which killed thousands of fish. In recent years, wastewater treatment plants have been consolidated into two facilities, and treated wastewater from PSU is being spray irrigated onto agricultural and forest lands. It is likely that water quality in Spring Creek is better now than it has been since 1900.

Deteriorating water quality and stocking of brown trout in the 1890s probably contributed to the decline of native brook trout in the watershed. Some wild brook trout persisted in the main stem of Spring Creek in the 1950s, but by then brown trout had taken over the main stem and much of the tributaries. Contamination of Spring Creek with kepone and mirex led to the cessation of stocking catchable size trout and imposition of no-harvest regulations in 1982 to prevent consumption of tainted fish. These management changes appear to have benefited brown trout; between 1980 and 1988, density of age-1 and older brown trout increased by 180% and in 1988 density ranged from 678 to 1327 trout/ha. Density continued to increase until 2000 and declined somewhat in 2006, when density ranged from 368 to 1563 trout/ha. Growth of brown trout was typical of limestone streams statewide; age-4 brown trout averaged 318 mm (12.5 in) total length. Stream flow and temperature, rather than trout density, seemed to have the most influence on growth. Above-average temperatures and below-average stream flow in summer suppressed growth, while above-average temperatures and flow in winter enhanced growth. Counts of brown trout redds from 1987 to 2005 indicate that spawning effort has increased, with the most notable increases occurring in the lower and middle reaches of the main stem.

By the late 1800s, Spring Creek had a reputation as an excellent trout fishery. This reputation was further enhanced in 1934 with the establishment of a specially regulated 1.8-km reach that later became known as Fisherman's Paradise. Terminal tackle was restricted to flies tied on barbless hooks, and anglers were initially allowed to harvest two trout per day. The reach was heavily stocked with large trout, and fishing pressure was intense over the two-month season. Angler-use peaked in 1952 with more than 44,000 angler trips. Poor water quality and high cost of the program led to its closure in 1961. Thereafter, Fisherman's Paradise was managed as a 'fish-for-fun' program, tackle restrictions remained in place, and stocking of trout was discontinued after the 1981 season. Fishing pressure remains high. From April to June 2006, estimated pressure was 5,063 angler-h/km, which was 34 times higher than the estimated average fishing pressure on limestone streams statewide in 2004.

Most of Spring Creek had been stocked with catchable size trout, and liberal harvest regulations

were in effect until the 1982 fishing season, at which time harvest was prohibited, there were no tackle restrictions, and the stream was open for fishing year-round. Angler surveys in 1988-1989 revealed high fishing pressure in sections with no tackle restrictions and catch rates that exceeded 1.2 trout/h. Fishing pressure has been increasing in recent years, and in April to June 2006, we estimated 4,344 angler-h/km in a section with good public access, which represents a 400% increase compared to a similar time period in 1989.

Conversion of forests and agricultural land to urban areas and to transportation networks represents the biggest threat to the watershed and the trout fishery. We monitored two sites on Spring Creek during construction of Interstate Highway 99 (I-99) and found that sediment loading to the stream increased during construction, but there was no evidence that trout spawning habitat or macroinvertebrate communities were affected. When macroinvertebrate communities were used to assess stream health, it seemed that urbanization in the upper one-half of the watershed was impairing water quality. In other watersheds, impervious surface area has been used as a good surrogate of urban development; when imperviousness reached 7-11%, trout populations were lost. The Spring Creek watershed had 12% impervious cover in 1995, and in the upper one-half of the watershed, impervious cover was 19%. We suggest that the reason Spring Creek is still able to sustain wild trout with this degree of urbanization is the relatively large input of groundwater into the stream. Further development that increases impervious cover, reduces groundwater recharge, or both, will certainly increase the stress on Spring Creek and reduce its ability to support wild trout.

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Introduction

The trout fishery in Spring Creek, Centre County, Pennsylvania, like many trout fisheries in the New England and mid-Atlantic states, has undergone substantial alterations since the 1800s, owing primarily to changes in the landscape brought about by ever-increasing perturbations from an expanding human population. Unlike many coldwater fisheries close to population centers, the Spring Creek fishery, though altered, has persisted quite well, and remains as one of the best trout fisheries in the Commonwealth.

Brook Trout

The distribution of native brook trout in the Spring Creek watershed is now confined to a few small tributaries

photo by B. Hollender

In this bulletin, we trace the history of the Spring Creek fishery, attempt to relate changes in the fishery to human activities, and look ahead to potential threats with the hope that this highly valued resource can be conserved through informed decision making by local and state agencies.

The trout fishery in Spring Creek has played an important role in the culture of the watershed community (Figure 1). Bellefonte was a destination for trout anglers beginning in the late 1800s. The former Bush House on the banks of Spring Creek in Bellefonte Borough provided lodging for anglers and had a long veranda extending over the stream from which anglers could catch "speckled beauties." Local officials undoubtedly recognized the importance of fishing and demonstrated this by mounting the outline of a trout on the weather vane that still sits atop of the County Courthouse in Bellefonte Borough.

The trout fishery in Spring Creek owes its prominence to the underlying karst geology of the watershed. The limestone and dolomite bedrock favors rapid infiltration of surface water into the ground, where it replenishes the groundwater reserve. This large groundwater reservoir, in turn, emerges in many large springs that account for about 80% of the stream flow in the main stem of Spring Creek (Giddings 1974). These springs serve to maintain adequate stream flow, even during dry periods, and help to maintain moderate water temperatures, because temperature of the springs is about 10oC (50oF) year-round, which approximates the mean annual air temperature. Some of the precipitation that infiltrates into the groundwater of the adjacent Spruce Creek watershed flows in a northeasterly direction and contributes to the aquifer of the Spring Creek watershed. The portion of the Spruce Creek watershed that contributes to the Spring Creek aquifer encompasses Gatesburg Formation bedrock, which captures a significantly higher percentage of recharge than other valley floor bedrock settings (Taylor 1997). Thus, a geologic anomaly has provided Spring Creek with an ample supply of groundwater that has nurtured an exceptional wild trout population.

Originally, native brook trout (see Table 1 for scientific names) sustained the fishery (Cooper 1983). In the early 1900s, introduced brown trout established a solid foothold in the stream, and, by the late 1950s, they had completely displaced brook trout in the main stem of Spring Creek. Additionally, the increasing human population along with increased pollution in the first half of the 20th Century may have contributed to the demise of brook trout. Fish kills in the 1950s provided the impetus for a series of studies by Dr. Edwin L. Cooper, Professor of Ichthyology at PSU, and state agencies. Cooper and his students produced the first comprehensive description of the fish community along the length of Spring Creek, and they made the first quantitative estimates of density and biomass of trout and other species. Hollender et al. (1981) completed a comprehensive assessment of the fish community with emphasis on trout in 1980, and he collaborated with the senior author to continue periodic assessments until 2006. Here, we rely primarily on these assessments to make some generalizations about the trout fishery and to try to understand how the fishery has responded to natural and human-induced perturbations.

Spring Creek flowing through Bellefonte

photo by R. Carline

The effects of urbanization on fish communities have received considerable attention recently. For example, Schueler (1994) reviewed studies dealing with effects of urbanization on physicochemical and biological characteristics of streams and suggested that when a watershed's area of impervious surfaces exceeded 10%, stream biodiversity declined. Similarly, Wang et al. (2003) found that trout were largely eliminated when connected imperviousness exceeded 10% of the watershed area. In the Baltimore region of Maryland, Stranko et al. (2008) showed that brook trout were extirpated from most streams when impervious surface reached about 7% of the watershed. These types of studies provide convincing evidence that there is some upper limit to the amount of urbanization, particularly imperviousness, above which coldwater fish communities are not likely to persist. Part of our motivation for this study was to assess the status of the Spring Creek watershed in relation to urbanization and to forecast potential changes in the wild trout fishery.

Study Area

Spring Creek flows 36 km (22 mi) from its source near Boalsburg to its confluence with Bald Eagle Creek in Milesburg. It drains a 378-km2 (146 mi2) watershed, which is located near the geographic center of the state and is part of the larger West Branch Susquehanna River drainage (Figure 1). The watershed lies within the Ridge and Valley Physiographic Province of the folded Appalachian Mountains (Cuff et al. 1989). The terrain is characterized by long, high ridges and broad valleys that run in a northeast-southwest direction. The ridges are comprised primarily of sandstone and some shales, while the valleys are underlain by calcareous formations that are 1,800 to 2,400 m (5,900 to 7,874 ft) thick (Giddings 1974). Soils on the ridges are coarse-grained and relatively thin. In the valleys, soils are derived from carbonates, are composed largely of silt and clay, and vary in thickness from a few centimeters to more than 60 m.

The mean annual air temperature is 9.7 oC (49.5 oF) at the State College Climatological Station, on the PSU campus. Mean annual precipitation is 97 cm (38 in), and average monthly precipitation ranges from 6.2 cm in February to 9.8 cm in May. First and second order streams that flow down the steep ridges often encounter sinkholes at the base of the slope, and much of the surface flow disappears below the land surface and becomes part of the groundwater.

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Fulton et al. (2005) provide a concise summary of the geologic and hydrologic setting of the Spring Creek watershed. Prominent features of the karst geology include sinkholes and dissolution cracks in the limestone and dolomite bedrock, which provide a substantial storage capacity for groundwater, and are the source of many large springs. Sinkholes form where the roofs of dissolution cavities collapse; many of these are found at the bases of the ridges. Sinkholes often have direct connections to caverns and large cracks, which act as conduits for the rapid transmission of groundwater (White 1988). There are at least seven springs in the watershed with an outflow greater than 0.04 m3/s (1 mgd), the largest of which is Big Spring in Bellefonte Borough, which yields about 0.83 m3/s (19 mgd; WRMC 2006). These large springs, together with many smaller springs and seeps, provide a relatively constant flow of groundwater to Spring Creek and its tributaries.

The average daily flow of Spring Creek at the Milesburg gage is 6.62 m3/s (234 cfs), and the contributing surface drainage area is 368 km2 (USGS 2008a). The gage is located about one km upstream of the mouth of Spring Creek, such that the total surface drainage area of the basin is 378 km2. The water yield of Spring Creek is relatively high, because the groundwater drainage area is about 17% larger than the surface water drainage area (Taylor 1997).

Of the five major tributaries to Spring Creek, Logan Branch contributes 35% of the total stream flow and the other four tributaries together contribute 29% (WRMC 1999). The Benner Spring and Bellefonte State Fish Hatcheries (Hatcheries) discharge into the main stem and provide 9% of the flow, two wastewater treatment plants add 5%, and Big Spring contributes 5% of the total flow (Figure 1). The remaining 17% of the flow comes from unmeasured springs that feed the main stem.

The chemical make-up of surface waters is largely dependent on the source locations in the watershed. First order tributaries that originate on the sandstone-shale ridges are typically low in dissolved materials. For example, Galbraith Gap Run had these characteristics: pH 7.25, total hardness 16 mg/L as $CaCO_3$, nitrate nitrogen 0.34 mg/L, and orthophosphate <0.01 mg/L (data from December 2007; G. Smith, Water Resources Monitoring Project). In contrast, first order streams that arise from limestone springs in the valley floor have relatively high concentrations of dissolved materials. The Axemann Spring, which flows into Logan Branch, had the following average values: pH 7.40, total hardness 328 mg/L as $CaCO_3$, nitrate nitrogen 5.8 mg/L, and total orthophosphate <0.01 mg/L (data from 2005-2007; G. Smith, Water Resources Monitoring Project). Most of the stream flow in Spring Creek originates from limestone springs; hence, the main stem has high concentrations of dissolved materials. Spring Creek at the Milesburg gage had the following average values: pH 8.3, total hardness 230 mg/L as $CaCO_3$, nitrate nitrogen 3.5 mg/L, and total orthophosphate 0.026 mg/L (data from 2005-2007; G. Smith, Water Resources Monitoring Project).

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Like water chemistry, stream temperature is strongly influenced by proximity to large springs, which have an average annual temperature of about 10 oC. Among monitoring stations at the mouths of tributaries and the main stem, the lowest July temperatures (12.6 oC) were at the upper Spring Creek site, near the confluence with Cedar Run (Figure 2; WRMC 2003a). There is a large spring immediately upstream of this site. With the exception of Buffalo Run, tributaries provided water cooler than that in the main stem. As water moves down the main stem, it gradually warms. As Spring Creek passes through the Borough of Bellefonte, Logan Branch and Big Spring enter and temperature in the main stem declines by about 2 oC in July.

During January, large springs tend to increase stream temperature. Water entering the main stem from tributaries is slightly warmer than that in the main stem, but, as the water moves down the main stem, it cools during winter. Here again, addition of flow from Logan Branch and Big Spring increase stream temperature by about 2 oC in January. Owing to the moderating effect of groundwater inputs, Spring Creek rarely freezes over in winter.

Human Population Trends and Land Use

Fisherman's Paradise section of Spring Creek corrider in Lemont

ClearWater Conservancy photo archives

The Spring Creek watershed was first colonized by white settlers around 1770, and Centre County, with a population of about 4,000, was established by the Commonwealth in 1800. The population grew steadily until 1890, a period characterized by resource extraction industries (Figure 3). For the next 50 years, the population remained stable until the onset of World War II, which stimulated the growth of diversified industries and service activities, including the expansion of PSU. By 2005, the county's population had exceeded 140,000, and more than one-half of the population resided in the Spring Creek watershed. We can only approximate the number of people residing in the watershed, because boundaries of the watershed and the municipalities do not coincide. Parts or all of 10 townships and the boroughs of Bellefonte, Centre Hall, Milesburg, and State College are in the watershed, and in 2005 the population of these 14 municipalities was 110,290. The townships of Benner, College, Harris, Patton, and Spring have all or most (>80%) of their land area in the watershed, and, together with three boroughs (excludes Centre Hall), these municipalities had a population of 84,013 in 2005. Hence, the population of the Spring Creek watershed was between 80,000 and 110,000 people in 2005. The Centre County Planning Office's estimates of land use in 2002 was 45% forest, 28% agriculture, 18% developed, and 9% undeveloped (Figure 2).

Historical and Contemporary Water Quality

The history of water quality in the Spring Creek watershed seems closely linked to chronic discharges of pollutants from point sources, such as wastewater treatment plants and fish hatcheries, and from episodic spills of pollutants that often resulted in fish kills, some of which were rather spectacular.

UAJA

The University Area Authority's wastewater treatment plant provides service to most residents in the State College area.

photo by J. Brown

Wastewater Treatment Facilities

PSU built the first wastewater treatment plant in the watershed in 1913 at its present location near the intersection of East College Avenue and University Drive. The plant received wastes from campus and part of the Borough of State College. The plant has undergone several renovations and expansions since its initial construction. Perhaps the most notable event in the plant's history occurred in 1958, when 2,000 trout in the Pennsylvania Fish Commission's (renamed the Pennsylvania Fish and Boat Commission (PFBC) in 1991) Benner Spring Hatchery died, owing to low levels of dissolved oxygen in Spring Creek, which supplied water to the rearing facilities. Respiration from a huge biomass of aquatic plants in Spring Creek caused dissolved oxygen to fall to very low levels at night. The aquatic plants were abundant because of high levels of phosphates in the treatment plant discharge (Cooper and Wagner 1976). At that time, phosphates were used in household detergents, and elevated phosphate concentrations were probably common in most wastewater treatment discharges. Pennsylvania Department of Health files (now located with Pennsylvania Department of Environmental Protection (DEP)) noted high concentrations of ammonia and a high biological oxygen demand (BOD) in the treatment plant effluent, so that the fish kill was probably not due solely to high respiration rates and subsequent oxygen depletion caused by excessive plant biomass. The plant was upgraded in 1963 and part of the treated effluent was spray irrigated on crops and woodlands in the Toftrees area about 5 km from the plant. By 1983, all treated effluent was spray irrigated and discharge to Thompson Run was completely eliminated.

The 1958 fish kill was notable, because it resulted in a series of investigations by Pennsylvania Department of Health biologists, Pennsylvania Fish Commission personnel, and faculty and staff from PSU. Prior to the 1958 incident, there was very little information on water quality in Spring Creek in agency files. The resulting investigations examined water quality, benthic macroinvertebrates, and fishes in Spring Creek, which provided the first quantitative estimates of fish populations (Cooper and Wagner 1976).

The State Correctional Institution at Rockview (SCI Rockview) opened in 1912, but it was not until about 20 years later that a wastewater treatment plant was constructed to accommodate 900 prisoners. The plant discharged into Spring Creek 3.5 km (2.2 mi) upstream of Fisherman's Paradise. In 1961, Fisherman's Paradise was closed to angling because of poor water quality that was traced back to the SCI Rockview treatment plant. The plant was upgraded in 1967, but water quality problems persisted. Between 1969 and 1994, the plant was frequently cited for non-compliance with its discharge permit. In 1992, all wastewater from the prison was piped to Bellefonte for treatment and the Institution's discharge to Spring Creek was eliminated. The prison also operated a cannery; wastewater was spray irrigated onto adjacent crop lands. In 2001, cannery wastes were applied to a man-made wetland, and a few years later, the cannery was closed.

Bellefonte constructed its first wastewater treatment plant in 1939, and it discharged into Spring Creek downstream of the borough. A new plant was constructed in 1971, and it was expanded in 1990 when its capacity was increased from 0.08 m3/s (1.75 mgd) to 0.11 m3/s (2.4 mgd). The plant has been treating wastewater from SCI Rockview since 1992, and its permitted capacity is 0.14 m3/s (3.22 mgd).

The Ferguson Township wastewater treatment plant in Pine Grove Mills was first permitted in 1966 (Personal communication, Josh Collins, Ferguson Township Engineer); it discharged into Slab Cabin Run. Although there are no records of water quality problems downstream from the plant, a series of permit violations during the 1980s and 1990s led to the plant's closure in 2000. Wastewater that had been treated by this plant was then rerouted to the University Area Joint Authority (UAJA) plant in College Township. In addition, the Hanover Canning Co. operated a cannery in Oak Hall from around 1950 to 1972. Overflows from its wastewater holding pond occasionally affected water quality in Spring Creek, but there are no records of fish kills related to these spills.

The UAJA's wastewater treatment plant went into operation in 1969. The plant discharges into Spring Creek about 2.5 km upstream of the Benner Spring Hatchery. The plant was expanded in 1992, and its permitted maximum discharge was increased from 0.17 to 0.26 m3/s (3.84 to 6.0 mgd). In response to a discharge permit condition that limits the temperature of treated discharge, the Authority implemented a water reuse project. Some of the plant's treated wastewater is further purified with new technology, such that the resulting water meets drinking water standards. This highly treated water is being piped to a golf course for irrigation, a laundry service, and a constructed wetland.

The PFBC operates three fish hatcheries in the Spring Creek watershed. The Pleasant Gap State Fish Hatchery discharges into the headwaters of Logan Branch. The Benner Spring and Bellefonte Hatcheries discharge directly into Spring Creek. Collectively, these three facilities discharge about 0.81 m3/s (18.4 mgd) of treated wastewater, and the quality of their discharge is regulated by DEP permits.

In addition to the above-mentioned discharges in the Spring Creek watershed, there are several small permitted discharges and perhaps several thousand private, on-lot septic systems that may contribute pollutants to surface waters and groundwater.

Water Quality in the first half of the 20th Century

The absence of water quality reports until the 1950s forces one to speculate about the conditions in Spring Creek in the early part of the 20th Century. There were no wastewater treatment plants in the watershed until 1913. Hence, raw sewage was flowing into the stream from Bellefonte Borough and probably from SCI Rockview starting in 1912, and the boroughs of State College, Lemont, and Boalsburg. Prior to 1913, PSU's wastewater was believed to have been discharged into a sink hole or cave near College Avenue. This raw sewage could have rapidly emerged in Thompson Spring. Given these multiple sources of raw sewage, it is likely that Spring Creek from Lemont to Milesburg had poor water quality compared to today's standards. After PSU constructed its plant in 1913, SCI Rockview followed, and, finally, Bellefonte Borough constructed its first plant in 1939. Presumably, water quality was reasonably good through the 1940s.

Water Quality since 1950

Conditions then began to deteriorate in the early 1950s. A fish kill below the Bellefonte Borough treatment plant was attributed to low levels of dissolved oxygen, possibly due to the plant exceeding its treatment capacity (Table 2). Then, point source discharges produced several fish kills. The 1954 spill from the Titan Metal Co. on Logan Branch decimated nearly all aquatic life in Logan Branch and for 2.4 km of Spring Creek downstream of the confluence with Logan Branch.

The most famous fish kill occurred in 1956 when sodium cyanide was poured down a drain in the Naval Ordinance Research Laboratory on the PSU campus (Glover 1957). As the cyanide passed through the wastewater treatment plant, it probably killed most of the microorganisms in the treatment system and then flowed out into Thompson Run, then to Slab Cabin Run, and finally to Spring Creek. More than 147,000 trout were killed in the Benner Spring and Bellefonte hatcheries, which indicates that this spill was still toxic 16 km downstream from the PSU treatment plant. An unknown number of fish (probably > 100,000) in these two tributaries and Spring Creek perished. This spill may have also had long-lasting effects on stream invertebrates. According to George Harvey, the green drake mayfly (*Ephemera guttulata*) was never seen after the cyanide incident. The deadly 1950s ended with the 1958 fish kill at the Benner Spring Hatchery, which was traced back to the PSU wastewater treatment plant.

Toxic spills continued during the 1960s, and several of these originated from Nease Chemical Co., which was located along State Route 26, 1.2 km from Spring Creek (Table 2). The 1965 spill caused a complete kill of fish for 2.4 km downstream of State Route 26. Spills from Nease Chemical Co. continued into the 1970s. The 1971 spill resulted in fish mortality for 4.0 km. Nease Chemical Co. may have accounted for more fish killed than any other single source. But, perhaps the Nease Chemical Co.'s most significant legacy is the contamination of groundwater with two toxic and highly persistent chemicals – kepone and mirex. In a following section, we address the kepone and mirex pollution in greater detail.

On the positive side, in 1968, the UAJA began operation of a new treatment plant that relieved the PSU plant of some sewage load and brought service to homes that had been using on-lot septic systems. The cannery operation in Oak Hall closed in 1972. The PSU plant ceased discharging to Thompson Run and began spray irrigating all of its effluent in 1983. SCI Rockview ceased discharging to Spring Creek in 1992, and the Ferguson Township treatment plant closed in 2000. Thus, by 2001, the number of major domestic wastewater treatment plants discharging in the watershed had been reduced from five to two plants. The two remaining domestic wastewater plants, Bellefonte Borough and the UAJA, have been operating in compliance with their discharge permits. The three state fish hatcheries have been or are being upgraded to improve the quality of their discharge. Thus, given all of these changes, we are comfortable in stating that the water quality in Spring Creek and its tributaries is better now than it has been since 1900, and perhaps much earlier.

Kepone and Mirex Contamination

Mark Hartle, fisheries biologist with the PFBC, provided the following synopsis of the kepone and mirex contamination of Spring Creek. During the late 1950s through mid-1970s, the Nease Chemical Plant (now Rütgers Organics Corporation) manufactured specialty chemicals, including the pesticides kepone (chlordecone) and mirex (dechlorane). Releases of kepone and mirex from handling and waste management practices resulted in these contaminants entering soil, groundwater, surface water, and sediment. Kepone and especially mirex are long-lived compounds that adsorb to soil, are transported through the movement of contaminated soil and sediment, and can accumulate in high concentrations in both stream sediment and biota. The contaminants were transported from the chemical plant site to Spring Creek via a surface water drainage ditch and through Thornton Spring, which discharges groundwater into Spring Creek.

