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Habitat Analysis by Hierarchical Scheme and Stream Geomorphology

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HABITAT ANALYSIS BY HIERARCHICAL SCHEME AND STREAM GEOMORPHOLOGY

Thesis submitted to
The Graduate College of
Marshall University

In partial fulfillment of the
Requirements for the degree of
Master of Science
Physical Science

By

James B. Spence

Dr. Thomas Jones, Committee Chairperson
Dr. Michael Little
Dr. Pam Edwards

Marshall University

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ABSTRACT

"Habitat Analysis by Hierarchical Scheme and Stream Geomorphology"

By James B. Spence

A study was undertaken to classify eight stream reaches in the North Branch of the Potomac River watershed and determine if geomorphologic differences influenced the availability of fish habitat structure and fish density. Stream reaches were classified using Rosgen Level II (1996) methods, and fish habitat was determined using Hydraulic Channel Unit (HCU) classification based on a method modified from Bisson et al. (1982). Other habitat variables were also studied such as stream shading and physical habitat based on the Rapid Bioassessment Protocol (Barbour et al. 1999). Despite the differences in HCU density between sites, HCU density did not influence fish density in the study streams. HCU density appeared to be mainly controlled by slope. Fish densities were highest in the relatively unimpacted streams, as expected. However, the impacted streams also appeared to have sufficient physical fish habitat structure to support fishes historically found in these streams. Other confounding variables, such as acid mine drainage, may be controlling factors in inhibiting fish populations in the impacted streams.

DEDICATION

The author wishes to dedicate this thesis to my wife Julie and my daughters Hannah and Olivia. I restarted my college career 7 days after we got married and have worked full-time and gone to school since. Her patience and support cannot be expressed in words.

ACKNOWLEDGMENTS

The author wishes to acknowledge Dr. Tom Jones for all of his help in preparing this thesis and during the field work, especially during the initial stages. Also invaluable was the support provided by Dr. Mike Little throughout the study. I also would like to especially thank Noah Kennedy for all of his help in completing the field work. I would like to thank Keith Donahue, Adam Cottrell, Joe Hughes and Doug for providing additional help during the field work. Thanks also to Dr. Edwards for her review and for participating on my committee. I would also like to thank Dr. Ralph Taylor and Mr. Barry Passmore for serving as adjunct committee members. Especially appreciated is the funding and support by Dominion Power through the dedication of Mr. Bill Bolin, Mr. Frank Massie and Ms. Kristin Edwards. Finally, much thanks is due to Wanda Dyke for making sure everything ran smoothly..

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Chapter I. Introduction

Project Background

The Stony River below Mt. Storm Lake has experienced land use effects due to previous mining and timbering in the watershed, among others. As such, the fish fauna in the stream has seen a serious decline in the past 30 years, especially below the confluence of the river with Fourmile Run (Figure 1.2) (WVDEP 1997). Past mining has introduced acid mine drainage (AMD) into the stream, and consequently fish populations have been kept low to non-existent below Fourmile Run.

The possibility exists for river rehabilitation/restoration below the dam at Mt. Storm Lake. As part of the baseline study for possible restoration of a fishery in this location, this study was initiated to look at physical fish habitat availability using a hierarchical system and geomorphology of the river.

The main goal of this study as part of the possibility of restoring the upper Stony River below the Mt. Storm Lake dam was to compare three reach types in the Stony River:

- Below dam outfall with minimal mine impairment;
- Mid-reach mine-impaired;
- Lower reach with reduced gradient with
- Two structurally similar streams with similar gradient and geology and
- Two streams sustaining diverse fish faunas.

In comparing these streams, care was taken to choose reaches within the North Branch of the Potomac River watershed as close as possible to the Stony River. For this study, only streams in the West Virginia portion of the North Branch of the Potomac River watershed were chosen (Figure 1.1). Pre-study scouting identified four reach locations on the Stony River for comparison, two structurally similar streams (Abram Creek and Difficult Creek), and two streams with historically diverse fish faunas (New Creek and North Fork Patterson Creek) (Figure 1.2).

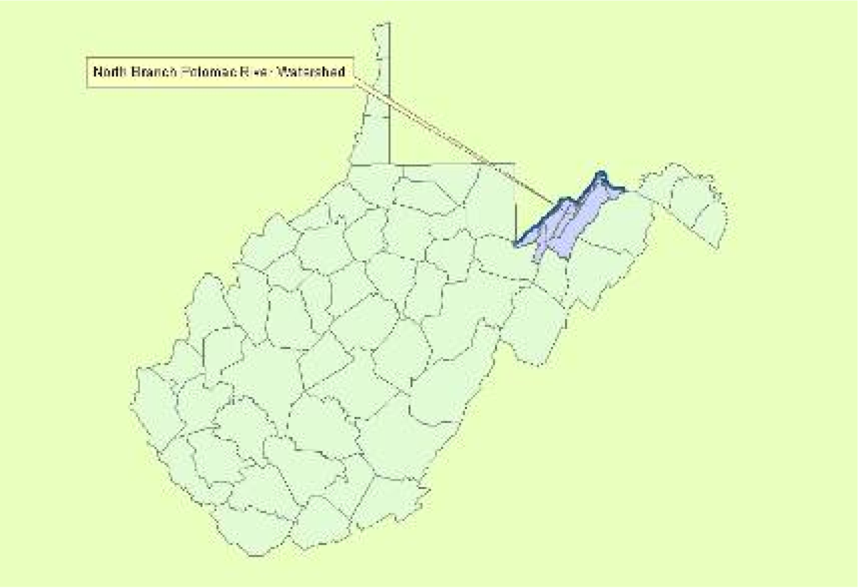

Figure 1.1. North Branch Potomac River Watershed in West Virginia.