In 1976, kepone and mirex were first detected in the flesh of brown trout from Spring Creek collected near Spring Creek Park during investigations by the Pennsylvania Department of Environmental Resources (now the Department of Environmental Protection). Subsequent analyses indicated that concentrations of the contaminants in brown trout exceeded the U.S. Food and Drug Administrations (FDA) action levels (mirex, 100 µg/kg; kepone, 300 µg/kg). In the years leading up to the discovery of kepone and mirex in Spring Creek, the stream was heavily stocked with trout. However, in 1977 due to the discovery of the contaminants, the Fish Commission reduced the stocking rate of trout downstream from the area where kepone and mirex were first identified and then discontinued stocking this reach in 1978 to eliminate human health risk to anglers and others consuming trout caught in contaminated areas. In 1982, the Fish Commission established a 'No-Kill Zone Due to Contamination' that prohibited the harvest of all fish in Spring Creek in the 28.5-km reach from the SR 3010 bridge in Oak Hall downstream to the mouth.

The Nease Chemical Plant site was added to the National Priorities List of contaminated sites in 1983 by the U.S. Environmental Protection Agency (EPA). Remedial activities affecting the surface water drainage ditch, soil, and groundwater have since proceeded under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, and the site was regulated by the U.S. EPA as a Superfund Site. Cleanup activities are nearing completion at the plant site, and monitoring of contaminants continues.

Kepone levels declined rather quickly through time, but mirex levels persisted in trout in excess of U.S. FDA action levels until 2001. In 2000, the PFBC established the Spring Creek Trout Management Area regulations on the same 28.5-km reach of stream designated in 1982 as a No-Kill Zone due to the kepone and mirex contamination, except for the 1.6-km reach of stream known as Fisherman's Paradise and the 0.8-km reach known as the Exhibition Area in Bellefonte Borough. No-harvest regulations were already in effect for Fisherman's Paradise, and angling is prohibited in the Exhibition Area. In 2001, the PFBC removed the No-Kill Zone regulations, because mirex levels in trout fillets had fallen below the U.S. FDA action level. Spring Creek continues to be managed under no-harvest regulations for trout. Harvest of other species, such as white suckers, is permitted under the current regulations, except for Fisherman's Paradise, where the taking of bait fish is prohibited.

Stream Flow and Water Quality Trends at the Axemann Gage

The U.S. Geological Survey (USGS) installed the first permanent stream gaging station on Spring Creek in 1942, about 1.6 km downstream of the Bellefonte Hatchery. This site is 2.6 km west of the village Axemann; hence, it was labeled the Axemann gage. Annual mean daily flow has ranged from 1.22 m3/s (43 cfs) in 1965 to 4.87 m3/s (172 cfs) in 2004, and it has averaged 2.49 m3/s (88 cfs) over a 66-year period (USGS 2008b). Annual variations in flow were closely linked to precipitation (Figure 4). When we used a multiple linear regression to predict annual mean daily flow using precipitation during the year of flow measurement and the previous year, a highly significant relation resulted (R2 = 0.75, P < 0.001). The addition of year as an independent variable did not improve the relationship, which indicates there have been no long-term changes in annual mean daily flow. Similarly, there have been no striking changes in short term low flows. In fact, the annual 7-day low flows from 1941 to 2005 show a slight increase, which suggests that groundwater reserves have been increasing rather than decreasing (personal communication, L. Fennessey, PSU).

The Pennsylvania Department of Health began collecting water quality data at quarterly intervals at the Axemann gage site in 1950. Sampling frequency increased through time until 1977, when monthly sampling was initiated. At the program onset, water was analyzed for pH, alkalinity, acidity, aluminum, iron, and sulfate. Total phosphorus, nitrate, nitrite, ammonia, and several other analyses were added in 1972. Stream pH has not varied greatly, and has averaged 7.9 (EPA 2007). Interestingly, total alkalinity has increased, on average, from about 160 mg/L as CaCO3 in 1950 to 180 mg/L as CaCO3 in 2004 (Figure 5). This change in alkalinity may reflect an increase in water withdrawal from alkaline wells for household use and subsequent treatment and disposal via wastewater treatment plants to the stream during the past 50 years. In the first half of the 21st century, more residents were relying on surface water supplies, which typically came from soft water sources on the sandstone ridges. These small water systems have now been largely replaced by larger water authorities that rely on wells deep into the limestone bedrock.

Since 1972 there have been substantial changes in stream nutrient concentrations. The most notable of these has been the reduction in total phosphorus, which declined from 0.9 mg/L as P in 1972 to less than 0.05 mg/L in recent years (Figure 6). Several factors have contributed to this decline. The diversion of treated effluent from the PSU treatment plant to spray irrigation in 1983 eliminated a major source of nutrients to the stream, and, more recently, the closure of treatment plants at SCI Rockview and Ferguson Township has further reduced nutrient loading. The major wastewater discharger in the upper Spring Creek basin (UAJA) has been using tertiary treatment to remove phosphorus from its discharge since the plant began operations in 1969. Hence, all of these changes have contributed to reducing phosphorus loading in Spring Creek.

Nitrogen, the other nutrient of concern, has also shown a decreasing trend over the past 35 years. Since 1972, nitrite has decreased from about 0.1 mg/L as N to less than 0.04 mg/L, which is the minimum detection level. Similarly, ammonia has decreased from about 0.3 mg/L as N to less than 0.02 mg/L. The reduction in these two nitrogenous compounds probably reflects the removal of some wastewater discharges and improved efficiency in the remaining wastewater treatment plants. Nitrate concentrations have not changed since 1972; concentrations have averaged about 4.0 mg/L as N. Stormwater runoff from urban and agricultural lands is the likely source of nitrates. Overall, data collected at the Axemann gage suggests that stream flow largely reflects annual precipitation, and water quality has improved.

Historical Notes on the Trout Fishery

Brown trout became well-established in the early 1900s and, by the 1940s, had become the dominant salmonid in the watershed.

Shields (2003) described the trout fishery of Spring Creek and how it has evolved through time. Historically, native brook trout sustained the fishery, which was apparently good enough to attract the famous angler, Theodore Gordon, who raved about the excellent brook trout fishing near Bellefonte Borough in the early 1870s (McDonald 1989). In a 1915 letter, Gordon writes about a subsequent fishing trip to Bellefonte and notes that brown trout had "taken possession" of the stream. The Corry State Fish Hatchery shipped six cans of brown trout fry to five railroad stations in the watershed between 1892 and 1898. Providing that these fish were stocked in Spring Creek and it tributaries, these stockings may have been responsible for the initial colonization of the stream by brown trout.

It is not clear how quickly brown trout displaced native brook trout. Joseph Humphreys recalls catching brook trout near Benner Spring from the 1930s to the early 1950s before the hatchery was built. He states that during summer months brook trout congregated in the cold outflow of the Benner Spring and in other localized areas influenced by springs. These observations suggest that there were still reproducing brook trout in the main stem of Spring Creek during the 1950s. But, it is likely that brown trout were the dominant salmonid, because in 1948 Donley (1948) surveyed Cedar Run upstream of Linden Hall and found no wild brook trout, but collected brown trout from several age groups, including young of the year. Given that brown trout had displaced brook trout well up into Cedar Run, it seems logical to conclude that brown trout had largely displaced brook trout throughout the main stem of Spring Creek. In the late 1950s, E. Cooper failed to collect any wild brook trout in the main stem of Spring Creek or Cedar Run. He collected wild brook trout in upper Slab Cabin Run, but none was found there in 2008.

On the basis of these admittedly meager records, we suggest that brown trout became well-established in the early 1900s and, by the 1940s, had become the dominant salmonid in the watershed. Brook trout continue to persist in Galbraith Gap Run; two tributaries to Slab Cabin Run; an unnamed stream flowing through Musser Gap and Roaring Run; Gap Run; and Logan Branch, but clearly, the native brook trout occupies but a small proportion of its former range within the watershed.

Trout Production

Early Years

In 1873, the State Commissioners of Fisheries (SCF) brought 35,000 brook trout eggs to the State Hatching House at Donegal Springs, Lancaster County, to be raised for possible stocking. By 1877, the output of brook trout fry reached 154,000. In the 1881-1882 report by the SCF, it was noted that more than 250,000 brook trout had been stocked in most of the central and eastern counties of the Commonwealth.

Much of the fish stocking was done by individuals who sent an application for fish to the Commissioner living closest to them. Annual or biennial reports of the SCF published in the late 1800s contained long lists of individuals who received shipments of fry of various species. Fish were shipped by rail in cans equipped with a plunger to aerate the water. The 1887-1888 report of the Commissioners included “Directions for Obtaining Fish”, which provides a stern warning: “No man shall go to sleep while transporting fish, and leave them alone while in the cans, as it will be sure death to them.”

The first report of brown trout coming to Pennsylvania is noted in the 1885-1886 Report of the SCF. Prof. Spencer F. Baird, U.S. Fish Commissioner, arranged for the shipment of 10,000 German trout eggs to the Corry Hatchery in southeastern Erie County. The 1887-1888 Report of the Commissioners states that 30,000 impregnated eggs of the Loch Leven trout, originally from Scotland, were sent to the Corry Hatchery by the Washington Commission. Presumably, the latter refers to the U.S. Fish Commission. During the period 1889-1891, the Corry Hatchery shipped 66,000 brown trout fry and 30,000 ‘Loch Laven’ fry. In 1895, the Corry Hatchery reported shipping 135,000 European brown trout fry, which suggests that the German and Scottish strains were mixed. Yet, in 1905, the Corry Hatchery reported shipments of 68,000 Loch Leven fingerlings. Thereafter, the distinction between the two European strains was not maintained.

“There are still many trout streams in Pennsylvania that afford full creels to the angler, but with the ever increasing army of fishermen it is absolutely essential that the supply must be kept up by restocking with artificially raised fish, because the streams under natural propagation will not furnish fish equal to the demand, because natural propagation in any stream is really but a small factor when the number of fishermen is considered.”

The practice of raising and stocking fish in Pennsylvania has a long history, founded on the notion that natural reproduction of fishes could not meet the demands of a harvest-oriented fishing public. These sentiments were expressed in the annual Report of the Department of Fisheries published in 1916: ,“There are still many trout streams in Pennsylvania that afford full creels to the angler, but with the ever increasing army of fishermen it is absolutely essential that the supply must be kept up by restocking with artificially raised fish, because the streams under natural propagation will not furnish fish equal to the demand, because natural propagation in any stream is really but a small factor when

Pleasant Gap Hatchery (historic)

The Pleasant Gap State Fish Hatchery in the early 1900's.

photo obtained from PFBC archives

the number of fishermen is considered." Apparently, this 'army' of anglers found Spring Creek, and fisheries officials deemed it necessary to stock the stream.

Detailed records of trout stocked in Spring Creek were available starting in 1931 (Table 3), when trout were stocked annually, until 1981. The Spring Creek Project, now known as Fisherman's Paradise, was started in 1934, and stocking there continued until 1981. More than 1.6 million trout were stocked and a vast majority of these fish were of catchable size. Fingerling trout were stocked on a few occasions, and even then, many more catchable size trout than fingerlings were stocked. Sizes of stocked trout typically ranged from 152 to 406 mm (6 to 16 in), including a small percentage of larger fish. Hatchery-reared trout as large as 762 mm (30 in) were stocked in Fisherman's Paradise.

We suspect that in those heavily stocked sections of Spring Creek, hatchery-reared trout sustained the fishery, and wild trout were an unimportant part of the catch. The only available fishery data outside of the specially regulated Fisherman's Paradise is from the Hartzler (1977) study, which was conducted immediately upstream of Fisherman's Paradise. On the basis of electrofishing surveys, he estimated that wild trout equaled less than 5% of the density of stocked trout. The low numbers of wild trout may have been related to poor water quality. Nonetheless, we suggest that the large numbers of stocked trout attracted large numbers of harvest-oriented anglers; hence, wild trout were subjected to high exploitation rates and possibly competition from large-bodied stocked trout.

High water events in 1972 from Hurricane Agnes and in 2004 from Hurricane Ivan flooded rearing ponds and raceways in the Benner Spring Hatchery and thousands of trout and other species escaped into Spring Creek. In 2004 anglers fished in the vicinity of the hatchery after flood water receded and they experienced rather high catch rates of trout. Our impression is that this exceptional fishery was short-lived and that by the following year, catch rates returned to normal levels for this reach of stream.

Fish Culture Facilities in the Spring Creek Watershed

Pleasant Gap State Fish Hatchery

The initial land purchase for the Pleasant Gap facility was made in 1903. The site was chosen because of large springs that reportedly produced 0.63 m3/s (10,000 gpm), and it was near the Pleasant Gap railway station, which was important for distribution of fish. The first trout were produced in 1904. In the early years, the hatchery raised mostly brook trout and rainbow trout, which were then called California trout. In 1908, the facility received five cans of fingerling brown trout from the Corry Hatchery. By 1909, it was believed that this facility was the largest trout hatchery in the U.S.; in that year, it produced 3.5 million brook trout and 42,000 rainbow trout. In the 1910 report, there is no mention of brown trout stocked from the hatchery. In 1912, 1,500 brown trout were stocked, but none in Centre County. By 1914, the hatchery produced 1.3 million trout, which included 216,000 brown trout. Between 1915 and 1932, brown trout produced at the Pleasant Gap Hatchery were stocked in Centre County, but individual streams were not named in Commissioners' reports. Today, this facility covers 15 ha (37 acres), uses about 0.20 m3/s (3,100 gpm) of water, and in 2007, produced 215,000 fingerlings and about 439,000 one-year and older trout that weighed about 115,700 kg (255,000 lb).

Bellefonte State Fish Hatchery

In 1933, the Fish Commission purchased 37 ha of land, which was developed into a production facility. The property included a large spring and 1.8 km of Spring Creek, which is now known as Fisherman's Paradise. The hatchery consisted of two units. The Upper Spring Creek facility was about 0.8 km upstream of the present facility. Initially, both units consisted of rearing ponds and hatching houses. The upper unit now has four extensive fish culture ponds that are used to rear several coolwater species. The lower unit has 79 raceways. In the 2006-2007 production cycle, this facility produced 10,000 fingerlings and 574,000 age-1 and older trout that weighed 163,000 kg, and its average discharge was 0.26 m3/s (4,175 gpm).

Benner Spring Hatchery (modern)

The Benner Spring State Fish Hatchery in 2009.

photo by B. Niewinski

Benner Spring State Fish Hatchery

A 5.3-ha property along Spring Creek was acquired by the Fish Commission in 1951 and was developed into a production facility. The tract included the Benner Spring, which had an output of 0.44 m3/s (7,000 gpm). This facility now rears several coolwater species and trout. In 2006-2007, this hatchery produced 320,000 fingerlings and about 572,000 age-1 and older trout that weighed about 156,000 kg; average discharge from the facility was 0.35 m3/s (5,500 gpm).

Fisherman's Paradise

Pleasant Gap Hatchery (historic)

The Pleasant Gap State Fish Hatchery in the early 1900's.

photo obtained from PFBC archives

In 1933, the Fish Commission purchased 37 ha of land along Spring Creek about 4.0 km north of Bellefonte Borough. The tract, which included 1.8 km of Spring Creek and a large spring, was labeled the Spring Creek Project with the dual purpose of fish cultural activities and demonstration of techniques to improve fish habitat. Owing to the exceptional fishing, the project later became known as Fisherman's Paradise. C. A. French, Commissioner of Fisheries, noted that "During 1932 and 1933, a wave of enthusiasm for stream restoration work swept through the Commonwealth of Pennsylvania" and sportsmen "were clamoring for advice on methods of construction" (French 1938). In 1934, the Commission installed 46 structures that included dams, deflectors, and log covers. To induce visitation to the project, a controlled fishing program was developed, and a 275-m long channel with habitat structures was constructed parallel to the main channel and was restricted to female anglers. The stream was heavily stocked with large trout, and anglers were subjected to a novel set of regulations. Anglers were required to register at a check-in station and were given an identification button. At the end of the day, anglers checked out and reported their catch. The 1938 season ran from May 10 to July 9; fishing was permitted daily from 8:00 AM to 8:00 PM, except on Sunday. Only artificial flies with barbless hooks were permitted; use of weights was not permitted, although in later years this restriction was changed to allow a maximum weight equivalent to two BB size shot. The minimum length limit was 254 mm on the main stem and 178 mm on the ladies' section. Anglers could catch 10 trout, but only two could be harvested (later reduced to one/day). Anglers were limited to five visits per year. To assist anglers, the Commission employed an instructor in casting and fly tying.

This innovative program proved to be rather successful judging from the number of anglers who fished there. The number of anglers increased from nearly 3,000 in 1934 to more than 20,000 in 1941 (Table 4). The sharp decline in anglers in 1943 was attributed to World War II, but by 1946, visitation increased to nearly 22,000 and doubled to 44,000 by 1952. By today's standards, this angler use represents an enormous level of fishing pressure, as we will discuss in a subsequent section. Interestingly, catches were not high; they ranged from 0.8 to 2.6 trout/angler trip and averaged 1.4. If trip lengths averaged three hours, catch rates were less than 0.5 trout/h, a modest catch rate for a specially regulated fishery.

Perhaps the size of the trout fueled angler interest. Mean weight of harvested trout increased over the period of record and reached a substantial size of 0.91 kg in 1952. To sustain a high trout density, project managers were feeding the fish, which would have helped to maintain weight of stocked fish and possibly bolstered their growth.

During the 1961 fishing season, Fisherman's Paradise was closed to angling because of poor water quality, presumably owing to inadequately treated wastewater from SCI Rockview's wastewater treatment plant. Poor water quality and the high cost of operating the project were cited as reasons for changing management of this historic reach of stream (Trembley 1963). In April 1962, the project was converted to a 'fish-for-fun' section, which entailed fly fishing only with barbless hooks, no harvest, and year-round angling. These regulations remain in effect today, and the fishery is sustained entirely by natural reproduction.

Fish Community Composition and Biomas

Slimy Sculpin

The slimy sculpin is probably is probably the most abundant fish species in Spring Creek, yet it is the least noticed.

photo by R. Criswell

Extensive surveys of the Spring Creek main stem by E. L. Cooper in 1958-1959 (Appendix 1) and 1966 (Appendix 2), and surveys by the authors in 2000 (Appendix 3) provide a good overview of the fish species composition. During these surveys, 32 species and one hybrid were collected, but most of these species have not sustained reproducing populations (Table 1). Eleven species and one hybrid were collected only on one or two occasions: American eel, northern pike, hybrid muskellunge, central stoneroller, goldfish, rosyface shiner, brown bullhead, redbreast sunfish, pumpkinseed, smallmouth bass, black crappie, and yellow perch. The American eel, central stoneroller, smallmouth bass, black crappie, and yellow perch probably moved into Spring Creek from Bald Eagle Creek, while the other species were introduced or escaped from culture facilities. Cooper collected several species only in 1966, but from several locations: golden shiner, spottail shiner, bluntnose minnow, northern hog sucker, and largemouth bass. The widespread distribution of some of these species suggests that they may have been reproducing, but perhaps for only a few years.

The Fishery of Spring Creek - A Watershed Under Siege

Among the 14 species we collected in 2000, we believe that nine species continue to maintain reproducing populations in the watershed. During surveys on Slab Cabin Run in 2005 and 2007, we collected four additional species that seem to be reproducing: fathead minnows, creek chubs, pearl dace, and banded killifish. Brown trout have been collected throughout the watershed and are clearly the most abundant salmonid. Reproducing brook trout populations persist in Galbraith Gap Run, two tributaries to Slab Cabin Run, Gap Run, and Logan Branch. Six species are common throughout the main stem of Spring Creek: cutlips minnow, blacknose dace, longnose dace, white sucker, tessellated darter, and slimy sculpin. The common carp was first collected at two stations in 1966 and at four stations in 2000. Though numbers of common carp have been rather small, their persistence and distribution suggests at least limited reproduction.

The only estimates of biomass and density of the entire fish community in Spring Creek were done by E. L. Cooper and his students. They sampled the fish communities in a clean, a polluted, and a recovering reach of Spring Creek in 1966 and 1967. The pollution was caused by the PSU wastewater treatment plant. The three reaches were (1) Section 4, the clean reach, then known as Neidigh's meadow, which is now owned by Hanson Aggregates, the limestone quarry between Lemont and Oak Hall; (2) Section 9, the polluted reach, was sampled upstream of the Benner Spring Hatchery at the site known as the "Rock"; and (3) Section 13, the recovery reach, which is immediately upstream of State Road 550 near the old Roopsburg Mill.

The only estimates of biomass and density of the entire fish community in Spring Creek were done by E. L. Cooper and his students.

Total fish biomass in the clean reach was an astounding 1,252 kg/ha (1,115 lb/ac; Table 5). Biomass of brown trout was relatively high (113 kg/ha) compared to today's standards for wild trout streams, yet brown trout comprised only 9.1% of the total fish biomass. White suckers accounted for 60.5% of the total biomass, and slimy sculpins ranked third at 23.3% of the total. Numerically, slimy sculpins at >85,000/ha accounted for 63% of all fishes.

The polluted reach supported about one-third of the biomass found in the clean reach, and white suckers dominated the community biomass. More species were found in the polluted reach relative to the clean reach, but brown trout and slimy sculpins were represented by only a handful of specimens. Wohnsiedler (1969) documented less than 2% survival of brown trout eggs that were held in hatching boxes in the polluted reach.

The recovery reach seems to have lived up to its name. It supported the highest number of fish species and a relatively high fish biomass, 995 kg/ha. White suckers dominated the community biomass, accounting for 86% of the total, while brown trout biomass (74 kg/ha) comprised 7.5% of the total. Slimy sculpins showed an improvement over the polluted section, but still represented only about 10% of those estimated in the clean reach.

We found only a few other estimates of fish biomass that were not restricted to salmonids. McFadden (1961) estimated the biomass of brown trout and several other species in Neidigh's meadow (Section 4) in 1958. White suckers (306 kg/ha) accounted for the largest portion of the total biomass and brown trout (65 kg/ha) ranked second. He did not attempt to estimate density or biomass of slimy sculpins, so that his total biomass estimate (396 kg/ha) is well below that of Cooper's estimate in 1966.

Scherer (1965) compared growth and fecundity of white suckers in Cedar Run and in a reach of Spring Creek near Benner Spring. He estimated biomass of white suckers >75 mm long in Cedar Run, where estimates ranged from 151 to 265 kg/ha. He noted that abundance of white suckers was related to the number of pools in a reach. Given that Cedar Run is about one-half the size of Spring Creek in Section 4, we would expect more and larger pools in Spring Creek than in Cedar Run, hence, a higher biomass of white suckers. Biomass of white suckers were also estimated by Mercando (1971) and Williams (1981), but either the sample sites were not clearly identified or the year of sampling was not specified.

The above-cited studies provide convincing evidence that brown trout, though they are usually the focus of fisheries studies, do not represent the largest portion of the fish community biomass. In unpolluted reaches, it is likely that white suckers will comprise the largest portion of the fish biomass, and slimy sculpins will be the most numerous species.

Contemporary Assessment Methods

Most of the population assessments that are summarized in this bulletin were conducted by personnel from the Pennsylvania Fish and Boat Commission (PFBC) or the Pennsylvania Cooperative Fish and Wildlife Research Unit (Unit). Methods employed by both groups were similar. Trout populations were usually sampled in July or August, and sample reaches ranged from about 300 to 500 m long. Survey crews used 220-V, DC electrofishing gear mounted in a small boat that was towed upstream. Mark-recapture methods were usually employed to estimate trout numbers. Trout collected during the initial electrofishing run were given a temporary finclip and measured to total length or enumerated by 25-mm length groups. A subsample was weighed, and frequently scales were scraped from an area between the lateral line and dorsal fin. Scales were subsequently mounted on microscope slides and examined at 85-100x magnification to estimate age.

We used the Chapman modification of the Petersen formula to compute estimated numbers and assumed a Poisson distribution when computing 95% confidence intervals (Ricker 1975). We computed separate estimates for age-0 (< 125 mm) and for age-1 and older trout, because of differences in capture efficiencies. The estimated number of trout was then apportioned among 10- or 25-mm length intervals on the basis of the relative number of captured fish in each length interval. Mean weights of trout in each length interval were multiplied by the estimated number of fish per interval to compute biomass.

A study was initiated in 1992 to investigate the potential effects of stream temperature on seasonal growth of brown trout.