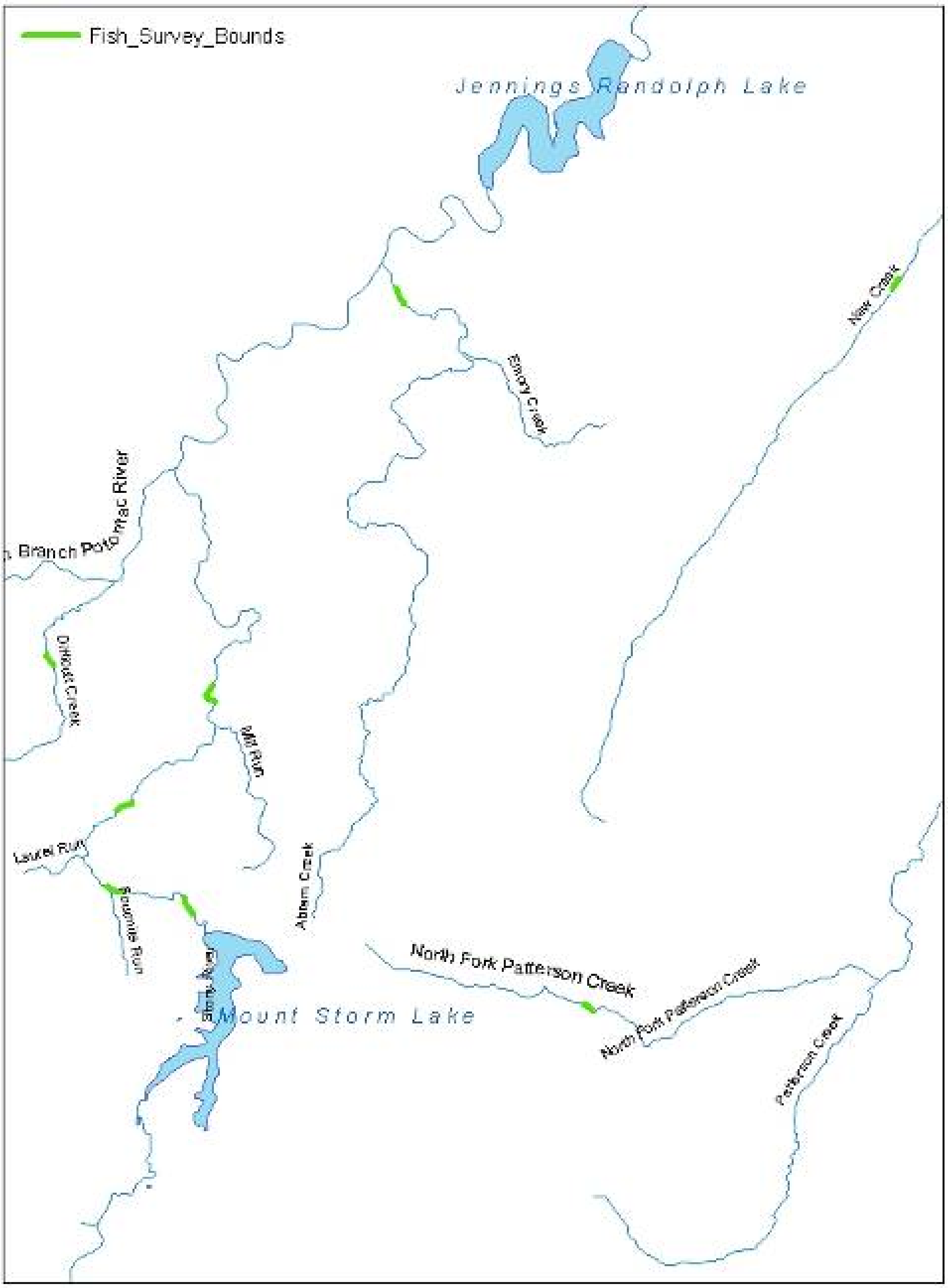

Figure 1.2. Study Locations and Streams.

Study Area

The North Branch Potomac River watershed contains approximately 3,450 km^2 in West Virginia (WVDEP 1997). This main stem of the river has been impacted by paper production, beginning with the construction of the paper mill at Luke, Maryland in 1888. The Stony River, among other streams in the area, was impounded on the upper portion (Stony River Reservoir) in order to supply water to the pulp mill at Luke, and in 1965 Mt. Storm Lake was constructed to provide water for cooling the existing Dominion power plant. Coal mining in the Stony River watershed traditionally supported this plant, although most of these mines have been reclaimed or are in some stage of reclamation. Past timbering and coal mining has contributed to the degradation of the Stony River and its traditional trout fishery (WVDEP 1997). Both the Stony River and Abram Creek have been listed as impaired due to dissolved aluminum (WVDEP 2004).

While strip mining has impacted the streams west of the Allegheny Front (in this study, Stony River, Abram Creek and Difficult Creek), most of the remaining land use in the watershed is forest, with small areas of agricultural production (WVDEP 1997). East of the Front, the New Creek and Patterson Creek watersheds support forest and more extensive agricultural production. The relatively flatter valleys of the Ridge and Valley province of the watershed are more conducive to agriculture, especially poultry production.

The western portion of the study watershed is part of the Allegheny Highlands province of the Central Appalachians ecoregion, while the eastern portion is consisted of the Northern Ridge and Valley province of the Central Appalachians Ridges and Valleys ecoregion. The Allegheny Front is a major geologic formation forming the edge of the Appalachian Plateau. This northeast to southwest running formation forms the western boundary of the Ridge and Valley province, and also separates the Allegheny Highlands province from the Ridge and Valley. Most of the Allegheny Highlands province is underlain by Pennsylvanian age rocks (280 – 310 mya) consisting of layers of sandstone, shale, clay, coal, and limestone (Cardwell et al. 1968). The coal in this region is considered low volatile bituminous. This province is a part of the Appalachian Plateau geomorphic province, consisting of a dissected plateau with high, sharp ridges, low mountains, and narrow valleys (McNab and Avers 1994). The Stony River, Abram Creek and Difficult Creek all have watersheds in this province.

As its name implies, the Northern Ridge and Valley province is characterized by long ridges separated by relatively wide, flat valleys, underlain by alternating layers of shale and sandstone. Bedrock in this region has been intensely faulted due to folding during creation of the Appalachian Mountains. The majority of the watershed in the Ridge and Valley province consists of Devonian age rocks (345 – 405 mya) consisting of layers of sandstone, shale, limestone and chert. This area of the watershed is also partially underlain by karst-like features consisting of Silurian age (405 – 425 mya) and Mississippian age (310 – 345 mya) rocks. None of the great glaciers reached West Virginia, and erosion has been the dominant geologic process since the Permian Period when the Appalachian Mountains were formed (Cardwell et al. 1968). New Creek and Patterson Creek have their watersheds within the Northern Ridge and Valley Province.

In the Ridge and Valley province of West Virginia, average annual precipitation ranges from 36 to 55 in (920 to 1,400 mm), while temperature ranges from 55º to 61º F (13º to 16º C) (McNab and Avers 1994). In the Allegheny Mountains, precipitation averages typically range from 45 to 60 in (1,140 to 1,520 mm) per year, with about 20 percent of this consisting of snow (up to 30 percent at higher elevations). Mean temperatures range from 39º to 54º F (4º to 12º C) (McNab and Avers 1994).

Previous research has indicated most of the freshwater fauna of the upper Potomac River watershed was generated through stream captures from the Monongahela River system to the west and the James River drainage to the south (Stauffer et al. 1978). Stream capture was facilitated by development of elongated streams along the synclinal formations of the Ridge and Valley province, and once landforms typical of the Appalachian Mountains were encountered, streams developed a more dendritic pattern.

The Stony River is a third order stream throughout the study area, along with Abram Creek and New Creek. The North Fork of Patterson Creek is a fourth order stream, while Difficult Creek is second order. All of the stream sections sampled in this study have relatively similar watershed sizes except for Difficult Creek and North Fork of Patterson Creek (Table 1.1).

Table 1.1 General Reach Information

Stream	Site	Reach Length (m)	Channel Widths Length	Mean Bankfull Width (m)[a]	Bankfull Width SDEV	Reach Area Mean (m^2)[b]	Reach Area SDEV	Watershed (km^2)[c]
Abram Creek	AC	574	27.3	21.03	2.80	12069	1608	112.1
Difficult Creek	DC	438	32.9	13.33	1.24	5839	544	15.2
New Creek	NC	428	26.7	16.04	1.05	6866	448	92.3
North Fork Patterson Creek	PC	409	30.6	13.35	1.56	5461	638	54.5
Stony River	SR1	601	26.2	22.95	3.75	13791	2256	83.6
Stony River	SR3	565	29.7	19.03	3.83	10753	2165	99.5
Stony River	SR4M	616	29.2	21.12	3.68	13012	2266	89.1
Stony River	SR4	767	33.2	23.07	3.19	17697	2446	126.5

[a] Based on field-measured bankfull widths
[b] Determined by multiplying mean bankfull width by reach length
[c] As measured from most downstream location of reach

Rosgen

In order to develop habitat comparisons among reaches, two main study components were used: hydraulic channel unit habitat classification and Rosgen methods as described in Rosgen's Applied River Morphology (1996). The Rosgen methodology allows for classification of stream reaches based on several factors. For this study, Level II classification methods were used. This Level uses sinuosity, width/depth ratio, entrenchment ratio, pebble count data, and slope to determine the Level II stream type.