Growth

Length at age

We collected scales from about 15 fish per 25-mm interval in 1988 to estimate growth in length. We had difficulty using scales to determine age of brown trout that were four years or older; hence, we tried collecting fin rays in hopes of obtaining more accurate estimates of age. We collected a 10-mm section from the base of the pectoral fin ray; most of these samples were taken from fish >250 mm. Details for processing scales and fin rays are provided in Carline et al. (1991).

Seasonal Variation

A study was initiated in 1992 to investigate the potential effects of stream temperature on seasonal growth of brown trout. Fish sampling sites were established in stream Sections 4, 8, 9, 11, 14, and 15 (Figure 1) with the intent of having stream sites that represented the range of thermal regimens throughout Spring Creek. The site sampled in Section 8 was immediately upstream of the outfall from the UAJA wastewater treatment plant, and site 9 was 800 to 1,400 m downstream of the outfall. The treatment plant was of particular interest because of anticipated increases in the volume of treated wastewater and its potential effect on stream temperature. Submersible recording thermometers (Ryan Tempmentor) were installed at each fish sampling site, and temperature was recorded hourly.

Fish sampling sites ranged from 200 to 300 m in length. Brown trout were collected in March, June, September, and December from September 1990 to March 1993. All trout were measured, and a subsample was weighed. Scales were collected from a subsample of trout up to 350 mm long. Age-0 trout that were captured in June and September were given a permanent distinct finclip to identify their year class when captured in future sampling. Population density and biomass were estimated in July and August 1990 and in September 1991 and 1992. To compare growth among sections and seasons, we computed daily instantaneous growth rate (G) as $G = (Loge(W1) - Loge(Wo))/t$

Where, W1 is the final mean weight of a cohort, Wo is the initial mean weight, and t is the number of days in the interval.

Redd surveys

We conducted redd counts in Sections 1 to 16 on nine occasions between 1987 and 2005 to obtain an index of spawning effort. Redd surveys were usually conducted November 20 – 30. A pair of surveyors walked the entire length of a section and counted all redds. In addition to Unit and PFBC personnel, volunteers occasionally assisted in making counts. Volunteers were given an orientation to help them distinguish between exploratory digging by female trout and areas where eggs were likely to have been deposited. When surveyors encountered large areas where several females had probably spawned, they estimated the total number of redds by assuming that each redd covered a surface area of 0.33 m2.

While monitoring selected stream reaches for spawning activity, we noticed that certain locations were used for spawning year after year. These observations prompted us to determine the frequency that a given spawning site was used in consecutive years. In November 1988 we randomly chose 50 redds in Sections 7, 8, 9, and 13. At each redd, we drove numbered metal pins into both stream banks on a line that intersected the redd and measured the distance from one of the pins to middle of the redd. The following November we returned to each set of pins and determined the location of the previous year's redd. If a new redd was within one m of the previous one, we considered this a reuse of the site.

Angler surveys

Three angler surveys have been conducted in the middle reaches of Spring Creek. In general, survey methods were similar. Instantaneous angler counts were used to estimate fishing pressure, and, in two surveys, anglers were interviewed to estimate catch rates. Hartzler (1977) conducted an angler survey from April 17 to June 20, 1976, on a 4.8-km reach from the Benner Spring Hatchery downstream to Fisherman's Paradise, which corresponds to the downstream reach of Section 9 through Section 11. The study section had been stocked with 6,268 age-1 and age-2 hatchery-reared trout, and the bulk of the legal harvest was hatchery trout.

Unit personnel conducted an angler survey from June 1 to November 30, 1988, and from March 15 to May 31, 1989 (Carline et al. 1991). Survey sections included a 1.3-km reach adjacent to the Benner Spring Hatchery in Section 9, the entire 1.7-km reach of Section 12 (Fisherman's Paradise), and a 4.0-km reach in Section 13. Like the Hartzler (1977) survey, this survey included angler interviews, but no-harvest regulations were in effect for the entire stream.

The most recent angler survey was conducted from opening day of trout season (April 15) to June 30, 2006. Angler counts were made by Unit personnel and volunteer survey clerks on Sections 12 and 13. Anglers were not interviewed; the primary purpose of this survey was to document possible changes in fishing pressure since the 1988-1989 survey.

Results

Fisherman's Paradise 1980-2000

The density and biomass of wild brown trout in the Fisherman's Paradise section has varied widely over a 21-year period, despite maintenance of the same no-harvest regulation and no stocking. Reproductive success, which had been rather erratic in this section, undoubtedly contributed to some of the population variation. Numbers of age-0 brown trout that were collected ranged from one to 423/ha (Table 6). Estimated numbers of age-1 and older brown trout varied by nearly 7-fold, and estimated biomass ranged from 80 to 425 kg/ha. The magnitude of these population variations was similar to that of other stream sections, where the brown trout population also peaked in 2000.

Main Stem

Density and biomass

Reproductive success of brown trout throughout Spring Creek varied greatly among sections and years on the basis of numbers of age-0 fish captured during their first summer (Table 7). Spatial variation within year was greatest in 1980, owing to high density in Section 2 and a year class failure in Sections 15 and 16, which supported few adult brown trout. In three of four years, the highest catches of age-0 fish were made in Sections 2 and 4. Temporal variations in catches of age-0 fish exceeded spatial variations. At Sections 4 and 16, there were more than 20-fold variations among years. Median catches among all stations ranged from 51 in 2006 to 332 in 2000.

Spatial and temporal fluctuations in reproductive success are probably linked to numbers of mature females and environmental conditions from time of spawning until the fishes' first summer of life. Beard and Carline (1991) found positive relations between numbers of mature females and numbers of redds, and between numbers of redds and density of age-0 fish. Because we do not have estimates of the number of mature females that produced the year classes in question, we cannot specifically address this question. In a subsequent section we examine trends in numbers of redds and brown trout density.

Spatial and temporal variations in density of age-1 and older brown trout were similar to those for age-0 fish. Spatial variation was greatest in 1980 owing to low adult densities in Sections 15 and 16 (Table 7). Temporal variations were also highest in these two sections. Across sections, median density ranged from 301 to 1,172/ha; four of five sections reached their highest density in 2000. Within and among year variations in density were highly correlated (r2 = 0.85) with biomass of age-1 and older brown trout.

Changes in biomass of age-1 and older brown trout among stations were rather consistent from 1980 to 2006 (Figure 7). Biomass increased from 1980 to 1988, and rather markedly in some sections. Biomass continued to increase in 2000 and then declined by 2006. Carline et al. (1991) concluded that the increase in brown trout from 1980 to 1988 was related to the combined effects of cessation of stocking and the imposition of no-harvest regulations in 1982. It is conceivable that cessation of stocking or elimination of harvest alone could have contributed to the resurgence of wild brown trout. Several studies (e.g. Bachman 1984; Vincent 1987) have shown that stocking catchable-size trout can negatively influence wild resident trout. And, high fishing pressure together with liberal harvest regulations in Spring Creek could have contributed to depressed numbers of wild trout. It is uncertain if these management changes were related to the continued increase in biomass of wild brown trout from 1988 to 2000. Thereafter, biomass decreased in all six sections for which we have comparable data.

We examined seasonal and annual stream flow to determine if the decline in trout abundance from 2000 to 2006 might be flow-related. Annual mean daily flows for 3-year and 6-year periods prior to the 2000 and 2006 estimates did not suggest any large departures from the average. We also examined flows during the March to June period for up to four years prior to the two estimates. This period was of particular interest, because Carline (2006) showed that high flows during this period were related to high mortality of adult brown trout in neighboring Spruce Creek. Nonetheless, average daily flows during March to June for up to four years prior to estimates were not related to population changes.

We then examined high flow events, because Carline (1994) found high mortality of stocked rainbow trout and wild brown trout in Section 9 following two large storms in April 1993, when flows at Milesburg peaked at 43.6 m3/s (1,540 cfs) and 45.3 m3/s (1,600 cfs). The number of days in which stream flow exceeded 42.5 m3/s (1,500 cfs) the year of and three years prior to population estimates were two days in 1977-1980, none in 1985-1988, one in 1997-2000, and two in 2003-2006. Among all of these peaks, the highest was 125 m3/s (4,420 cfs) on September 18, 2004, the result of heavy rains from Hurricane Ivan. This was the second highest flow on record (since 1972) for this site. Conceivably, the peak flow on September 18, and a flow of 48.1 m3/s (1,700 cfs) the following day resulted in mortality or emigration of brown trout. More extensive investigations are needed to reveal possible cause-and-effect relationships between extreme flows and trout mortality.

Size Structure

Data for age-1 and older brown trout from Sections 4, 13, and 15 illustrate typical size structures in the upper, middle, and lower reaches of Spring Creek from Oak Hall to Milesburg. Since 1982, these sections have had the same no-harvest and no-lure restriction regulation. Unlike brown trout density, size structure at these three sections did not vary greatly among years (Figure 8). In Section 4 (mean width = 10.6 m; 0.7 m3/s (25 cfs)), the largest proportion of fish was usually in the 200- to 250-mm length interval. In Section 13 (mean width = 19.5 m; 1.7 m3/s (60 cfs)) and in Section 15 (mean width = 14.5 m; 4.3 m3/s (152 cfs)), the largest proportion of fish was in the 250- to 299- mm length interval. Typically, numbers of brown trout >350 mm long were relatively small. In Sections 4 and 13, fish >350 mm long accounted for 2.4% of all age-1 and older trout, and in Section 15 they accounted for 4.4 % across all four census years.

Brown trout that are >457 mm (18 in.) and >508 mm (20 in.) long seem to be the most prized sizes for anglers. In 2000, we sampled 12 sections of Spring Creek between Oak Hall and Milesburg, including Fisherman's Paradise, and measured 5,903 age-1 and older (>150 mm; 6 in.) brown trout. Among these fish, eight were >457 mm long and only one was >508 mm long. Although Spring Creek supports large numbers of brown trout, the highly prized large fish are relatively scarce.

Length at Age

We selected data from 1988 to illustrate variations in length of age-0 to age-4 brown trout among sections. Length of age-0 fish varied among sections, but did not change consistently from upstream to downstream sections (Figure 9). Mean lengths of age-1 to age-4 fish tended to increase in the downstream direction, but differences in length were not large. The maximum difference in length among sections for age-2 fish was 11.2%, and it was only 5.5% for age-4 fish. Differences in mean length among sections were not related to differences in brown trout density. Among 11 sections sampled in 1988, density of age-1 and older brown trout ranged from 310 to 1,304/ha and biomass ranged from 104 to 245 kg/ha. Despite these large variations in density and biomass, we found no significant relationships between growth and density or biomass (Carline et al. 1991).

Mean length at age for brown trout among all stations in Spring Creek in 1980 and 1988 was rather similar to the statewide average for brown trout collected in limestone streams (Figure 10). The only deviation from this trend was for age-2 fish from in Spring Creek in 1980; they were 15% shorter than the statewide average. For brown trout of all other ages, mean lengths of those in Spring Creek were + 5% of the statewide average.

Spatiotemporal Variations in Growth

Among the six sites that were sampled quarterly in 1990-1992, brown trout tended to grow fastest in Section 11 (Figure 11), which is located near the middle of the entire study reach, and they tended to grow slowest in Section 4, which is near the upper end of the study reach. Growth of brown trout did not vary consistently among the other four sampling sites. Seasonal variations in growth were similar among sites. Instantaneous growth was highest during the spring months (March-April), and of the total annual instantaneous growth, about one-half occurred during this period (Figure 12). Brown trout grew at approximately the same rate during the other three sampling periods.

We used simple regression analyses to determine if trout density or water temperature might explain differences in growth among sites. Mean weights of age-0 brown trout in September ranged from about 9 to 20 g among sites from 1990 to 1992 and were inversely related to the catch rate of age-0 at each site (Figure 13). Mean weights were not related to density or biomass of age-1 and older trout nor were they related to mean water temperature during the summer months. We then correlated instantaneous growth rates of age-0 and age-1 brown trout during the fall, winter, spring, and summer periods to trout density and stream temperature. None of the correlations was significant ($P > 0.05$). Therefore, among sites, variations in growth of age-0 trout during their first summer of life could be partly explained by density of age-0 trout, but thereafter, neither trout density nor stream temperature accounted for differences in growth among sites.

We computed median instantaneous growth rate among sites for each cohort and compared these values to stream temperature and discharge to determine if these variables might explain differences in growth rate among years. Differences in growth rates of age-1 and age-2 brown trout during spring 1991 and 1992 were not consistent, and

Brown Trout

The brown trout was introduced to the watershed in the late 1800s and now occupies the entire main stem and much of the tributaries of Spring Creek.

photo by J. Detar

differences were not large, i.e., <20% (Figure 12). Mean daily discharges (6.7 and 8.3 m3/s; 237 and 293 cfs) and mean stream temperatures (10.7 and 13.9 oC) were similar during spring 1991 and 1992; hence, it is not surprising that there were no substantial differences in growth rates between years. Because growth of brown trout is highest between 10 and 15 oC (Elliott 1994), one would expect growth to be highest during the spring, provided that food supplies were adequate.

Growth rate of age-1 trout during summer 1991 was about 50% slower than in 1992, and growth rate of age-2 trout in summer 1991 was less than one-half of that in 1992. Mean daily discharges during the two summers were nearly equal (4.2 and 4.3 m3/s; 147 vs. 153 cfs), but mean daily stream temperatures were warmer in 1991 than in 1992 (18.2 vs. 17.2 oC). If food supplies were similar, one would expect slower growth in 1991 than in 1992 on the basis of energy budgets developed by Elliott (1994). Maximum daily stream temperatures may also be important. Elliott (1994) defined the upper critical range of brown trout as 19 to 30 oC. When temperatures exceed 19 oC, brown trout cease feeding. In 1991, daily maximum temperature in Section 11, where growth was highest, was >20 oC on 67 days from June through August, while this temperature was exceeded on 34 days in 1992. Thus, both mean daily and maximum daily temperatures suggest that the thermal conditions for growth were less favorable in 1991 than in 1992.

It is possible that lower growth rate during summer 1991 relative to summer 1992 was related to differences in trout biomass. In 1991, mean trout biomass was about 17% higher (163 vs. 136 kg/ha) than in 1992. If these differences in biomass influenced growth, one might expect growth differences during the spring period, yet growth during spring 1991 and spring 1992 was similar. Thus, it does not seem likely that differences in biomass in 1991 and 1992 accounted for differences in summer growth.

Growth rates of age-0 and age-1 trout in fall 1990 and fall 1991 were similar (<10% difference), while age-2 trout had a small negative growth rate in 1991 and a small positive growth rate in 1992 (Figure 12). Growth rates during the ensuing winter periods suggested some between-year differences. Instantaneous growth rates of age-0 trout in winter 1990 were twice that in 1991. Growth rates of age-1 (+14%) and age-2 (+23%) trout were also faster in winter 1991 compared to 1992. The winter of 1990 was warmer and wetter than in 1991. Mean daily stream temperature in Section 11 was 6.3 oC in 1990 compared to 5.0 oC in 1991, and mean daily discharge was 9.5 m3/s (335 cfs) in winter 1990 compared to 4.2 m3/s (148 cfs) in 1991. Increased stream flow should increase available habitat for trout and possibly enhance invertebrate drift, while warmer temperatures would favor increased growth.

Overall, trout density did not seem to influence growth, except for age-0 trout during their first spring and summer of life; thereafter, water temperature best accounted for among-season and between-year differences. Much of the annual growth occurred during spring months when temperatures were most favorable. Warm summer temperatures seemed to retard growth, while above-average temperatures during winter enhanced growth.

Reproduction

In 1987 and 1988, Beard and Carline (1991) conducted the first comprehensive redd surveys on Spring Creek, from Milesburg to Boalsburg, a distance of 32 km. They found relatively high numbers of redds in the upper (Sections 1-6) and lower (Sections12-16) reaches of the stream and low numbers in the middle reach. Embryo survival was also lowest in the middle reach. We resumed redd surveys in 1997 and continued them until 2005, though high, turbid water conditions forced cancellation of surveys in 2001 and 2003. Our motivation for monitoring redd distributions was to determine if riparian restoration projects in the Slab Cabin and Cedar Run sub-basins might have contributed to reduced sediment loading and improved spawning conditions for brown trout. In addition, we wanted to continue monitoring redd numbers, because Beard and Carline (1991) showed that brown trout density among sections was positively related to redd numbers; hence, redd counts should serve as a surrogate for population estimates.

Total redd counts ranged from 764 to 2,077 and averaged 1,392 from 1987 to 2005 (Appendix 4). In the upper stream reach, annual redd counts tended to be rather variable, and there was no long-term trend; the annual average count was 33 redds/km (Figure 14). Redd counts in the middle reach increased markedly. In 1987 and 1988, we counted an average of eight redds/km. From 1997 to 2005, redd counts ranged from 31 to 60/km and averaged 45 redds/km. Redd counts in the lower reach of Spring Creek showed a steady increase from 1987 to 2005, and the overall average was 54/km. These data suggest that spawning effort has increased in Spring Creek, with the most notable increases occurring in the middle reach.

Female brown trout constructed redds in locations where mean velocity was about 35 cm/s (1.1 ft/s), depth was about 28 cm, and substrate size ranged from coarse sand to gravel (4 to 64 mm in diameter; Beard and Carline 1991). Certain locations seemed to be particularly attractive, because different females were observed spawning at the same location over a period of several weeks. When we randomly selected 50 redds, marked them, and returned the following year, newly constructed redds were found at 52% of the marked sites. This high rate of site reuse, suggests that habitat features of these sites are not changing greatly from year-to-year, which is consistent with our observations that locations of riffles, runs, and pools change very little, even after major storm events.

Recreational Fishery

The suspension of stocking and harvest after the discovery of kepone and mirex in fish had profound effects on the recreational fishery in Spring Creek. Much of Spring Creek had been heavily stocked with hatchery-reared trout throughout the 1960s and until 1977, when 21,650 were stocked. Numbers of trout stocked were reduced to about one-third in 1978, and the stream was last stocked with 4,900 trout in 1981. Hartzler's (1977) study in 1976 presumably reflected the nature of this fishery when the stream was heavily stocked (Table 8). In the reach from Benner Spring to Fisherman's Paradise, he documented heavy angling pressure in April (1,551 h/ha), declining rapidly in June (354 h/ha). Catch rates declined from 0.25 to 0.14 trout/h, and harvest declined from 129 trout/ha in April to 12/ha in June, with hatchery trout comprising nearly the entire harvest.

By 1988, seven years after stocking in this reach had been suspended and no-harvest regulations had been in effect for six years, numbers of wild brown trout had increased, although 40% of the trout in this reach appeared to be hatchery-reared; presumably, they were escapees from the Benner Spring Hatchery. Fishing pressure from April to June during the 1988-1989 survey in Section 9 was substantially less than in 1976 (500 vs. 1,295 angler-h/ha/30 d). Fishing pressure from July to November 1988 was moderately high, ranging from 122 to 641 angler-h/ha. Thus, when trout were stocked and harvest was legal in 1976, fishing pressure was intense over a short period of time, while in 1988-1989, when catch-and-release regulations were in effect, fishing pressure was much lower than in 1976, but it was sustained throughout the 8.5-month survey period.

The other major differences between results from these two surveys were the catch rate and total catch of trout (Hartzler 1977). Despite high stocking rates in 1976, catch rates of trout were rather low (0.22/h; Table 8), while catch rates in 1988-1989 were quite high (1.25/h). Differences in catch rates do not seem directly related to differences in trout density. On opening day of the trout season in 1976, stocked trout and wild trout (6% of the total) amounted to 915/km and four in-season stockings added 445 trout/km. During this period, daily catch rates never exceeded 0.55 trout/h. In contrast, trout density in Section 9 was 1,022/km in July 1988, and catch rate for the entire census period was more than twice as high as the highest daily catch rate (ca. 0.52) in 1976. Hartzler (1977) estimated that 77% of the stocked trout were harvested in 1976; hence, continual removals of trout would have operated to lower trout density and, presumably, reduce catch rates. The no-harvest regulation in 1988-1989 would have helped to preserve the high density of trout and allow sustained high catch rates throughout the fishing season.

The excellent fishery in Section 9 in 1988-1989 was mirrored farther downstream. Fishing pressure at Fisherman's Paradise (Section 12) was comparable to that in Section 9, but catch rates were lower in Section 12 than in Section 9. Both sections are entirely on public land and access is good; hence, similar fishing pressure at both sections is not surprising. Differences in catch rates may be related to differing regulations. In Section 9, there were no restrictions on terminal tackle, and bait anglers accounted for 52% of the total fishing pressure. Bait anglers had catch rates of 1.34 trout/h, compared to 1.17 trout/h for anglers using artificial flies or lures. Only artificial flies with barbless hooks were permitted at Fisherman's Paradise, where catch rates averaged 0.77 trout/h. Trout density may have also influenced catch rates in Sections 9 and 12. Density of age-1 and older trout in Section 9 was 24%

higher than in Section 12 (664 vs. 504/ha). While both angling method and trout density may have influenced catch rate, given the available data, we cannot separate the relative importance of these two variables.

Fishing pressure on Section 13 was substantially lower in 1988-1989 than in the upstream sections, probably because of access. All riparian land along Section 13 was in private ownership; most of the stream was open to angling, but there were few parking areas. We suspect that this lack of access was the primary reason for the relatively low fishing pressure. This section supported a high density of wild brown trout (1,076/ha), and catch rates were correspondingly high – 1.29 trout/h.

The role of access in affecting fishing pressure was apparent from results of the 2006 angler survey. In 2001, the PFBC purchased 47 ha of land along Spring Creek that included 3.7 km of stream frontage. PFBC personnel constructed four parking areas along Section 13 and one along Section 12. During the April-June periods, fishing pressure in 2006 was 159% higher than in 1988-1989. Part of this increase in fishing pressure may have also resulted from increased notoriety of the Spring Creek fishery. For these same periods, fishing pressure at Fisherman's Paradise increased by 87%. We did not survey Section 9 in 2006, because the parking availability at the Shiloh Road access was much reduced owing to a closed bridge. Despite the poor access, based on our observations, fishing pressure seemed to be consistently high in Section 9, in the vicinity of the Benner Spring Hatchery.

To put the fishing pressure on Spring Creek into perspective, we can compare it to other limestone streams in the state. The PFBC surveyed anglers on wild trout streams in 2004 from opening day (April 17) until September 3. Streams were divided into two size categories: those less than 6 m wide and those wider than 6 m, which included Spring Creek. The estimated fishing pressure for streams in the >6 m width class was 148 angler-hr/km (Greene et al. 2006). Angling effort on Sections 12 and 13 of Spring Creek in 2006 ranged from 4,344 to 5,063 angler-hr/km. Hence, the surveyed reaches in Spring Creek had 29 to 34 times more fishing pressure than large streams statewide, even though the Spring Creek census did not include data from July and August. This extremely high fishing pressure can be attributed to Spring Creek's long-recognized reputation as an excellent fishery, special regulations that tend to raise angler expectations, and relatively good public access.

Tributaries

Logan Branch

Logan Branch is the largest tributary to Spring Creek, accounting for about one-third of the total flow. It originates on Nittany Mountain, flows for about one km, and then enters a small impoundment on SCI Rockview property. Logan Branch then flows through McBride Gap and, upon reaching the valley floor, much of the flow percolates through the stream substratum. Flow increases substantially as the stream passes alongside the Pleasant Gap Hatchery, where springs and discharge from the hatchery enter. As the stream flows northwest towards Bellefonte, several springs augment flow, particularly the Axemann Spring, which is used as a domestic water supply and discharges about 0.13 m3/s (4.52 cfs; Fulton et al. 2005).