Rosgen's methods require hierarchical nesting of stream types within the parent valley types (Rosgen 1996). The criteria used to characterize streams at Level I include plan-view morphology, cross-section morphology, channel sinuosity, channel slope, and bed features. Channel sinuosity is a primary indicator of channel type at Level I, and is the ratio of the stream channel length to down valley distance. The plan-view morphology provides a more general description of sinuosity, ranging from relatively straight to torturously meandering to complex stream patterns (braided). Cross-section morphology at Level I generally describe the relationship of the stream channel to the presence and extent of a floodplain, and describe the entrenchment of the stream within its channel. Bed features are related to channel slope, and describe general in-stream habitat features, from cascades and step-pools to riffles, rapids, and scour pools. Bed features are inferred from channel slope and channel sinuosity.

Level II classification involves field measurements of several parameters, noted above. One of the most important aspects at Level II as described in Rosgen (1996) is the identification of at least one "reference reach" for each Level I channel type. Rosgen recognized Level II classification might apply to reaches from tens of meters to a few kilometers. The identification of reference reaches becomes especially important when making extrapolations to other reaches with similar valley and geology types.

At Level II, entrenchment is actually determined based on filed measurements at reference cross-sections, and indicates the degree of incision of the stream within its channel and the ability of the stream to reach or maintain a floodplain (Rosgen 1996). The value for entrenchment ratio is the flood-prone area width (measured at twice the bankfull maximum depth) to the bankfull width. Width/depth ratio, measured as bankfull width divided by mean bankfull depth, is used as a descriptor of energy dispersion within the channel. This process determines the amount and size of bedload movement within the stream. Channel materials as determined from pebble counts further describe the availability and influence of certain substrate sizes. Channel slope is actually field measured at Level II. Sinuosity is determined using the same methods as at Level I.

Stream Habitat

Stream habitat has long been recognized as a primary influence on distribution of both macroinvertebrates and fishes. Most management plans for rivers and streams include some aspect of habitat management, whether it is preservation of existing "good" habitat, or restoration/rehabilitation of a particular stream to improve habitat. In order to manage habitat, many studies have been initiated to determine particular species' habitat preferences, and overall quality of stream habitat to assemblages and communities as a whole. These studies have ranged from region-wide and basin-wide studies, to studies of microhabitat use at the sub-meter level or below.

In this study, attempts were made to nest stream habitat within the particular geomorphologic setting of the sample streams. This study used a particular type of habitat classification to identify units below the traditional riffle/pool level of classification. Other studies have used various levels and parameters to determine the appropriate scale for these types of studies (see Chapter II). Hydraulic channel unit classification methods were based on Bisson et al. (1982). However, different authors have subsequently adapted these classifications to particular studies and study objectives (e.g. Bryant et al. 1992). These previous studies found particular fish associations with specific channel units as significant.

Bisson et al. (1982) recommended 100-m stream reaches for conducting detailed habitat mapping and hydraulic channel unit classification. However, they also recognized the benefit of providing rapid inventory of habitat types without dimensional measurements to characterize longer stream reaches.

Fish Surveys

To further develop the framework for comparison of habitats among reaches, fish surveys were used. These fish surveys (for total fish numbers, or density) would be used to compare reaches in order to determine if observed habitat differences correlated with observed fish densities. An important aspect of this study was no water quality data (chemistry) was taken during the fieldwork. In that way, only physical fish habitat would be compared between reaches regardless of existing water quality. The identification of physical habitat types within the Stony River reaches, especially the upper section below Mt. Storm Lake, would possibly facilitate management goals for restoration of the fishery. The presence of particular physical habitat parameters also may allow specific fish species to be chosen as stock to restore the fishery.

Although fish were not identified in the surveys for this study, previous work has indicated historical species' use of all of the streams in this study (see Table 1.2). In addition to this information, New Creek and North Fork Patterson Creek are stocked with trout twice in February, once in January, and once per week between March and May by the West Virginia Department of Natural Resources. In addition, the North Branch of the Potomac River is also stocked with trout once per month between February and May.

Table 1.2. Traditional Fish Species by Site[a].