Water quality in Logan Branch has been problematic for many years. Iron forges and other industries polluted it in the 1800s. A number of fish kills and contaminated fish have been attributed to former metal processing plants: Titan Metal Manufacturing Co., then Cerro Metal Products, and, more recently, Bolton Metal Products, which closed in 2008. The upper reach of Logan Branch had elevated levels of lead that originated from the Corning-Asahi plant in Pleasant Gap. The plant closed in 2003. Discharge from the Pleasant Gap Hatchery has occasionally not met its permitted discharge limits. A partial recirculation system that uses microscreen disk filters was installed in 2007, and this system will reduce suspended solids in the hatchery discharge by more than 50%. With recent industry closures and improved treatment of hatchery discharges, we anticipate that water quality throughout Logan Branch will be substantially better than it has been in many years.

Wild brook trout are common in upper Logan Branch above the reservoir on the Rockview Correctional Institution property. Once the stream reaches the valley floor, brook trout disappear, and wild brown trout are abundant. Logan Branch was stocked with trout until 1997 and has been managed for wild trout as a Class A stream since 1998. During a 2000 survey, PFBC personnel estimated there was 237 kg/ha of brown trout at RK 4.3 and 201 kg/ha at the same site in 1998. The stream is open to public fishing along much of its banks, and it is managed under general statewide trout angling regulations.

Gap Run

Gap Run, a tributary to Logan Branch, originates on Nittany Mountain a short distance from Pleasant Gap, where it reaches the valley floor and enters a sinkhole. PFBC personnel sampled Gap Run during 2008 and documented a robust brook trout population at RK 0.43. The presence of a dense brook trout population in this stream was somewhat surprising, given the high levels of disturbance that occurred during the widening of State Route 144 during the 1980s and its close proximity to much of the stream. Nonetheless, the presence of an excellent brook trout population indicates sustained good water quality and may provide some insight as to the caliber of brook trout populations that Spring Creek and its hard-water tributaries may have historically supported.

Buffalo Run

Buffalo Run originates on Bald Eagle Mountain. Construction of Interstate Highway 99 has lead to pollution of the upper reach of Buffalo Run and is discussed in more detail in a following section. The stream flows about 1.8 km from the ridge to the valley floor, where a large part of the flow percolates into the groundwater. The stream regains some flow about 2 km downstream near Waddle. Farther downstream, it again loses flow near Fillmore, and regains flow as it approaches Bellefonte. Water quality has been monitored regularly since 1999 at RK 1.1 and RK 12.8 (WRMC 2006). At these two sites, nitrates have been less than 2.0 mg/L, orthophosphate has been below detection limits, and total suspended solids have ranged from 7 to 14 mg/L, which is near the average for all sites in the watershed.

No brook trout have been found in the Buffalo Run watershed in recent years, and brown trout are common. During the most recent survey by PFBC personnel conducted in 2002, brown trout biomass was 78 kg/ha at RK 6.0.

Slab Cabin Run

Slab Cabin Run originates on Tussey Mountain, a short distance from Pine Grove Mills, where it reaches the valley floor. Like Buffalo Run, Slab Cabin Run is “perched”, that is, the bottom of the stream channel is above the groundwater table. This condition results in movement of water through the stream substrate into the groundwater. During wet periods, this loss of water is not evident, but during dry periods, long reaches of Slab Cabin Run are dry. The entire lower one-half of the stream is subject to dewatering until Thompson Run enters just before Slab Cabin Run joins Spring Creek. Water quality in Slab Cabin Run has improved since riparian restoration projects were completed in the 1990s (Carline and Walsh 2007). In 2006, total suspended solids and nutrients were similar to most other surface waters in the watershed (WRMC 2006).

No brook trout were collected in the extreme upper reaches of Slab Cabin Run in 2008. We collected brook trout in two tributaries to Slab Cabin Run in 2008: Roaring Run and an unnamed tributary that flows through Musser Gap. Brown trout were found near the Route 26 bridge, and they occur from that point downstream to Spring Creek. The senior author has been monitoring fish populations at four sites since 1991. Numbers of brown trout in May ranged from 0 to 35/100 m and averaged 7.8/100 m. Sampling stations with few or no trout were those subjected to dewatering during summer. Among all stations, densities were highest after several consecutive wet years. Clearly, the low trout density in Slab Cabin Run is attributable to inadequate year-round stream flow.

Galbraith Gap Run

Galbraith Gap Run arises on Tussey Mountain in the Rothrock State Forest, and upon leaving the forest, flows a short distance through suburban development and into Spring Creek. The stream maintains a strong year-round flow, which usually exceeds the flow of Spring Creek at its confluence. Water quality of the stream as it leaves the forest is quite good; total suspended solids and nutrients are well below the average for the watershed (Godwin 2006; WRMC 2006). Juvenile and adult brook trout range from common to abundant in the forested section of the stream. During the most recent survey by PFBC personnel conducted in 1999, brook trout biomass was 46 kg/ha at RK 2.8. Among the five headwater streams that still support brook trout, Galbraith Gap Run is the only one that does not disappear into the stream channel or a sinkhole. Even though there are no barriers to brown trout movement into Galbraith Gap, brown trout have not displaced brook trout.

Upper Spring Creek

Upper Spring Creek arises in the valley floor from a few small springs and flows about 6 km until it is joined by Galbraith Gap Run. This upper reach resembles an ephemeral stream in dry years. After Galbraith Gap Run enters, Spring Creek flows about 1 km and then begins to lose water. During dry summers, the channel through Boalsburg may be completely dewatered. When Spring Creek is about 500 m from its junction with Cedar Run, several large springs enter and year-round flow is restored. This large input of groundwater helps to maintain good water quality and moderate stream temperatures (WRMC 2006). This lower 500 m of Spring Creek supports a dense population of wild brown trout; in November 2006, biomass was 181 kg/ha and density was 76 trout/100 m.

Cedar Run

Cedar Run arises in the valley floor from limestone springs, as does its major tributary, Mackey Run. Unlike most other first and second order streams in the watershed, Cedar Run does not seem to lose water. Riparian restoration projects in the watershed were effective in reducing sediment loading, but nitrate concentrations have been consistently higher than at monitoring stations at all other tributaries and the main stem of Spring Creek. Since 1992, mean density of age-1 and older brown trout at four sampling sites has been 38/100 m.

Threats from Invasive Species

Spring Creek, like many streams in the eastern USA, is vulnerable to colonization by nonnative invasive species. The former McCoy-Linn dam between Milesburg and Bellefonte, and the dam at Talleyrand Park in Bellefonte have served as upstream barriers to fishes, yet intentional or unintentional introductions of nonnative fishes remains a serious threat. In addition, Spring Creek is vulnerable to invasion by potentially harmful plants and invertebrates. Here, we focus on two potential invaders, the diatom *Didymosphenia geminata*, a single-celled alga, the New Zealand mud snail *Potamopyrgus antipodarum*, and on a recent invader, the rusty crayfish *Orconectes rusticus*. There are other potential invaders, but these will serve to illustrate the possibly devastating effects of invasive species on the current fish and invertebrate communities in Spring Creek.

The single-celled diatom, *Didymosphenia geminata*, is microscopic in size, yet it produces long, branched stalks that can form mats as thick as 20 cm (Spaulding and Elwell 2007). This diatom is native to North America, Europe, and Asia, and has recently been introduced in New Zealand. Historically, it had been found in low-nutrient waters in northerly latitudes. In recent years it has expanded its range into the western states and is moving eastward. In New York, its presence has been documented in the Batten Kill near the Vermont border and in the East Branch and West Branch of the Delaware River and in the main stem between New York and Pennsylvania (NYDEC 2009). To the south, *Didymosphenia* has been found in the Gunpowder Falls in Maryland (MDDNR 2009). It has been found in high nutrient waters at or above a pH of 7, and high density blooms frequently occur in cold tailwaters below dams (Spaulding and Elwell 2007).

When *Didymosphenia* develops large blooms and produces thick mats, it can greatly alter the benthic macroinvertebrate community. Larson and Carreiro (2007) found a reduction in density and diversity of mayflies, caddisflies, and stoneflies in Rapid Creek, South Dakota, when *Didymosphenia* developed large blooms. They also noted reductions in brown trout numbers, though this could have been related to reduced stream flows. These nuisance blooms can also negatively affect anglers and other recreationists.

idymosphenia geminata, a single-celled alga

The New Zealand mud snail was introduced in the western USA in 1987 and has been spreading east (Benson and Kipp 2009). This small (usually 4-6 mm) snail has been found in the Great Lakes, including eastern Lake Erie and Lake Ontario in New York. It has been found in rivers and lakes with a wide range of environmental conditions, and it can attain densities of several thousand per square meter. At high densities, it can dominate macroinvertebrate production (Kerans et al. 2005; Hall 2006). In the Green River, Utah, brown trout and rainbow trout with mud snails in their guts had lower condition factors than those trout without mud snails in their guts (Vinson and Baker 2008). These authors also showed that when rainbow trout were fed exclusively mud snails they lost weight and more than 50% of the snails passed through the trout alive.

We believe that both *Didymosphenia* and New Zealand mud snails can live in Spring Creek and potentially increase to nuisance levels. Both of these organisms can negatively affect the macroinvertebrate communities

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that largely support the wild brown trout in the main stem and brook trout in some headwater tributaries. Gates et al. (2007) found that a substantial amount of sediment was attached to anglers' waders and felt-sole boots and could be readily transported among watersheds. These observations suggest that both Didymosphenia and mud snails can be spread by anglers. Because of the widespread distribution of these organisms, anglers need to disinfect their wading gear after fishing in other watersheds both in state and out of state.

The rusty crayfish is native to the upper Midwest and was first discovered in Pennsylvania in the mid-1970s (Bouchard et al. 2007). Since then it has spread throughout the southeastern part of the Commonwealth and is firmly established in the Delaware, Potomac, and Susquehanna river basins, where it is often very abundant (Bouchard et al. 2007; Lieb et al. 2007). This large, aggressive species can attain densities in excess of 200/m2 (Roth and Kitchell 2005), it usually displaces native species (Lodge et al. 2000), and can suppress benthic macroinvertebrate communities through its foraging activities (Nyström 2002; McCarthy et al. 2006).

Zealand mud snail Potamopyrgus antipodarum

rusty crayfish Orconectes rusticus

Rusty crayfish were first collected from Spring Creek in May 2007 by Geoffrey Smith of the ClearWater Conservancy. To determine their distribution within the basin, David Lieb, a Ph.D. candidate at PSU, surveyed 22 sites on Spring Creek, two on Slab Cabin Run, one on Cedar Run, and one on Bald Eagle Creek for crayfish. He found large numbers of rusty crayfish along a 6-km section of Spring Creek upstream of Bellefonte Borough. Within this reach, *Cambarus bartonii* and *Orconectes obscurus*, which are native to Pennsylvania, were present but rare. Rusty crayfish seem largely confined to the reach, because only a few specimens were collected immediately upstream and downstream, but the remainder of the watershed is vulnerable to further expansion of this species.

The establishment of rusty crayfish will certainly have direct effects on native crayfish by displacing them and may have direct and indirect effects on brown trout. While x-raying brown trout to assess spinal deformities (Weber and Carline 2000), we frequently observed crayfish in their stomachs, particularly for brown trout longer than 275 mm. Based on studies with a variety of fish species, we would expect that rusty crayfish will be less vulnerable to predation by trout than native crayfish, because rusty crayfish quickly grow to a size that reduces their susceptibility to predation, they possess relatively large chelae, and they are aggressive (Didonato and Lodge 1993; Mather and Stein 1993; Garvey et al. 1994; Roth and Kitchell 2005). If rusty crayfish attain densities as high as that found in other Pennsylvania streams, reductions in benthic macroinvertebrates are likely, and this could readily translate into reduced growth of trout. Because of these threats to trout, we think that direct management intervention to eliminate rusty crayfish or at least control its expansion should be considered by the PFBC and its partners.

Response to Landscape Alterations

A coalition of private and public entities initiated a riparian restoration project in the Spring Creek watershed in 1990 with the goal of reducing sediment loading from eroding stream banks. Many of the project sites were associated with agricultural lands. The motivation for this project was stimulated by findings from Beard and Carline (1991), who showed that poor reproductive success of brown trout downstream of the confluence of Slab Cabin Run with Spring Creek was linked to high concentrations of fine sediments in spawning habitat. Riparian restoration projects on tributaries and the main stem of Spring Creek were completed by 1998, and post-treatment assessments were just getting underway when construction of I-99 began in 1999. Two construction sites were adjacent to Spring Creek and potentially threatened water quality. One site was a large interchange near the junction of Spring Creek and Slab Cabin Run, and the second site was a bridge crossing about four km downstream (Figure 15). Funds provided by the Pennsylvania Department of Transportation allowed Unit personnel to assess the effects of construction activities at these two sites on Spring Creek. In this section, we briefly summarize the results of these two studies, and we also describe effects of I-99 construction activities related to exposure of pyrite rocks at the headwaters of Buffalo Run.

Riparian Restoration

From 1990 to 1998, 25 riparian restoration projects were completed on Spring Creek and tributaries (Figure 15). All of the 17 project sites on Slab Cabin Run and Cedar Run were on riparian pastures, whereas at most of the downstream sites, stream bank erosion was linked to storm water runoff or other high flow events. Treatments to reduce erosion included (1) installation of rock-lined ramps to allow livestock to access the stream for water or to cross the stream, (2) stream bank fencing to exclude livestock from the riparian zone, and (3) placement of rock along steep banks. The size of the projects varied from installation of a single rock-lined access to construction of several crossings, thousands of meters of fence, and extensive bank stabilization. Typically, riparian buffers were three to four m wide. In total, 56 accesses and crossings and 11,500 m of fence were installed; more than 1,800 m of stream bank were stabilized with rock.

Unit personnel conducted a series of pre- and post-treatment studies on Slab Cabin Run and Cedar Run to assess stream responses to riparian restoration; the upper Spring Creek watershed served as a reference (Carline et al. 2004; Carline and Walsh 2007). Within three to five years after construction of riparian buffers, stream bank vegetation increased markedly and the proportion of fine sediments in stream substrates decreased significantly in Cedar Run, but not in Slab Cabin Run. The most notable response to riparian restoration was in suspended sediments in base flow and storm flow, which decreased by 47% to 87% after riparian treatments. Macroinvertebrate diversity did not change, but macroinvertebrate density increased significantly. Density of age-1 and older brown trout more than doubled in Cedar Run. While density of brown trout also increased in Slab Cabin Run, the population remained small, owing primarily to rather low stream flows, particularly during summer, in this sub-watershed. Overall, this study showed that even narrow grass buffers can significantly reduce sediment loading from riparian pastures and that macroinvertebrates and trout will respond positively.

I-99 Construction

Unit personnel conducted a 4-year study at the Park Avenue interchange adjacent to Spring Creek and at the Rock

Road bridge crossing (Figure 15). Stream sampling stations were established upstream and downstream of each construction site, and water was collected at hourly intervals during storm flow (Carline et al. 2003). About 100 storm events were successfully sampled at each site. In addition, stream substrate composition, numbers of brown trout spawning sites, and benthic macroinvertebrate communities were monitored upstream and downstream of each site.

Construction activities resulted in an approximately 14% increase in sediment loading to the stream at each site. Though the percentage increase was modest, the absolute mass of sediment was substantial – about 180 metric tons per year at the Rock Road site. This increase in sediment loading did not seem to influence other measures of stream health. We found no difference in diversity or density of benthic macroinvertebrates upstream and downstream of the construction sites. Similarly, composition of substrate collected from brown trout redds did not vary with stream location, and numbers and distribution of trout redds were not influenced by construction. By the end of the study, construction was completed and all previously disturbed earth was seeded and stabilized. Therefore, we concluded that construction was responsible for a significant, though short-term, increase in suspended sediment that did not affect benthic invertebrates nor trout spawning activity.

Another phase of the I-99 Transportation Project, which began in 2003, entailed cutting through a rock formation atop of the Bald Eagle ridge at an area locally known as Skytop (Figure 15). This rock formation was rich in iron pyrite. Excavated material was moved to several disposal sites on the ridge, and as water saturated these disposal piles, iron-laden, acidic water began seeping from the disposal piles. Some acidic water infiltrated into the groundwater and some flowed directly into the headwaters of Buffalo Run, which travels about 1.8 km through the valley floor and then largely infiltrates through the channel bottom into the groundwater. Presumably, after mixing with alkaline groundwater, the stream re-emerges near the village of Waddle about two km farther downstream. At this point, stream water chemistry and benthic macroinvertebrate sampling suggest little or no effect of the acidic drainage that originated from the Skytop area (personal communication; D. Spotts, PFBC). In August 2007, a remediation plan was put into operation. It involved moving more than 600,000 m3 (800,000 yd3) of material heavily laden with pryrite from the Skytop area, covering exposed pyrite formations, and treating acidic drainages. The net effect of these measures remains to be seen, but as of August 2007, it does not seem that acidic drainage from the construction site has had a measurable effect on the fishery resources in Buffalo Run.

Using a Biotic Index to Assess Stream Condition

Pennsylvania DEP biologists and a PSU student sampled macroinvertebrate communities at the same 14 sites on the main stem of Spring Creek four times during the period 2001 to 2006. They used the same sampling methods (PADEP 2006), and an Index of Biotic Integrity (IBI) score was computed following Botts' (2006) protocol for limestone streams. The index is based on six criteria: total number of invertebrate taxa, total number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa, the Hilsenhoff Biotic Index, percentage of intolerant taxa, percentage of tolerant taxa, and the Shannon Diversity index. A site with an IBI score of 55 or less is considered impaired (Botts 2006). Sites with scores of 100 are similar to references sites in streams with minimal human disturbance. Here we examine these macroinvertebrate data in an attempt to describe year-to-year variability, site-to-site variability, and to look for trends that might suggest causes for changes in stream condition.

Green Drake

The green drake mayfly, a casualty of the 1956 cyanide spill, has not been able to recolonize Spring Creek.

photo by G. Hoover)

Among years and sites, IBI scores ranged widely, from 15 at RK 16.6 below the Benner Spring Hatchery to 99 at RK 27.7, which is upstream from Lemont (Figure 16). In general, site-to-site variation in IBI scores was consistent among years, although overall variation among years was large. The lowest IBI scores were recorded in 2001, when the mean score was 48.0, and nine of 14 sites were ranked as impaired (Table 9). Three years later the mean IBI score had increased to 68.6, the highest of the four years, and only two sites were impaired. The IBI scores in 2005 and 2006 were relatively high, with four and seven sites, respectively, ranked as impaired.

While it is possible that year-to-year changes in water quality could result in changes in the macroinvertebrate community, examination of water quality records from the Water Resources Monitoring Project network and DEP data for the Axemann Water Quality Network site did not indicate any trends consistent with those for IBI scores. Rather, it is likely that annual variations in stream flow had a significant effect on macroinvertebrate communities. We used stream discharge data from the USGS Axemann gaging station, computed the mean monthly flow for a 12-month period prior to each macroinvertebrate collection, and compared those flows to the long-term average for this gaging station. These data indicate that the 2001 collection, which had the lowest IBI score, was preceded by the lowest stream flow among years (Table

9). The IBI scores for 2004 to 2006 were all relatively high, and preceding flows were near or well above normal.

There are at least two reasons why benthic macroinvertebrate communities would be positively affected by above-average flows. When stream flow is above average, pollutants from point source and non-point sources would be more diluted than at below normal flows; hence, toxic effects of pollutants would be reduced. The second reason is that at above-normal stream flows, there is less accrual of fine sediments in the riffles and runs, where benthic macroinvertebrate communities are sampled. The adverse effects of fine sediments on macroinvertebrates have been well-documented. For example, Kaller and Hartman (2004) showed that in West Virginia trout streams, numbers of mayfly, stonefly, and caddisfly taxa were consistently negatively related to the amount of fine sediment in substrates. And, in drought years, the amount of fine sediment in riffles and runs would probably increase, and diversity of these sensitive insect groups would be further reduced.

There were several notable changes in IBI scores when moving from the upstream-most site toward the stream mouth at Milesburg. In three of four years, the IBI score declined from the site upstream of Lemont (RK 27.7) to Spring Creek Park (RK 24.6; Appendix 1). A substantial amount of urban runoff from Lemont and the State Route 26 (East College Avenue) corridor enters the stream between these two sites. Then, Slab Cabin Run joins Spring Creek at about RK 24, and the IBI score at RK 23.7 was consistently lower than at the site upstream of Slab Cabin Run, which carries large amounts of urban runoff from State College and the PSU campus, plus runoff from agricultural lands upstream of North Atherton Street.

Discharge from the UAJA treatment plant had no apparent effect on the already low IBI scores upstream of the plant. During the period 2001 to 2006, the UAJA plant discharged an average of 0.21 m3/s (4.9 mgd; personal communication, J. Brown, UAJA). In contrast, IBI scores declined in all four years after discharges from the Benner Spring and Bellefonte Hatcheries entered Spring Creek (Figure 16). These declines in IBI scores were due, in part, to reductions in the number of EPT taxa and increases in the sowbug *Lirceus*, which is highly tolerant of pollution (Lenat 1993; Maxted et al. 2000). We presume that high densities of *Lirceus* are linked to organic enrichment from hatchery effluents that promote growth of microorganisms.

PFBC biologists also sampled macroinvertebrates upstream and downstream of the Benner Spring and Bellefonte Hatcheries in spring 2001, 2005, and 2006 (Kepler 2006) using the same protocols as DEP. Trends in IBI scores derived by the two agencies were similar in 2001 and 2006, but not in 2005. The scores derived by DEP in 2005 showed little change from upstream to downstream of the Benner Spring Hatchery (55 to 53) and a substantial reduction from upstream to downstream of the Bellefonte Hatchery (86 to 66). In contrast, PFBC data showed increases in scores from upstream to downstream of the Benner Spring Hatchery (36 to 51) and at the Bellefonte Hatchery (64 to 68). Reasons for these discrepancies are not evident.

Downstream of Bellefonte Borough, IBI scores increased by an average of 50% in all four years. It is likely that the large increase in stream flow, owing to Logan Branch, Big Spring, and Buffalo Run, benefited the macroinvertebrate community downstream of Bellefonte Borough at RK 2.9. In three of four years IBI scores declined downstream of RK 2.9. The Bellefonte Borough wastewater treatment plant discharges into Spring Creek a short distance downstream of RK 2.9, and the stream had been impounded by McCoy-Linn Dam. It is conceivable that the impoundment had some effect on downstream macroinvertebrate communities, and if so, it is not possible to separate out possible effects of the Bellefonte treatment plant and of the impoundment. McCoy-Linn Dam was subsequently removed during fall 2007, and Spring Creek is now free-flowing from Talleyrand Park in Bellefonte to the mouth.

If indeed IBI scores are good measures of benthic macroinvertebrate community health, we can make several generalizations from these data. Year-to-year variations in IBI scores were large and seemed related to stream flow. Site-to-site variations in IBI scores were large, but reasonably consistent among years. Benthic communities responded negatively to inputs of urban runoff and discharges from hatcheries. The length of stream classified as impaired ranged from 5.9 km (21.2% of the total) to 18.5 km (66.9%).

Threats from Increasing Urbanization

The macroinvertebrate assessments by DEP suggest that urban influences in the upper part of the watershed are having negative effects on stream health. Given the extensive development in and around the Borough of State College and the PSU campus, impacts on Spring Creek are not surprising. The effects of urbanization on stream ecosystems have been well-documented in the literature, and most of these impacts are readily apparent in nearly all reaches of Spring Creek.

Schueler (1994) and Brown et al. (2005) provide concise overviews of how urbanization affects streams, and here, we briefly summarize their work. Urbanization reflects the conversion of forest and agricultural land to impervious surfaces that can be categorized as buildings (rooftops) and the transportation system. An increase in impervious surface coverage has profound effects on the hydrologic cycle, because the amount of rainfall that infiltrates into the groundwater is much reduced, and surface runoff, often referred to as storm flow, is greatly increased. Reduced recharge of groundwater translates to reduced stream base flow, which is particularly important to the maintenance of coldwater stream communities. As imperviousness increases, the frequency and magnitude of storm flow events increase, and the physical components of the receiving streams are altered. Higher stream flows require a large stream channel to transport water; hence, the response is erosion of stream banks (widening) and downcutting of the stream bottom (deepening). These types of alterations degrade habitat for invertebrates and fishes. Surface runoff from impervious surfaces during summer months can deliver warm water to the stream and cause elevated stream temperatures, which can lead to a shift from coldwater to warmwater fish communities (Steffy and Kilham 2006). Storm water runoff affects water quality by increasing sediment load, reflected in turbidity, and by increasing the amount of nutrients and pollutants in the stream. The cumulative effects of physical, thermal, and chemical alterations linked to storm water runoff lead to degradation of biological communities.

Schueler (1994) proposed that imperviousness, expressed as surface area in a watershed, could serve as a unifying theme to quantify the degree of urbanization. Arnold and Gibbons (1996) have supported the notion that imperviousness is a key environmental indicator. Although others (e.g. Short et al. 2005) have developed an index of urbanization that incorporates a large number of physical variables, Schueler's (1994) single variable index seems to be a useful predictor for coldwater communities. He suggested that urban streams could be classified on the basis of percentage of impervious surface area in the watershed, and Arnold and Gibbons (1996) slightly modified Schueler's (1994) categories, which we have depicted in Figure17.

Schueler (1994) suggested, on the basis of available literature, that if an urban watershed was less than 10% impervious, stream channels would be stable and the diversity of biological communities would be protected. Results from several recent studies on trout streams seem to indicate coldwater fish communities are not likely to be protected when watersheds reach 10% imperviousness. Stranko et al. (2008) examined over 100 sites in Maryland that supported brook trout or did not support brook trout but had their preferred habitat; they concluded that brook trout were lost when imperviousness reached 6.6%. Stanfield et al. (2006) studied more than 400 streams in southern Ontario and found that salmonid populations were eliminated when imperviousness ranged from 6.6 to 9%. In 39 southwest Wisconsin and southeast Minnesota streams, Wang et al. (2003) found significant declines in trout populations when imperviousness was 6 to 11% and no trout when it exceeded 11%. We have depicted these upper limits for salmonids in the middle of Schueler's (1994) "degraded" category, though one might argue that these values belong in the "impacted" category (Figure 17).

Spring Creek seems to be an anomaly compared to previously cited studies, because imperviousness is well beyond the range where trout populations persist. In 1995, it was estimated that 12% of the Spring Creek watershed was impervious (CCPO 1996), and, given that the population has been growing steadily, imperviousness must be greater than 12% in 2008. The Centre Region encompasses about the upper one-half of the watershed, and in 2002, imperviousness was 19.3% (CCPO 2003). Clearly, if Spring Creek followed the pattern of other watersheds, we would not expect wild trout populations to survive in this environment (Figure 17).

We suggest that the persistence of wild trout in the Spring Creek watershed is attributable to the large number of springs that contribute well-oxygenated coldwater to the stream and serve to moderate high summer temperatures. During their examination of Maryland streams, Stranko et al. (2008) found brook trout in a watershed with 42% impervious land cover compared to the 6.6% threshold for other watersheds. Summer water temperatures in this highly developed watershed were similar to sparsely developed watersheds. Valley Creek, in southeastern Pennsylvania, is another stream that still supports wild brown trout, but had 17% impervious surface.

Steffy et al. (2004) attributed the persistence of brown trout in this urbanized watershed to the large number of springs, but, more recently, brown trout populations have shown evidence of decline (Steffy and Kilham 2006). Like Spring Creek, Valley Creek is characterized by karst geology, and most of the development is in the upper part of the watershed.

Among the watershed studies that we have reviewed, the two most frequently cited factors critical to maintenance of coldwater fish communities were stream base flow and summer water temperatures (Zorn et al. 2002; Wang et al. 2003; Stanfield et al. 2006; Steffy and Kilham 2006; Wehrly et al. 2006; Stranko et al. 2008). Stream base flow reflects the amount of groundwater entering the stream, which directly influences stream temperature; hence, streams with large groundwater inputs have cooler summer temperatures and warmer winter temperatures relative to streams with minimal groundwater inputs. From these observations, we infer that the future of wild trout populations in the Spring Creek watershed is dependent upon maintenance of adequate groundwater inputs and summer water temperatures suitable for trout.

We are not aware of any long-term records of water temperature for Spring Creek; hence, we cannot make any generalizations about long-term trends. Our analysis of stream flow at the Axemann gage suggests that mean annual flow has not changed, nor have annual 7-day low flows. Whether stream flow will remain reasonably stable in the face of a growing population remains uncertain. Clearly, the amount of groundwater pumped from the aquifer has increased with the growing population in the watershed (3.1 mgd in 1980 to 9.1 mgd in 2002; Taylor 2005), but much of this water is treated and returned to the stream. The difference between the amount pumped and the amount returned to the stream is that lost to evapotranspiration, where homeowners and businesses irrigate lawns and gardens. Evapotranspiration undoubtedly accounts for a large proportion of PSU's treated wastewater that is spray irrigated during the growing season. As the population continues to increase, we can expect more losses to evapotranspiration with potential consequences to the groundwater reserves.

Lieb and Carline (2000) monitored the temperature of Thompson Run just downstream of a small impoundment that receives storm water runoff from the Borough of State College and part of the PSU campus. In June 1995, they recorded hourly temperature increases of up to 6.6 oC following thunderstorms. In 1999, temperature monitors were installed in Thompson Run about 0.7 km downstream of the site monitored by Lieb and Carline (2000). During the months of June through September 1999 to 2007, an average of 22 storms per year produced hourly increases of >2oC, and the mean increase for these storms was 3.7 oC (personal communication, G. Smith, ClearWater Conservancy). The highest hourly increase was 9.6 oC. Despite these temperature increases, wild brown trout continue to persist in Thompson Run. It is likely that as imperviousness increases, we can expect more inflows of heated storm water runoff, but in the absence of good empirical information, we cannot predict the degree of imperviousness that may eventually lead to summer temperatures that are unsuitable for trout populations. Careful management of land and water resources can forestall likely outcomes of urbanization, and some such management practices are already in place or planned.

Managing Treated Wastewater and Storm Water

Stormwater

Silt-laden stormwater runoff flows into Spring Creek at the State Highway 26 Bridge.

photo by G. Hoover)

PSU Land Treatment Area

Perhaps the most significant water resource project in the watershed was completed in 1983 when PSU's entire volume of treated wastewater was no longer discharged into Thompson Run. Instead, treated wastewater was spray irrigated onto forest and agricultural land about 5 km from campus. This project is now labeled as the Land Treatment Area, because the water is further treated through nutrient uptake by microorganisms as it percolates through the soil. The PSU treatment plant is permitted to treat up to 0.18 m3/s (4 mgd) of wastewater; in 2006, the average daily discharge was 0.10 m3/s (2.2 mgd; personal communication, J. Gaudlip, PSU). This treated effluent was sprayed onto 210 ha. This system has benefited Thompson Run, the lower reach of Slab Cabin Run, and Spring Creek, because potential toxic and thermal effects of treated wastewater were eliminated and much of the treated wastewater, which originated from groundwater, is being returned to the groundwater. Spring Creek, immediately downstream of its confluence with Slab Cabin Run, has shown signs of impairment owing to storm water runoff in recent years, and it is likely that this impairment would have been even greater if PSU's treated wastewater was being discharged into Thompson Run.

Beneficial Reuse

Another project with potentially significant effects on water resources in the Spring Creek watershed was recently implemented by the UAJA, which treats wastewater from the State College area in the upper part of the watershed and discharges into Spring Creek about 2.5 km upstream of the Benner Spring Hatchery (Figure 1). The treatment plant is permitted to discharge up to 0.26 m3/s (6 mgd), and it is anticipated that the volume of incoming wastewater will exceed this limit by the year 2016 (personal communication, D. Smith, UAJA). To handle the increased volume of wastewater, the UAJA constructed a system that takes treated wastewater as it leaves the clarifiers and subjects it to microfiltration, reverse osmosis, and advanced disinfection to produce water that meets drinking water standards (UAJA 2008). This water will then be pumped back up into the watershed from where it came, and is available for a variety of beneficial uses, hence, the project name – Beneficial Reuse.

In 2008, this treated water was piped to a golf course for irrigation and to a commercial laundry facility, and 106 l/min (28 gal/min) was discharged into a constructed wetland, where one might expect some groundwater recharge to occur. Because the treated water meets drinking water standards, it could be re-injected into the groundwater, where it could be recycled through domestic water supply systems. The uses and fates of this treated water are currently under study, but the project will benefit Spring Creek, because it will prevent further increases in treated effluent to the stream, it may reduce the amount of groundwater that is pumped for industrial uses and irrigation, and it may recharge the groundwater.

Storm Water Management

In the face of increasing urbanization and associated threats to water quality, the municipalities in the Spring Creek watershed took an important step to reduce impacts of development when they crafted a storm water management plan for the Spring Creek watershed in 2001 (Sweetland 2001). After approval of the plan by the County Commissioners and DEP, model ordinances were adopted by participating municipalities.

The foundation of the storm water management plan is a set of performance criteria to control runoff from new development, maintain groundwater recharge, reduce channel erosion, minimize non-point source pollution, and others, which, in total, will help to greatly reduce future impacts from storm water runoff. There are no provisions in the plan to deal with runoff from existing development; hence, reaches of Spring Creek that are showing signs of degradation will not improve as a result of the plan.

Riparian Buffer Restoration

Over the past 20 years, a large number of studies have demonstrated the value of intact riparian buffer zones to the health of streams (Lowrance et al. 1984; Sovell et al. 2000). Public and private conservation groups in the Spring Creek watershed initiated a riparian restoration project in 1990, and these efforts continue today. Agricultural lands were targeted in the early stages of the project, but, in more recent years, landowners outside of the agricultural community are being engaged in riparian restoration efforts (personal communication, K. Ombalski, Clearwater Conservancy). Stream habitat enhancement projects are underway on several reaches of publicly owned land. The Centre Regional Planning Agency has drafted a model ordnance for the establishment and protection of stream buffer zones (CRPA 2008). Local municipalities will have to adopt the ordnance before it can be put into practice. These non-regulatory and regulatory measures to enhance riparian zones offer a way in which harmful effects of storm water can be diminished. But, the amount of riparian restoration necessary to reverse stream degradation is unknown, and it could be huge.

Summary

The sport fishery in Spring Creek has evolved from one dominated by brook trout in the late 1800s to one dominated by brown trout by the mid 1900s. Stocking of brown trout in the 1890s and later stocking of catchable size trout, poor water quality, and possibly heavy exploitation contributed to the decline of brook trout. Now brook trout persist in just a few headwater refugia.

In the early 1900s, several reaches of Spring Creek were probably severely polluted, because there were no wastewater treatment plants in the watershed. As treatment plants were built between 1913 and 1968, some pollution was abated, though toxic spills from industrial sources were common. By 2001, the number of wastewater treatment plants had declined from five to two, and no reaches of stream were badly polluted. Storm water runoff has now become the major threat to water quality.

Since 1980, when the first comprehensive survey of trout populations was made, densities of wild brown have increased substantially. In addition to improved water quality, the elimination of stocking trout and the implementation of no-harvest regulations were largely responsible for the increase in wild brown trout. Growth in length of brown trout was similar to the statewide average for brown trout in limestone streams. Growth was not density dependent except for age-0 trout during their first spring and summer. About one-half of the annual growth occurred between mid March and mid June. Stream flow and water temperatures influenced growth. During summer, low flow and warm temperatures reduced growth. Growth during winter was best when flows and water temperature were above normal. The number of trout redds counted in Spring Creek between Milesburg and Boalsburg more than doubled from 1988 to 2005. The largest increase occurred in the middle reach between Slab Cabin Run and Fisherman's Paradise.

Since 1934, when the Spring Creek Project at Fisherman's Paradise was initiated, there have been two distinct sport fisheries on Spring Creek. Special regulations on the 1.8-km reach known as Fisherman's Paradise initially allowed a harvest of two trout per day, and terminal tackle was restricted to flies tied on barbless hooks. The reach was heavily stocked with large trout. The project became enormously successful after a few years, and in 1952, more than 44,000 anglers fished there. Poor water quality led to a change in management in 1962, when harvest was discontinued, but tackle restrictions remained. The rest of the main stem of Spring Creek had no tackle restrictions and statewide harvest regulations were in effect until 1982 when harvest of all fish was prohibited, owing to chemical contamination. Fishing pressure on Fisherman's Paradise and the rest of the main stem has been quite high, and in 2006, it was about 30 times higher than the average for other similar size streams in the state.

A recent invasion by rusty crayfish and the potential of invasion from the diatom *Didymosphenia geminata* and the New Zealand mud snail pose a significant threat to macroinvertebrate and fish communities in Spring Creek. Development in the watershed, stimulated in part by major projects such as the construction of I-99 poses an additional threat. When macroinvertebrates were used to assess stream health, there was convincing evidence that urban runoff in the upper part of the watershed was degrading water quality. The amount of impervious surface area in the watershed exceeds 12%, which is higher than threshold values for other watersheds that have lost coldwater fish communities. Increasing urbanization represents a serious threat to the trout fishery of Spring Creek. Protection of groundwater recharge areas is vital to ensuring that spring inflows to Spring Creek are maintained. Strict controls on storm water runoff and innovative ways to treat and dispose of domestic wastewater will help to reduce future urbanization impacts, but the watershed is clearly under stress.

Acknowledgements

We sincerely appreciate the data, assistance, and manuscript reviews provided by PFBC biologists: J. Arway, T. Cochran, R. Greene, M. Hartle, D. Miko, D. Spotts, R. Wilberding, and L. Young. Pennsylvania DEP biologists J. Ryder and J. Sengle provided assistance with IBI calculations and manuscript reviews. D. Smith and J. Brown, UAJA, kindly provided data and helpful reviews of the manuscript. R. Jacobs and B. Rider, Centre County Planning Office, provided data on population trends and land use. L. Fennessey and J. Gaudlip, PSU, offered data and insightful reviews. Mark Ralston, Converse Consultants, reviewed the manuscript and suggested valuable references. G. Smith, ClearWater Conservancy, cheerfully provided data and review of the manuscript. We thank D. Shields for loan of reference materials. D. Lieb, PSU, drafted most of the crayfish section. We are indebted to all of these people for their generous help.

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Figure 1

Map of the Spring Creek watershed, Centre County, Pennsylvania. Sample sections numbered 1 to 16.

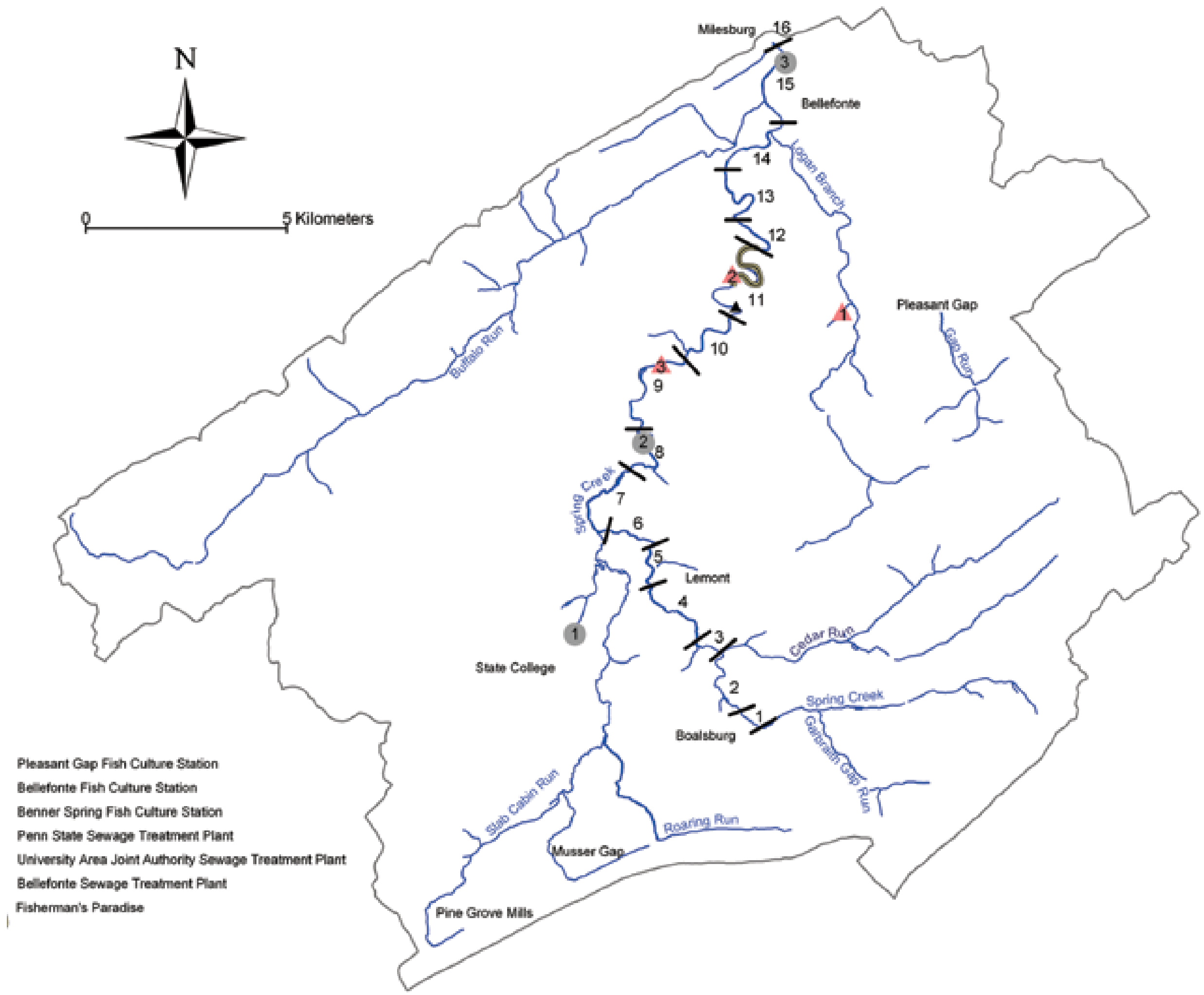


Figure 2

Land use in the Spring Creek watershed (CCPO 1996) and mean daily stream temperatures for July and January (in parenthesis) for the period July 1999 to July 2003 (WRMC 2003).

Figure 3

Human population of Centre County, 1800 - 2005. All municipalities includes the boroughs of Bellefonte, Centre Hall, Milesburg, and State College and the 10 townships with some land in the Spring Creek watershed. The major municipalities include three boroughs (excludes Centre Hall) and Benner, College, Harris, Patton, and Spring townships, which have most of their land in the watershed.

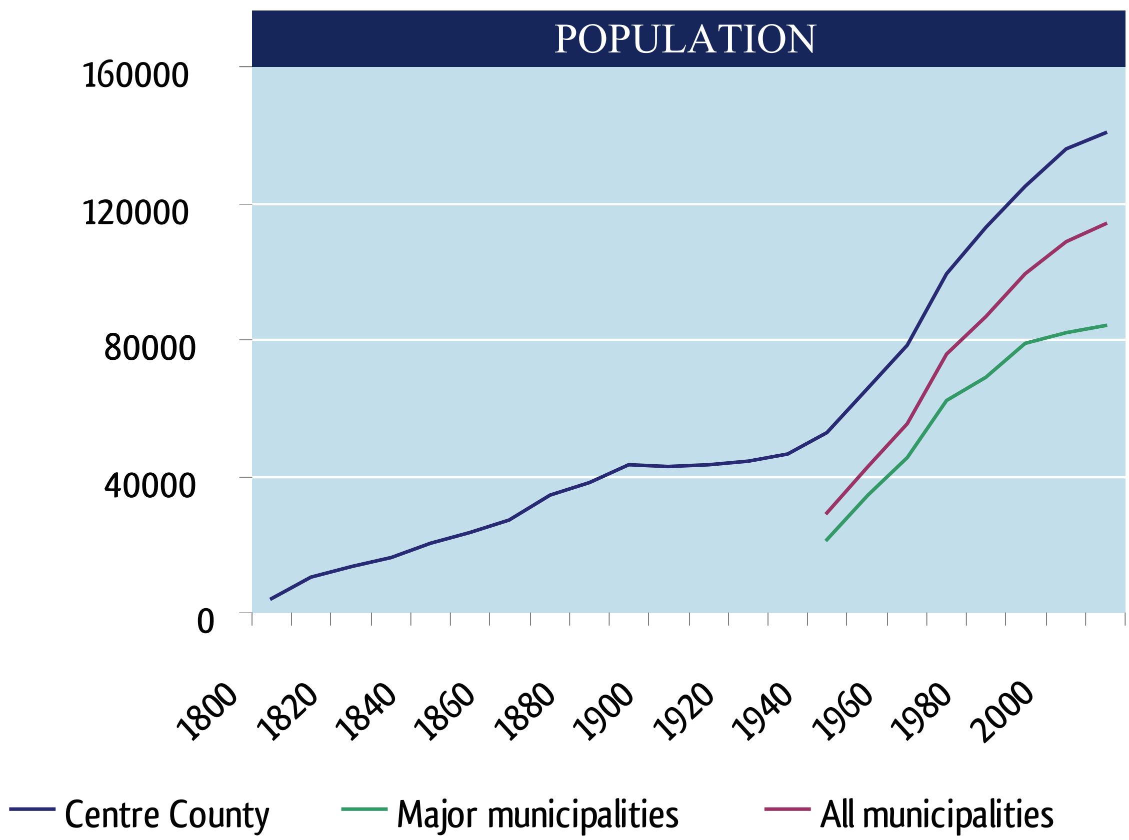


Figure 4

Average annual flow in Spring Creek near Axemann (USGS 2008b) and average annual precipitation measured at the Pennsylvania State University weather station.

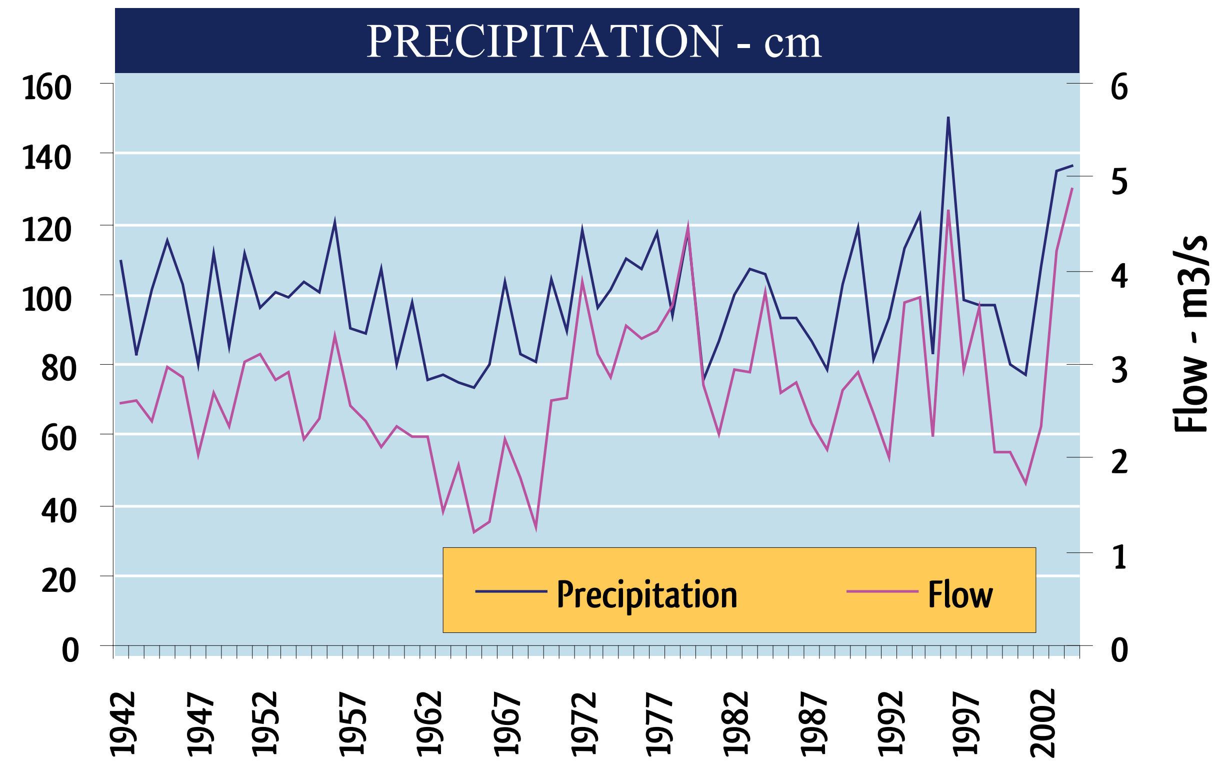


Figure 5

Average annual alkalinity of Spring Creek near Axemann (EPA 2007).

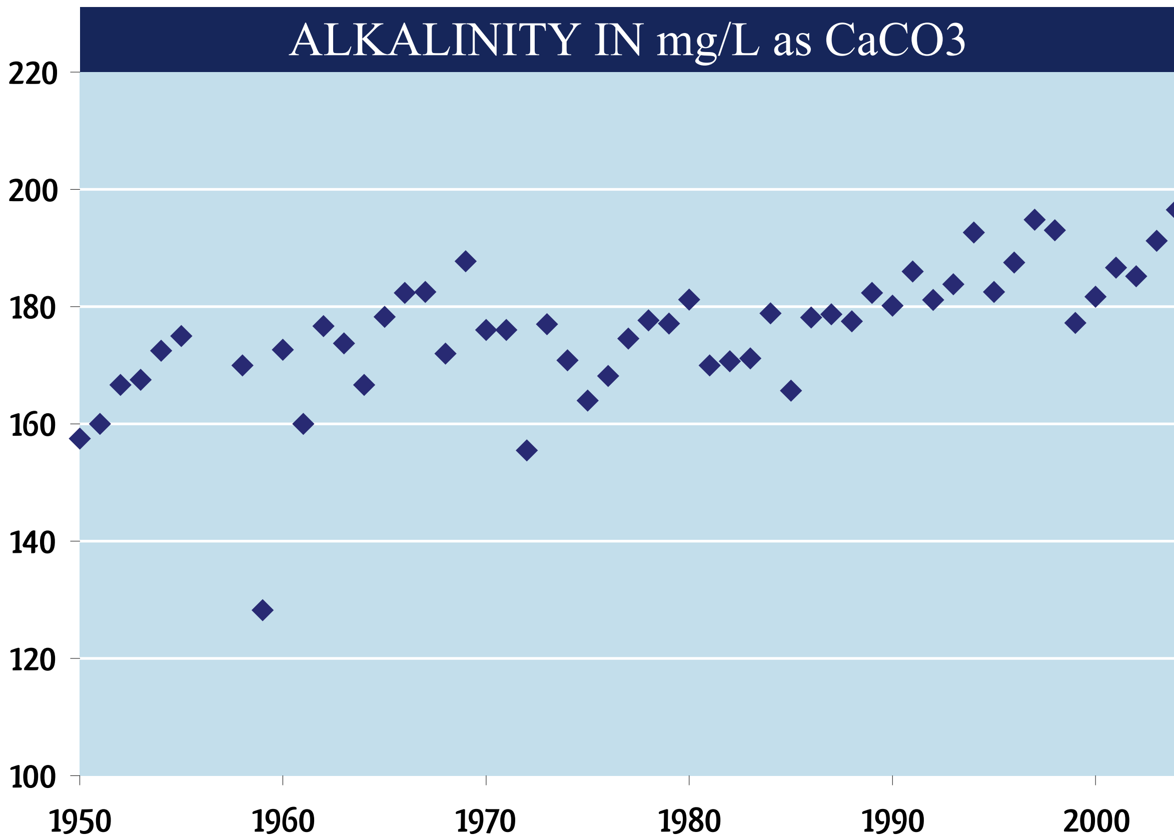


Figure 6
Concentrations of total phosphorus in Spring Creek near Axemann (EPA 2007).

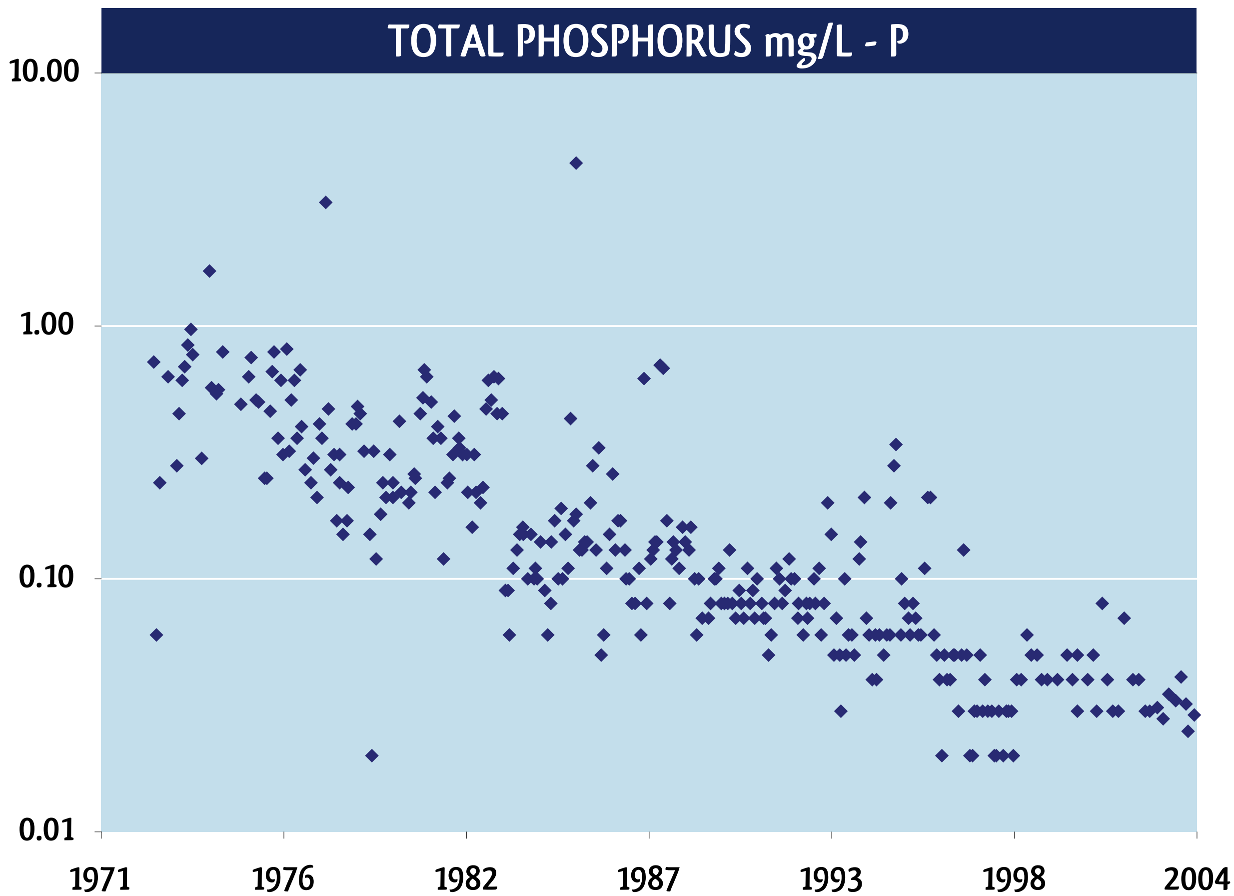


Figure 7

Estimated biomass of age - 1 and older brown trout in eight sections of Spring Creek, 1980 - 2006.

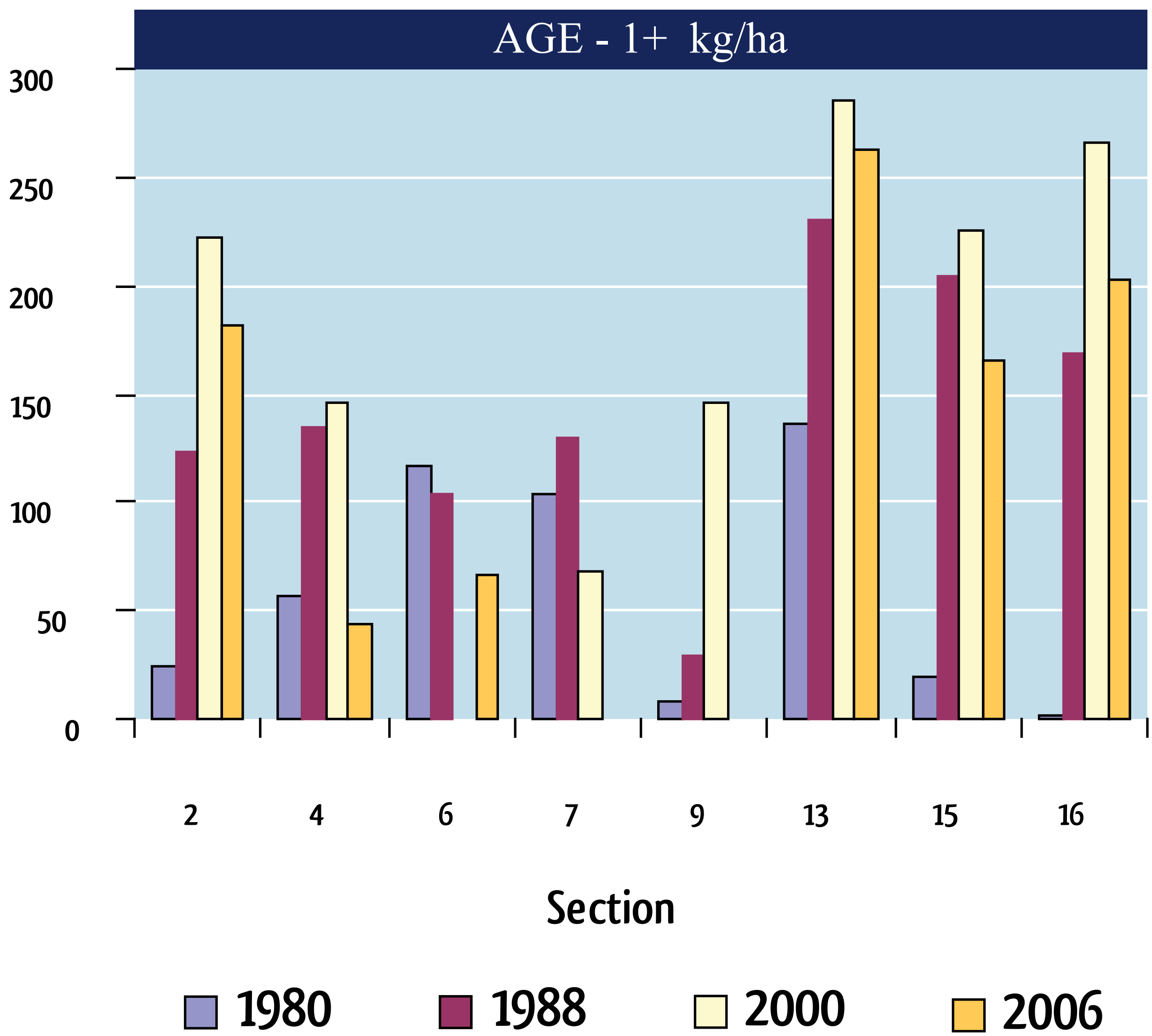


Figure 8

Size structure of brown trout>150 mm total length in three sections of Spring Creek. Values for length intervals represent the upper limit of each interval.

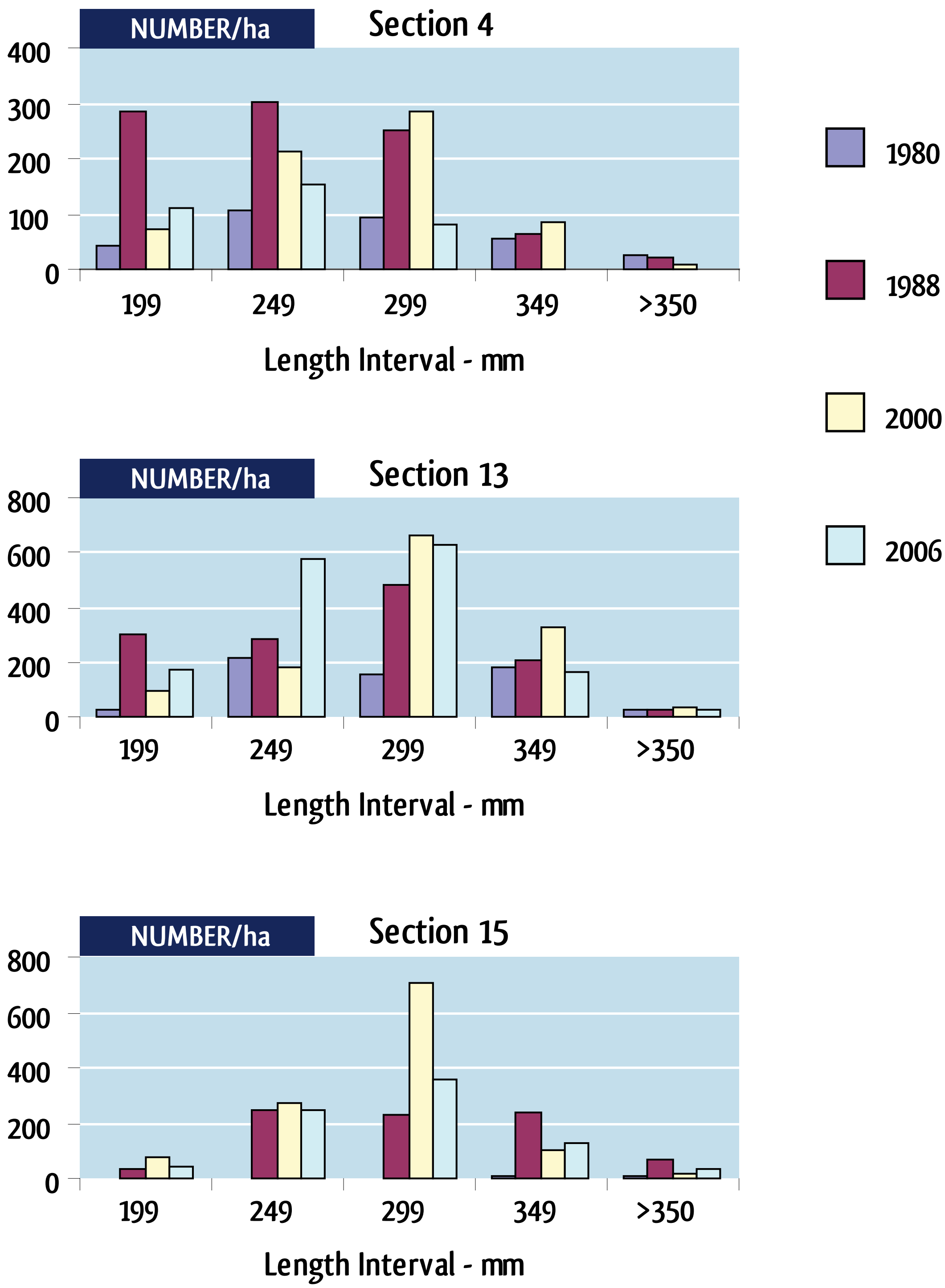


Figure 9

Mean length at capture of brown trout ages 0 to 4 in four sections of Spring Creek, August, 1998.

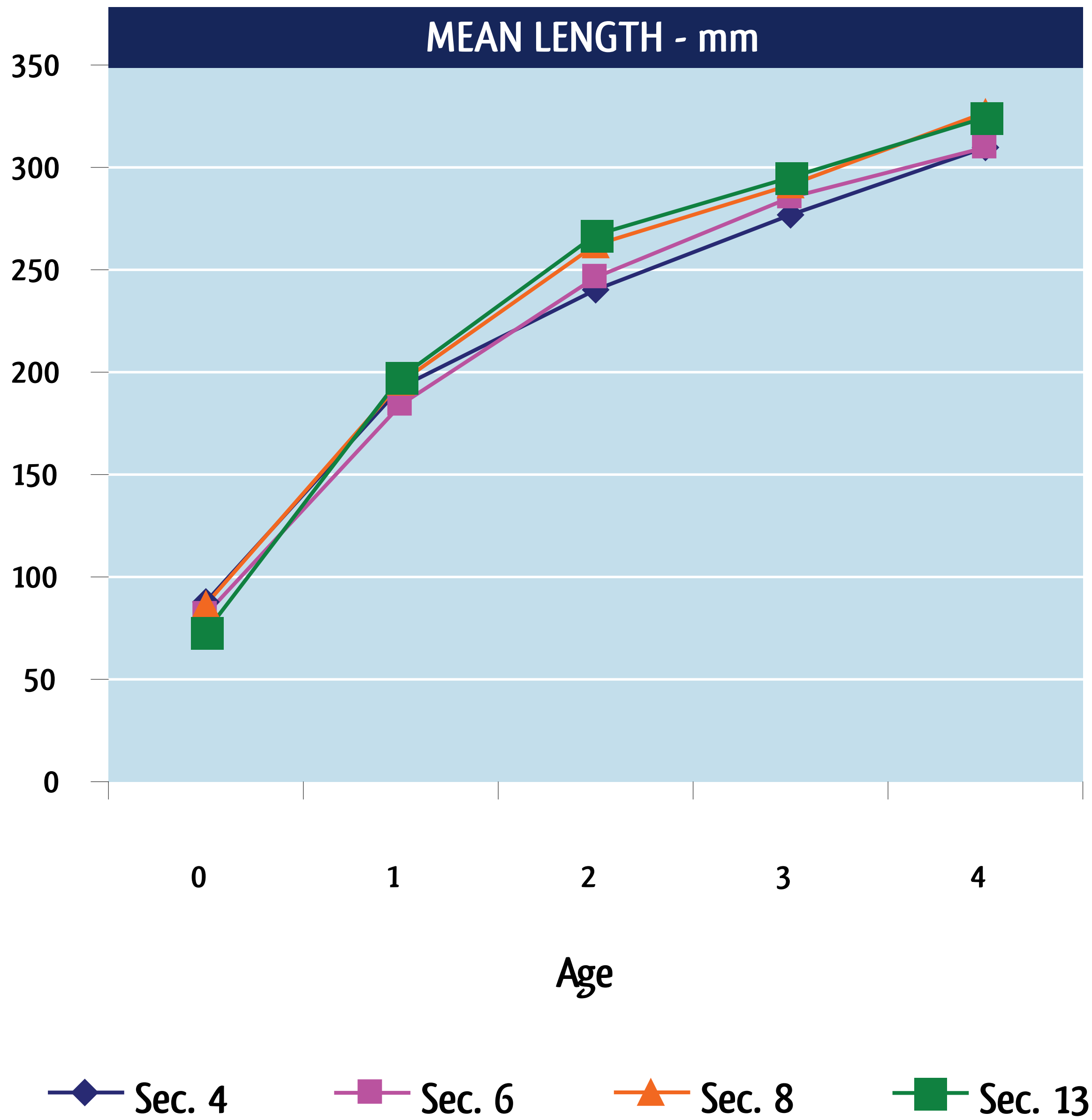


Figure 10

Mean length at capture of brown trout ages 0 to 6 in Spring Creek in 1980 and 1988 and for brown trout collected from limestone streams statewide, 1976 - 2006.

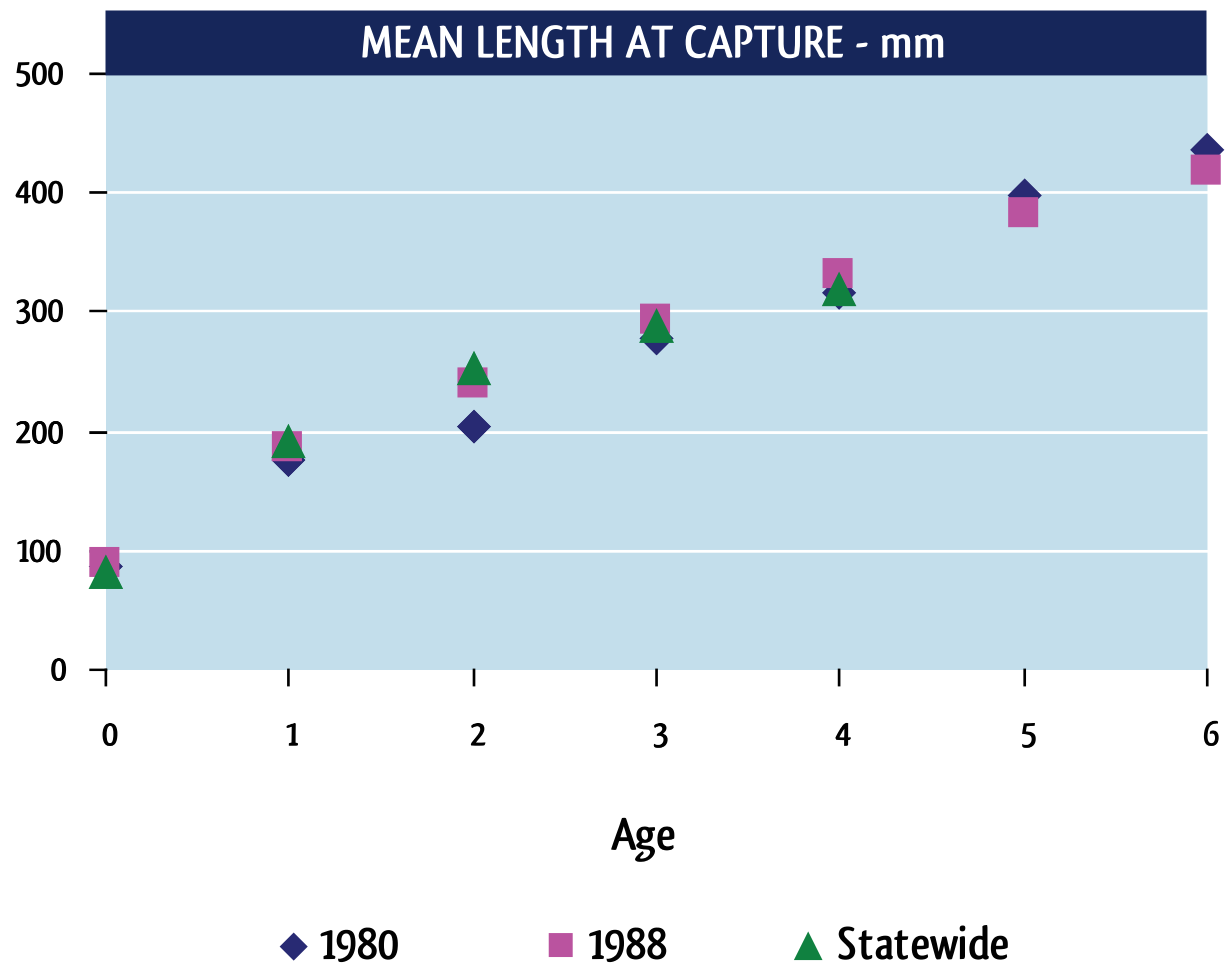


Figure 11

Mean weights of brown trout ages 0 to 3 in six sections of Spring Creek. Collections were made at quarterly intervals, April 1990 - April 1992.

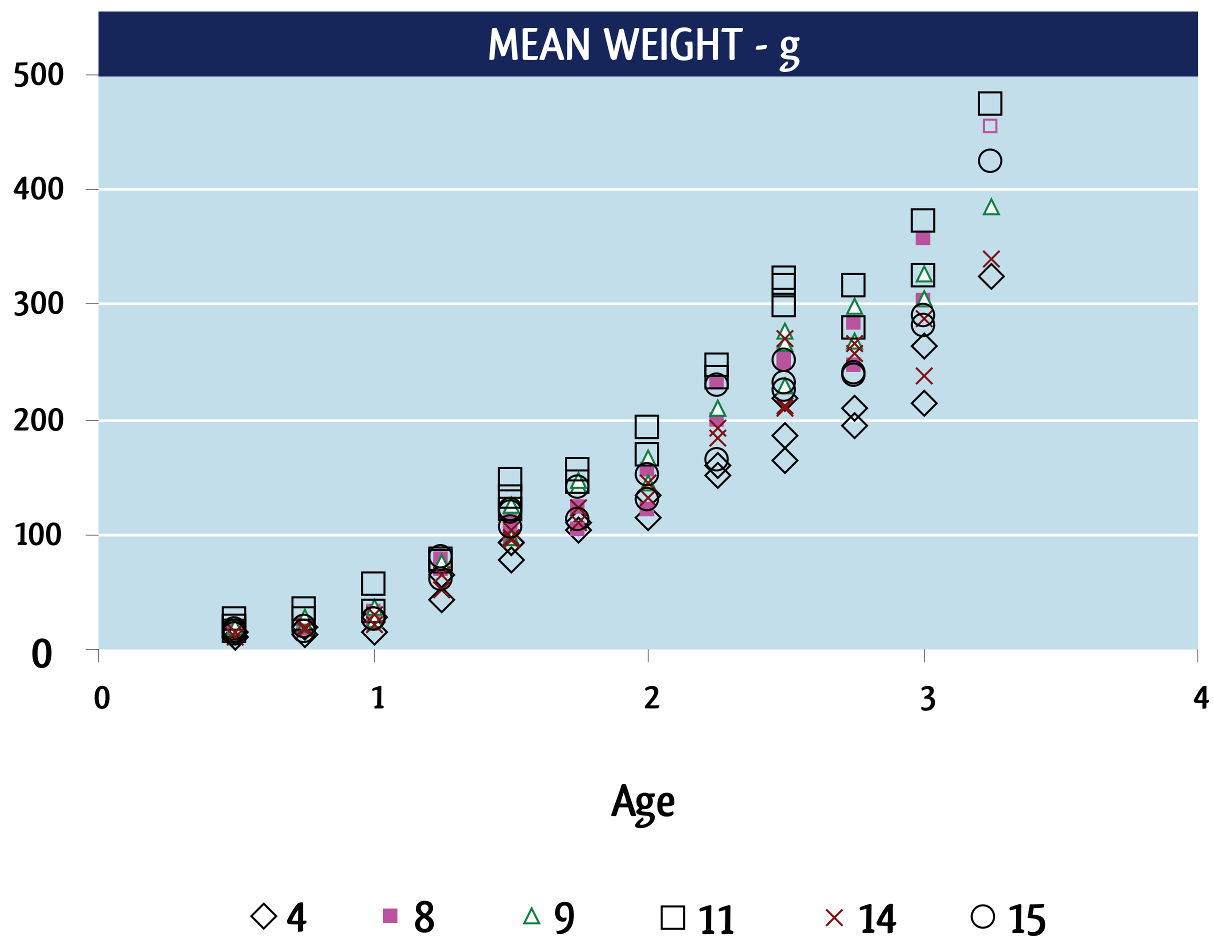


Figure 12

Median instantaneous growth (G) per 100 days of ages 0 to 2 brown trout collected in fall (Fa), winter (Wi), spring (Sp), and summer (Su), 1990 - 1992. Values are means from six stream sections.

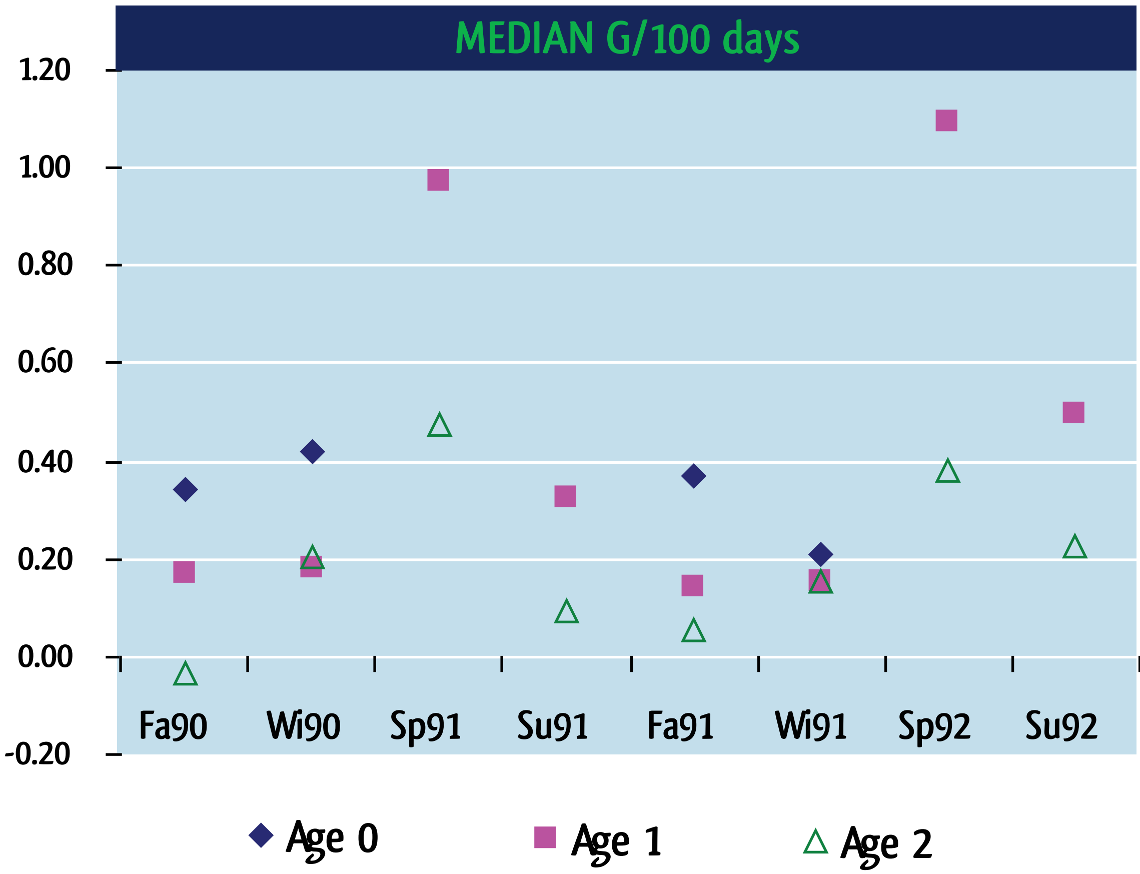


Figure 13

Mean weight of age - 0 brown trout in August in relation to the number of age - 0 brown trout captured. Each point represents the mean weight and catch rate for a section. Data were derived from two sections in 1990, 6 sections in 1991, and 5 sections in 1992.

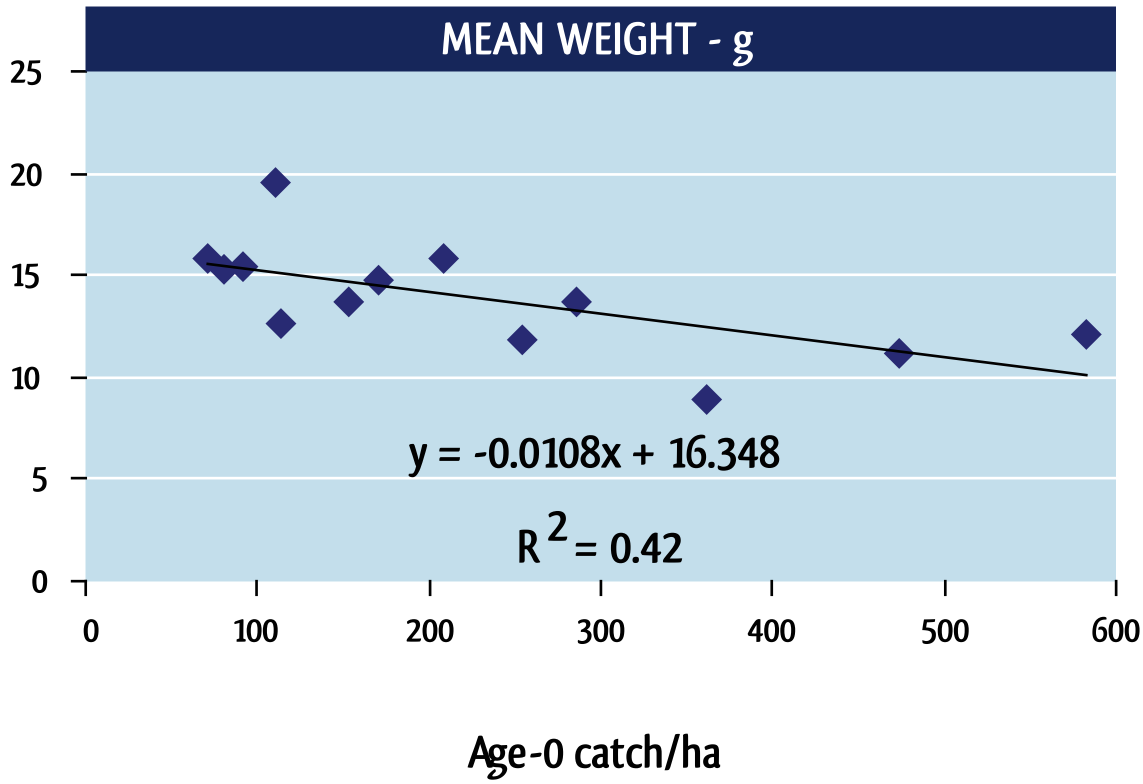


Figure 14

Number of redds counted in Spring Creek, 1987 - 2005. The upper reach includes sections 1 to 6, the middle includes sections 7 to 11, and the lower reach includes sections 12 to 16.S

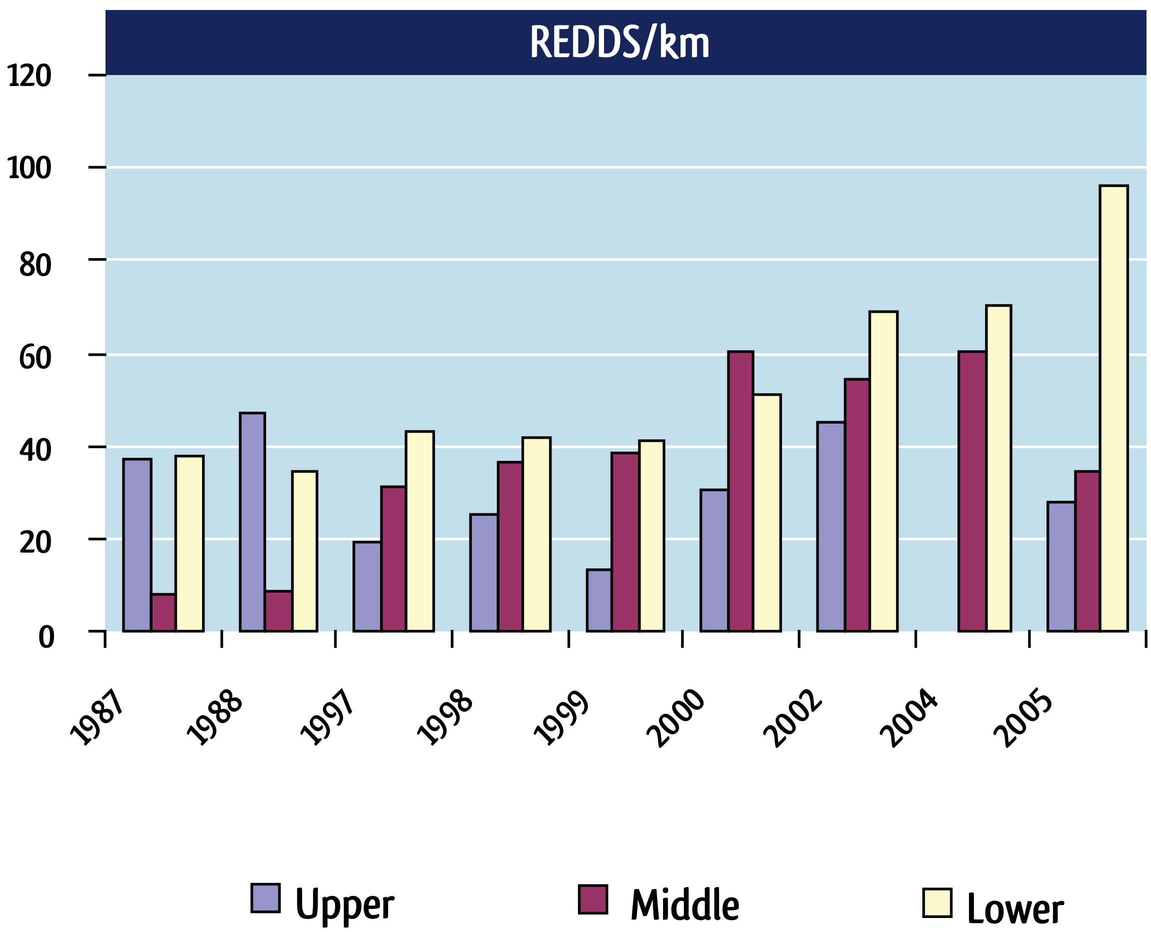


Figure 15

Map of the Spring Creek watershed showing sample section numbers, riparian restoration sites, and construction sites associated with Interstate Highway 99.

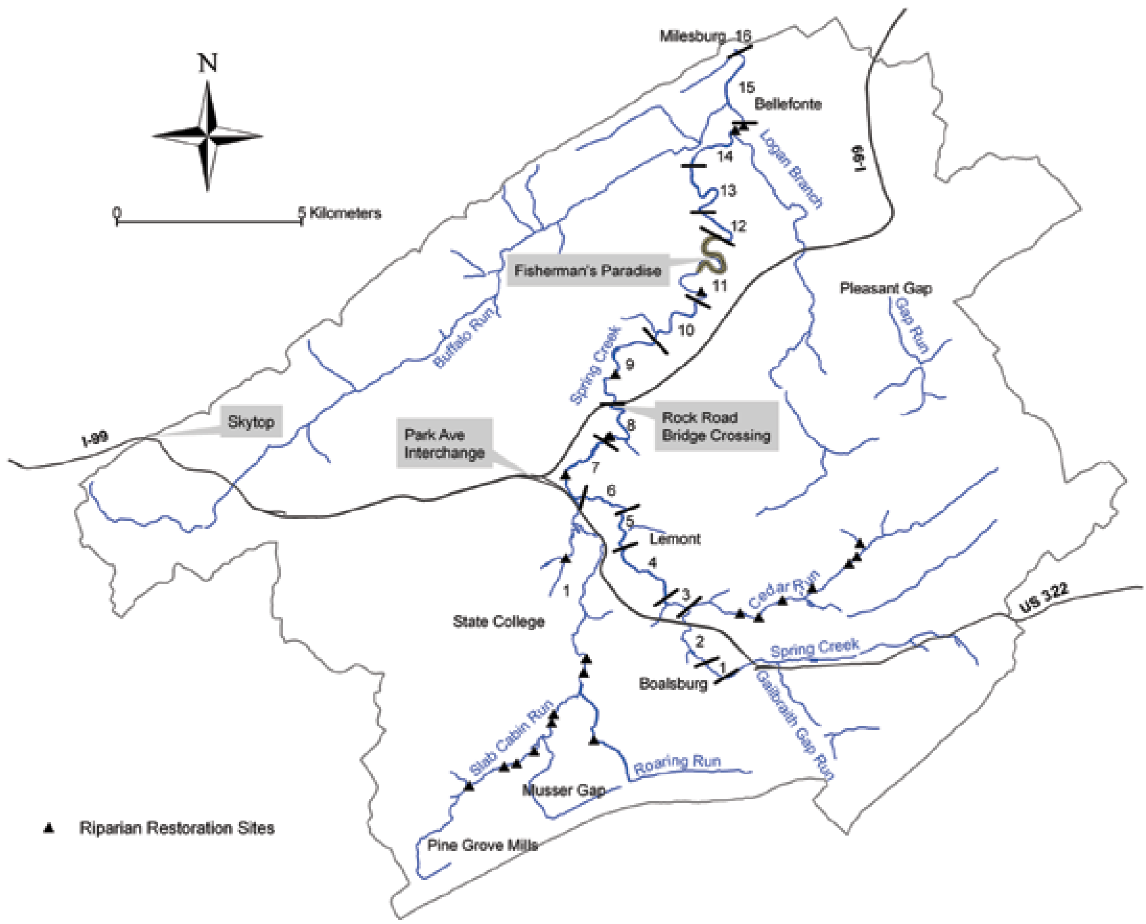


Figure 16

Index of Biotic Integrity (IBI) scores computed from benthic macroinvertebrate data collected from 14 sites on Spring Creek, 2001 - 2006. Date from Hughey (2002; 2006), Meck (2004) and Ryder (2007). Entry points of Slab Cabin Run, University Area Joint Authority (UAJA) wastewater treatment plant, Benner Spring and Bellefonte State Fish Hatcheries (SFH), Logan Branch, and the Bellefonte wastewater treatment (WWT) plant are denoted by single arrows.

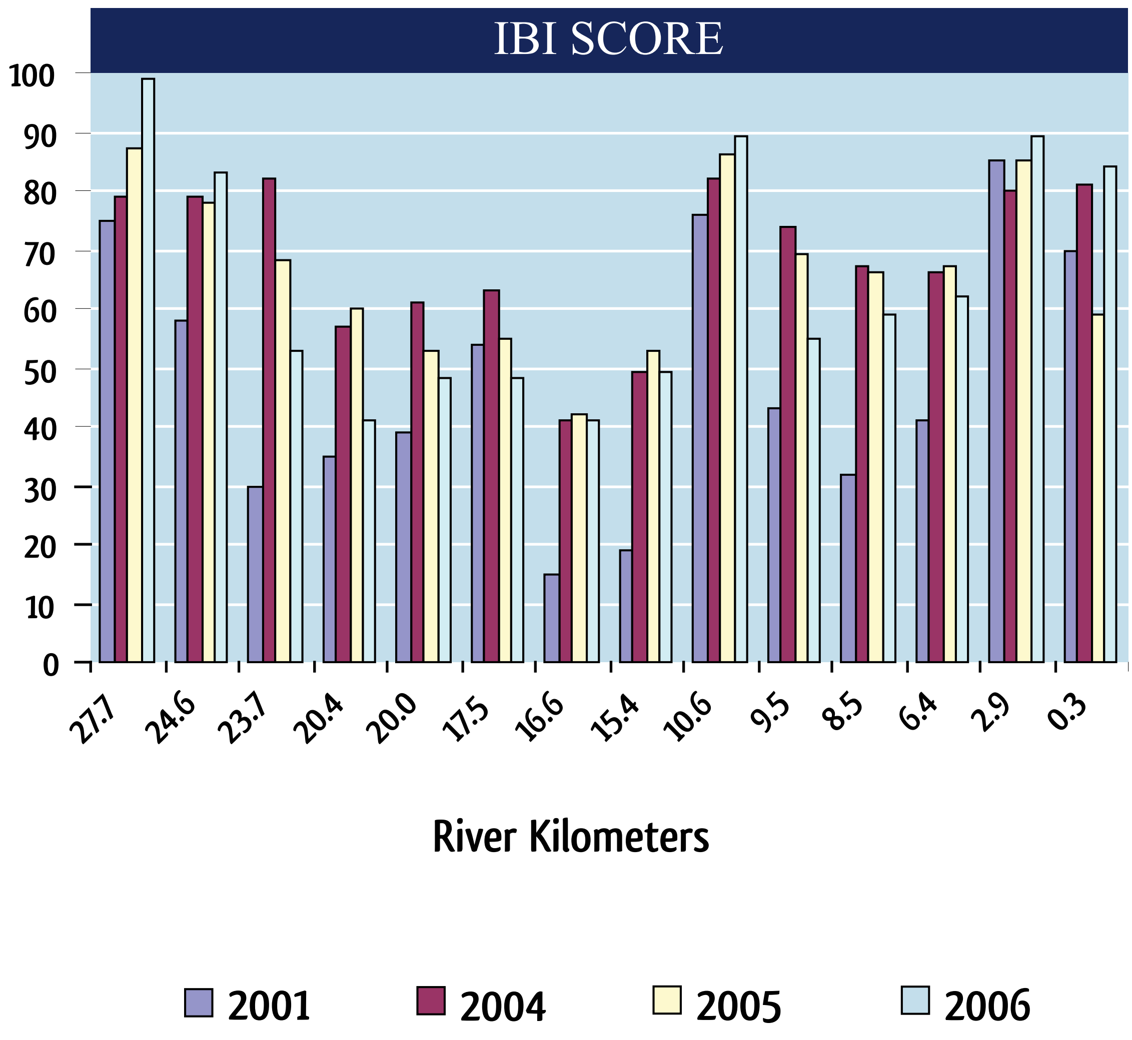


Figure 17

Percentage of impervious land cover in a watershed and categorization of watershed condition following ranges recommended by Schueler (1994) and Arnold and Gibbons (1996). The symbol for Spring Creek represents the entire watershed and that for Centre region represents the upper part of the watershed. Values for other studies are the threshhold limits beyond which salmonids were no longer found: A - Stanfield et al. (2006), B - wang et al. (2003), and C - Stranko et al. (2008).

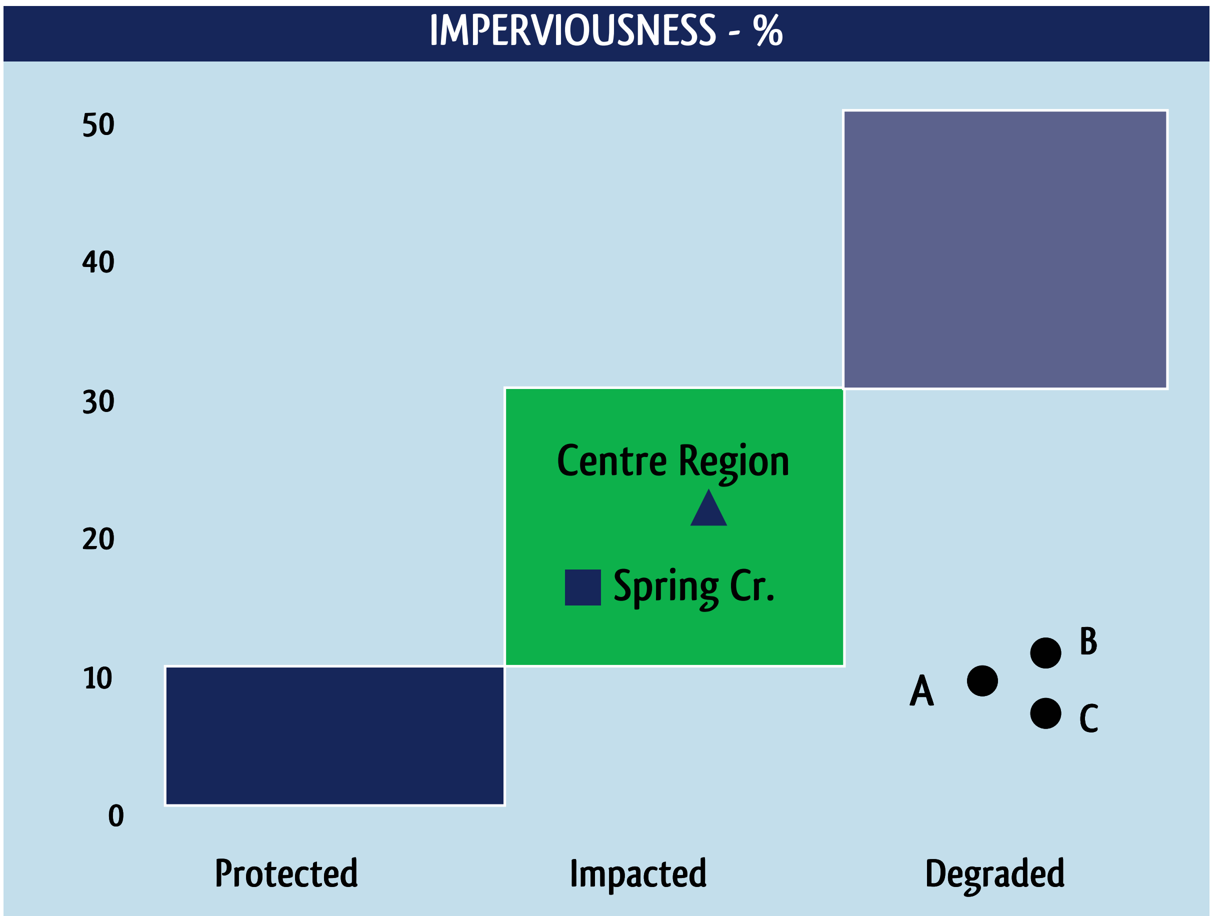


Table 1

List of common and scientific names of fishes captured in the Spring Creek watershed, 1958-2008. Collections were made by R. F. Carline, E. L. Cooper, J. E. Detar, and B. A. Hollender.

Common Name	Scientific Name
American eel	Anguilla rostrata
Rainbow trout [a]	Oncorhynchus mykiss
Brown trout [bc]	Salmo trutta
Brook trout [c]	Salvelinus fontinalis
Northern pike [a]	Esox lucius
Hybrid muskellunge [a]	Esox lucius x E. masquinongy
Central stoneroller	Campostoma anomalum
Goldfish [b]	Carassius auratus
Common carp [bc]	Cyprinus carpio
Cutlips minnow [c]	Exoglossum maxillingua
Common shiner	Luxilus cornutus
Golden shiner	Notemigonus crysoleucas
Spottail shiner	Notropis hudsonius
Rosyface shiner	Notropis rubellus
Bluntnose minnow	Pimephales notatus
Fathead minnow [c]	Pimephales promelas
Blacknose dace [c]	Rhinichthys atratulus
Longnose dace [c]	Rhinichthys cataractae
Creek chub [c]	Semotilus atromaculatus
Pearl dace [c]	Semotilus margarita
White sucker [c]	Catostomus commersoni
Northern hog sucker	Hypentelium nigricans
Brown bullhead	Ameiurus nebulosus
Banded killifish [c]	Fundulus diaphanus
Rock bass	Ambloplites rupestris
Redbreast sunfish	Lepomis auritus
Pumpkinseed	Lepomis gibbosus
Smallmouth bass [a]	Micropterus dolomieu
Largemouth bass	Micropterus salmoides
Black crappie	Pomoxis nigromaculatus
Tessellated darter [c]	Etheostoma olmstedi
Yellow perch	Perca flavescens

a Introduced from elsewhere in North America.
b Introduced from outside of North America.

Table 2

Fish kills in Spring Creek and tributaries in which more than 100 fish were reported or suspected killed. Information obtained from the Pennsylvania Fish and Boat Commission files.

Year	Pollutant and source	Number and type of fish	Location in Spring Creek or tributary
1952	Low dissolved oxygen in discharge from Bellefonte treatment plant	Hundreds of white suckers	Spring Creek downstream of treatment plant
1954	Warmwater effluent from West Penn Power Plant	~100	Spring Creek, Milesburg
1954	Waste discharge from Titan Metal Co.	Unknown number of several species	Logan Branch and 2.4 km of Spring Creek
1956	Sodium cyanide from Penn State University	147,072 hatchery trout and an unknown number of wild fishes	Benner Spring and Upper Spring Creek hatcheries; Thompson Run, Slab Cabin Run, Spring Creek
1958	Low dissolved oxygen linked to organic loading from Penn State University treatment plant and abundant plant growth	~2000 trout	Benner Spring hatchery
1963	Butyl alcohol discharge (~100 gal) from Nease Chemical Co.	1,500 trout, minnows, suckers	Downstream of Highway 26 bridge
1963	Butyl alcohol discharge (~175 gal) from Nease Chemical	1,600 of several species	Downstream of Highway 26 bridge
1965	Large discharge of toluene from explosion and fire at Nease Chemical Co.	Unknown number of several species	Complete kill of all fish for 2.4 km downstream of Highway 26 bridge
1970	Sewage discharge (130,000 gal) from UAJA	1,100 trout	Spring Creek downstream of treatment plant
1971	Spill from Nease Chemical Co.	6,000 trout	Downstream of Highway 26 bridge
1971	Toxic discharge from Nease Chemical Co.	Thousands of several species	Spring Creek downsteam of Highway 26 bridge for 4.0 km
1972	Fuel oil spill (2,700 gal) from Skat service station	>25,000 wild and hatchery trout	Downstream of Highway 26 bridge
1972	Unknown	>400 of several species	Thompson Run and Slab Cabin Run to Spring Creek
1988	Chlorine discharge from UAJA	>1,000 of several species	Downstream of UAJA outfall
1990	Chlorinated pool water from PSU discharged into Thompson Run	Unknown	Thompson Run and Slab Cabin Run to Spring Creek
2005	Low flow conditions and high temperatures	> 250 trout	Slab Cabin Run

Table 3

Numbers of hatchery-reared trout that were stocked in Spring Creek in sections where statewide regulations were in effect and in Fisherman's Paradise.

Statewide Regulations

	Trout Species			
	Brook	Brown	Rainbow	Subtotal
1931		400		400
1932		2560		2560
1933	960	6880		7840
1934		13520		13520
1935	800	6720	4620	12140
1936		4000	3440	7440
1937	2280	6040	6040	14360
1938	3280	8725	13590	25595
1939	2000	10800	7700	20500
1940	3500	5600	8900	18000
1941	5625	8800	11500	25925
1942	10100	9000	7200	26300
1943	7790	3750	1760	13300
1944	9000	12050	2350	23400
1945	6224	7845	3800	17869
1946	11750	13253	8138	33141
1947	16050	10550	7000	33600
1948	2800	24680	5500	32980
1949	11185	13460	14798	39443
1950	2800	23785	14665	41250
1951	400	21750	16100	38250
1952	6275	18190	21245	45710
1953	1803	17240	22257	41300
1954	10782	15967	17906	44655
1955	7450	15480	19231	42161
1956	19406	17213	18724	55343
1957	17393	9160	18301	44854
1958	1352	18030	10539	29921
1959	500	13545	13645	27690
1960	9030	7450	5850	22330
1961	18615	8355	2280	29250
1962	6650	24880	3945	35475
1963	0	23630	2680	26310
1964	2508	19305	5	21818
1965	6117	6804	1039	13960
1966	3999	14609	528	19136

Fisherman's Paradise

Trout Species				
Brook	Brown	Rainbow	Subtotal	Stream Total
				400
				2560
				7840
2122	4440	2125	8687	22207
1200	7261	244	8705	20845
	3320	805	4125	11565
473	3176	2039	5688	20048
421	1422	4879	6722	32317
	2250	2201	4451	24951
603	11543	2772	14918	32918
550	6170	5338	12058	37983
611	7149	6578	14338	40638
333	2158	535	3026	16326
1057	6911	137	8105	31505
6376	7773	2988	17137	35006
175	4990	5660	10825	43966
485	7881	6715	15081	48681
2485	5165	5135	12785	45765
75	8590	3800	12465	51908
75	6065	11685	17825	59075
405	6485	5570	12460	50710
130	8535	3870	12535	58245
225	8805	5370	14400	55700
200	7170	6610	13980	58635
795	5905	7365	14065	56226
1050	6250	8610	15910	71253
450	7225	8695	16370	61224
1320	8260	5135	14715	44636
400	7645	5235	13280	40970
365	5535	5905	11805	34135
960	6225	5165	12350	41600
375	825	100	1300	36775
36	400	464	900	27210
	825	75	900	22718
	1275	375	1650	15610
125	1490	75	1690	20826

a Number of trout requested to be stocked; actual number stocked is not available; species not distinguished.

Statewide Regulations

Trout Species				
	Brook	Brown	Rainbow	Subtotal
1967	4541	12961	2074	19576
1968	2515	21283	902	24700
1969	2470	24730	1079	28279
1970	500	15745	13620	29865
1971	4241	31203	11231	46675
1972	4430	15165	12530	32125
1973	2420	25700	5230	33350
1974	2760	17170	9320	29250
1975	1440	10068	14542	26050
1976	3100	11650	11300	26050
1977	2060	11800	7790	21650
1978	2500	3715	2485	8700
1979	20	4095	4185	8300
1980	540	2315	2845	5700
1981	100	2300	2500	4900
Totals				1292896

Fisherman's Paradise

Trout Species				
Brook	Brown	Rainbow	Subtotal	Stream Total
95	1295	310	1700	21276
35	1550	150	1735	26435
	1300		1300	29579
			1700[a]	31565
			1700[a]	48375
			1700[a]	33825
			1700[a]	35050
			1700[a]	30950
			1700[a]	27750
			1700[a]	27750
			1700[a]	23350
	715	1055	1770	10470
20	585	795	1400	9700
40	815	845	1700	7400
	450	450	900	5800
				1652252

aNumber of trout requested to be stocked; actual number stocked is not

Table 4

Fishery statistics for the specially regulated Fisherman's Paradise, 1934 - 1952.

Year	Number of anglers	Number of trout caught	Trout Harvested	
			Number	Mean weight (kg)
1934	2,952	4,729	2,472	0.25
1935	3,265	8,457	3,247	0.39
1936	6,513	8,467	2,663	0.43
1937	9,123	7,028	4,101	0.37
1938	12,932	13,662	4,796	0.46
1939	14,755	14,556	5,950	0.49
1940	16,891	18,750	8,149	0.47
1941	20,412	18,566	7,680	0.62
1942	16,629	20,133	6,448	0.54
1943	2,764	5,314	1,805	0.56
1944	12,300	12,471	5,895	0.49
1945	13,505	21,258	6,676	0.48
1946	21,882	29,906	9,469	0.60
1947	26,994	30,236	10,799	0.65
1948	28,566	50,683	6,670	0.76
1949	34,323	58,121	6,127	0.79
1950	34,796	76,197	8,057	
1952	44,034		8,999	0.91

Table 5

Density and biomass of age-0 and older fishes in Section 4 (RKa28.0), the clean reach, Section 9 (RK 18.4), the polluted reach, and Section 13 (RK 6.4), the recovery section in 1966. Brown trout include only wild specimens (Wohnsiedler 1969). Estimates of all other species were obtained from E. L. Cooper's files.

	Section 4		Section 9		Section 13	
Species	Number/ha	kg/ha	Number/ha	kg/ha	Number/ha	kg/ha
Brown trout	910	113.41	5	0.47	379	74.28
Common carp					1 [a]	
Cutlips minnow			25	0.56	596	4.04
Common shiner			72	0.56	798	15.13
Golden shiner			262	1.57	1 [b]	
Spottail shiner					400	4.04
Bluntnose minnow					259	0.34
Fathead minnow			198	0.56	20	0.11
Blacknose dace	29,650	31.83	3,623	16.03	1,310	4.15
Longnose dace	13,531	57.72	4,154	11.10	3,037	14.57
Creek chub			1,596	58.85	647	13.11
White sucker	6,501	757.70	1,707	294.79	5,960	851.85
Northern hog sucker					47	7.51
Brown bullhead					27	0.11
Pumpkinseed			57	0.04		
Slimy sculpin	85,473	291.09	10	0.01	845	5.72
Totals	136,065	1,252	11,708	385	14,327	995

a River kilometers from mouth of Spring Creek.
b Only one specimen was collected.

Table 6

Density and biomass of wild brown trout in Fisherman's Paradise, 1980 - 2000. VValues for age-0 brown trout represent the total number of captured during two electrofishing passes. Values for age-1 and older brown trout are based on population estimates.

Year	Age -0	Age -1 and older	
	Number/ha	Number/ha	kg/ha
1980	19	612	252
1981	1	386	150
1982	12	278	106
1983	101	396	80
1989	90	424	138
2000	423	1889	425
Median	55	410	144

Table 7

Density of wild brown trout in six sections of Spring Creek, 1980 - 2006. Values for age-0 brown trout represent the total number captured during two electrofishing passes. Values for age-1 and older fish are estimated numbers.

	1980		1988		2000		2006	
Section	Age 0	Age 1 and older	Age 0	Age 1 and older (Number/ha)	Age 0	Age 1 and older	Age 0	Age 1 and older
2	1399	291	348	861	233	1144	114	1034
4	358	310	416	927	1278	255	61	368
6	78	453	173	678			20	527
13	378	609	241	1327	456	1302	213	1563
15	20	56	180	827	332	1172	40	798
16	9	6	230	728	111	1418	22	1131
Median	218	301	236	844	332	1172	51	916

Table 8

Fishery statistics for three sections of Spring Creek. The 1976 survey extended from April 17 to June 20, and harvest was legal (Hartzler 1977). The 1988 - 1989 survey extended from June 1 to November 30, 1988 and from March 15 to May 31, 1989 (Carline et al. 1991). The 2006 survey extended from April 15 to June 30. Trout/hour and catch/hectare represent numbers harvested in 1976 and numbers caught and released in 1988 - 1989.

Year	Section	Angler-hour/ha			Trout/hour	Catch/ha
		Apr-Jun	Remaining months	All months		
1976	9	2,763			0.22	207
1988 - 1989	9	1,517	1,857	3,374	1.25	4,249
	12	1,714	1,666	3,380	0.77	2,765
	13	526	440	966	1.29	1,374
2006	12	3,209				
	13	1,363				

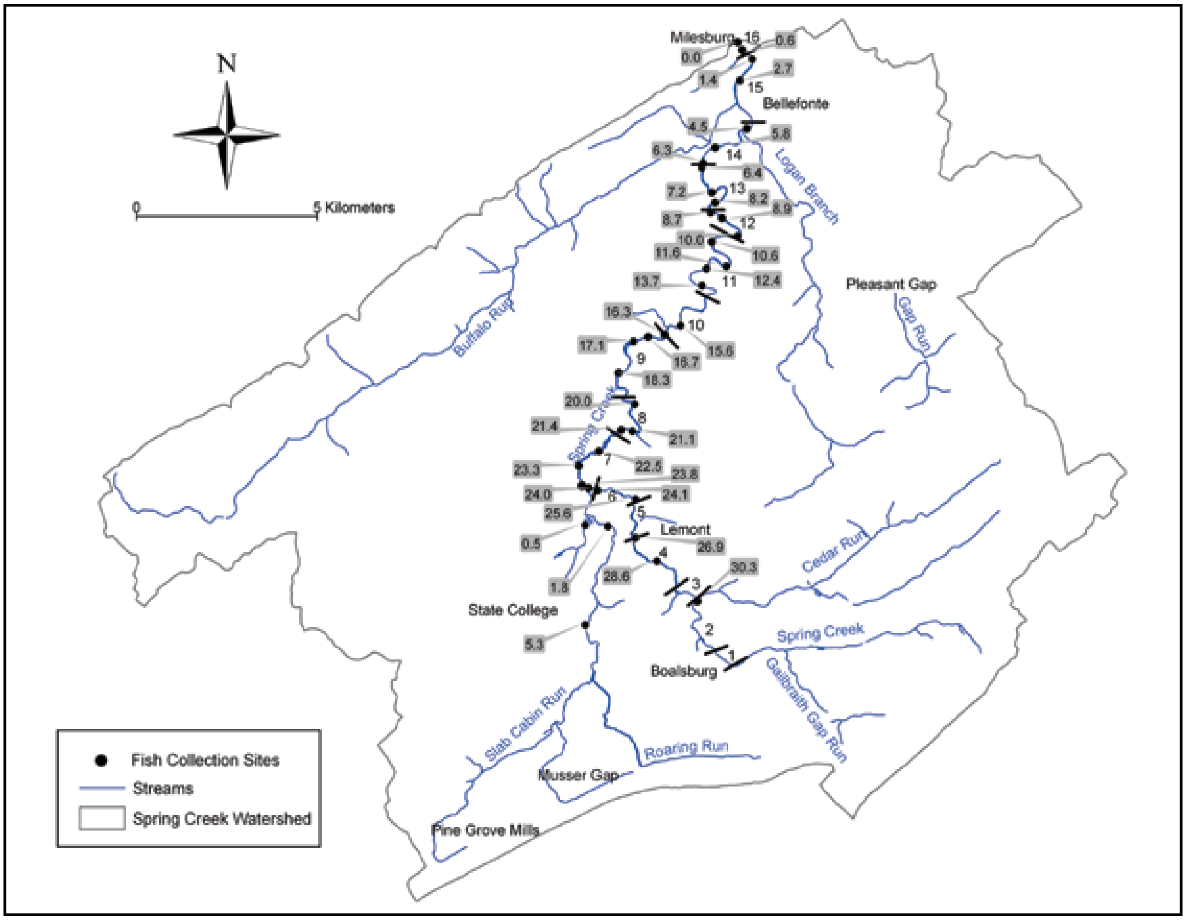
Table 9

Summary of Index of Biotic Integrity (BI) scores for 14 sites on Spring Creek. Impaired sites had an IBI score of >55. Length of impaired stream was computed from the midpoint between sites when IBI scores changed from unimpaired to impaired or vice versa. The percentage of impaired stream length was based on a total length of 27.7km. The percentage deviation of stream discharge was computed by using discharge data from the Axemann gage site on Spring Creek. IBI scores were taken from or computed from data in Hughey (2002, 2006), Meck (2004), and Ryder (2007).

Year	Mean IBI score	Number of impaired sites	Length of stream impaired		Percent deviation of stream discharge from long term average during 12 months prior to sample collection
			(km)	(%)	
2001	46.4	10	18.5	66.9	-26.3
2004	70.1	3	5.9	21.2	64.2
2005	66.3	4	7.2	25.9	84.9
2006	64.3	7	12.2	43.9	- 3.1

Appendix Figure 1

Locations of fish sampling sites (denoted as river kilometers, RK, upstream from the stream mouth) on Spring Creek and tributaries.



Appendix 1

Fishes captured with electrofishing gear in spring Creek and tributaries by E. L. Cooper in 1958 and 1959. Numbers of fishes in Section 4 are estimated populations based on mark-recapture techniques.

	Spring Creek											Slab Cabin Run		Thompson Run
Section	4	6	7	8	9	9	10	11	11	12	13			
River kilometer	27.95	24.20	22.46	21.14	18.28	17.11	16.28	15.60	11.61	9.90	6.32	0.02	1.75	0.42
American eel							2a	>3[b]	>7	C				
Rainbow trout	1													
Brown trout	404	A	C	4	4	2	8	>3[b]	>35	C	15	10	2	
Brook trout	2				1		8[a]	>10[b]	>16[b]	C		3		
Northern pike														
Central stoneroller														
Goldfish														
Common carp														
Cutlips minnow	1	7	4		2		1	30	12	14	36			
Common shiner				1	11		7	44		6	16		8	
Golden shiner														
Spottail shiner														
Rosyface shiner														
Bluntnose minnow														
Fathead minnow			1											
Blacknose dace	1,970	57	40	26	24	93	13	170	43	32	68	68	55	1
Longnose dace	200	11	5	12	8	18	22	12	5	20	52	4	25	
Creek chub	2	2	18	13		1	1	5			13	43	23	1
Pearl dace	199			1								1		
White sucker	1,577	15	1	5	5	5	10	17	A	A	166	26	63	
Northern hog sucker														
Rock bass														
Redbreast sunfish														
Largemouth bass														
Tessellated darter		3						1	2		2		13	
Slimy sculpin	A	27		4	5	16	53	6			3	1		

a Hatchery-reared
b Several with adipose clips indicating hatchery origin

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Appendix 2

Fishes captured with electrofishing gear in Spring Creek and Thompson Run by E. L. Cooper in 1966.
Abundant = A

	Spring Creek																	Thompson Run
Section	5	6	6	7	8	8	9	9	12	13	13	13	13	14	14	16	16	
River kilometer	25.53	23.96	23.86	22.46	21.14	19.91	18.28	16.77	8.91	8.24	7.25	6.45	6.42	5.86	4.46	1.37	0.00	0.39
American eel																	2	
Rainbow trout								6[b]		1	1							
Brown trout	ca. 50[a]	ca. 15[a]	11	20		24[a]	4[b]	94[b]	A	25a	158a	83a	A[a]	A[a]	1a		Few	
Brook trout						17[a]		4[b]	1	1								
Northern pike															1			
Central stoneroller																	2	
Goldfish					1													
Common carp									1					3				
Cutlips minnow					2	9	8	3	9	8	9	7		6			4	
Common shiner			1				9	8	6	13	12	3	5	8	10		12	12
Golden shiner			1	1	4	1	4	2		4	2				1			
Spottail shiner									2			2	1	5			4	
Rosyface shiner																	10	
Bluntnose minnow									3		11	1	12	17	16		1	
Fathead minnow							13		11	11	3				2			1
Blacknose dace	18	19	6	5	3	2	24	7	12	22	16	9	15	6	1	2	1	7
Longnose dace	8	21	10	16	4	3	15	5	4	11	18	2	9	6			9	16
Creek chub	4	9	6	8	2	13	15	7	7	3	30	4	18	4		1		9
Pearl dace		1		2														
White sucker	7	1	4	9	3	9	14	7	26	9	27	2	13	5	10	5	6	5
Northern hog sucker										1	2			1				
Rock bass																	1	
Redbreast sunfish								1										
Largemouth bass									1						2			
Tessellated darter																	3	
Slimy sculpin	26			2		5				1	7	1	28					

[a] Includes age-0 fish
[b] Hatchery reared

Appendix 3

Fishes captured with electrofishing gear in Spring Creek by Pennsylvania Fish and Boat Commission and Pennsylvania Cooperative Fish and Wildlife Research Unit personnel, 2000.

Spring Creek													
Section	1	2	4	7	8	9	11	11	12	12	13	15	16
River kilometer	32.09	29.95	27.37	23.50	21.69	18.41	13.23	12.18	10.53	8.67	6.42	2.61	0.60
American eel													
Rainbow trout					4[b]				6[b]	2[b]	x	13[b]	2[b]
Brown trout	272[a], 2[b]	134[a]	378[a]	141[a]	91[a]	201[a]	360[a]	649[a]	710[a]	538[a]	496[a]	554[a]	459[a], 3[b]
Brook trout													
Northern pike													
Central stoneroller													
Goldfish													
Common carp							x			x	x		x
Cutlips minnow				x	x	x	x	x	x	x	x	x	x
Common shiner													
Golden shiner													
Spottail shiner													
Rosyface shiner													
Bluntnose minnow													
Fathead minnow													
Blacknose dace				x	x	x	x	x					
Longnose dace				x		x	x	x	x	x	x	x	x
Creek chub													
Pearl dace													
White sucker	x	x	x	x	x	x	x	x	x	x	x	x	x
Northern hog sucker													
Rock bass													
Redbreast sunfish													
Largemouth bass													
Tessellated darter					x								
Slimy sculpin	x	x	x	x	x				x	x	x		
Pumpkinseed							x	x	x	x	x	x	x
Black crappie													x
Smallmouth bass													x
Yellow perch													x

[a] Includes age-0 fish
[b] Hatchery reared

Appendix 4

Numbers of trout redds counted in Spring Creek during the last two weeks of November.

Spring Creek									
Section	Year								
	1987	1988	1997	1998	1999	2000	2002	2004	2005
1	23	30	28	8	2	2	31	37	2
2	92	114	43	17	24	31	171	79	3
3	35	50	15	29	19	18	37	56	14
4	71	103	57	109	35	139	71	142	73
5	56	73	5	38	2	39	34	26	60
6	42	38	17	14	30	36	46	123	88
7	23	9	47	32	36	38	75	52	109
8	20	14	19	35	15	42	116	248	36
9	16	39	128	156	143	193	259	234	143
10	26	38	83	48	98	157	162	79	44
11	12	7	123	190	199	337	80	152	110
12	19 [a]	135	158	195	143	243	150	196	443
13	165	157	142	161	127	135	260	264	251
14	77	61	137	90	134	89	176	97	267
15	37	51	49	35	49	107	162	194	142
16	50	15	33	22	45	44	85	98	57
Totals	**745**	**934**	**1084**	**1179**	**1101**	**1650**	**1915**	**2077**	**1823**

[a] Surveyed before peak spawning