Species	AC	DC	NC	PC[b]	SR1	SR3	SR4M	SR4	Stony R. (below Mt. Storm Lake)
Ambloplites rupestris	X			X					X
Campostoma anomalum			X		X		X	X	X
Catostomus commersoni	X		X		X		X		
Cottus bairdi	X	X	X						X
Cottus girardi			X	X					
Cyprinella spiloptera				X	X		X	X	X
Ericymba buccata				X					
Esox niger				X					
Etheostoma blenniodes									X
Etheostoma flabbelare	X		X						X
Exoglossum maxilingua	X			X					X
Hypentelium nigricans			X						X
Ictalurus punctatus					X		X		
Lepomis cyanellus					X				X
Lepomis gibbosus			X						
Lepomis macrochirus			X						X
Luxilus chrysocephalus									X
Luxilus cornutus	X		X	X					
Micropterus dolomieu			X		X		X	X	X
Micropterus salmoides			X				X		X
Nocomis micropogon									X
Notemigonus crysoleucas				X					

Species	**AC**	**DC**	**NC**	**PC**[b]	**SR1**	**SR3**	**SR4M**	**SR4**	**Stony R. (below Mt. Storm Lake)**
Notropis rubellus			X	X					X
Oncorhynchus mykiss			X						
Pimephales notatus									X
Rhinichthys atratulus	X		X					X	X
Rhinichthys cataractae			X	X					X
Salvelinus fontinalis	X	X							
Semotilus atromaculatus	X		X		X		X	X	X
Semotilus corporalis				X					

[a] All records based on Fishes of West Virginia (Stauffer et al. 1995) except SR1, SR4M, SR3, and SR4, where records are from previous Dominion Power studies.

[b] Records from Stauffer et al. (1995) taken in main stem of Patterson Creek immediately upstream and downstream of mouth of North Fork

In a study of stream fish assemblages in the Mid-Atlantic Highlands area (which includes the study area), McCormick et al. (2000) found most taxonomic groups in these streams were dominated by 1 or 2 taxa, including blacknose dace (*Rhinichthys atratulus*), creek chub (*Semotilus atromaculatus*), white sucker (*Catostomus commersoni*), slimy sculpin (*Cottus cognatus*) and brook trout (*Salvelinus fontinalis*).

Purpose of Project

As indicated above, the main goal of this study was to supply information for the possibility of restoring the upper Stony River below the Mt. Storm Lake dam was to compare three reach types in the Stony River:

1. Below dam outfall with minimal mine impairment;
2. Mid-reach mine-impaired;
3. Lower reach with reduced gradient with

- Two structurally similar streams with similar gradient and geology and
- Two streams sustaining diverse fish faunas.

Chapter II. Literature Review

Stream Geomorphic and Habitat Classification

Stream habitat studies have been a part of freshwater aquatic research for many years, and in recent times, researchers have recognized the importance of placing the stream into its geologic and climatic setting to provide a framework for comparison. Hierarchical systems, where streams are first classified by geologic setting or ecoregion, are fast becoming essential foundations upon which all subsequent studies are based. Kondolf (1995) recognized a hierarchical framework provided information indicating streams with similar lithology, geomorphology and land use belong to particular classes. He recognized a progression from the catchment (or watershed) scale down through particular stream segments, reaches, pool/riffle units, and microhabitats. He also indicated geomorphological characteristics vary in a continuous fashion across all stream channels, and one geomorphic-based system may be just as valid as any other, and any classification system involves drawing arbitrary lines between classes, which may or may not result in significantly different stream classes. He indicated the best models gather data on channel pattern, sinuosity, dimension and gradient; bed material sizes; alluvial versus bedrock controls; and watershed variables including drainage area, basin relief, lithology, valley gradient and/or annual rainfall. Finally, he warned against lumping channels into the nearest "class," indicating channels should be classified as they are.

Bisson et al. (1982) provided a basis for classifying habitat units within particular streams. Their study has spawned numerous classification systems, some based solely on visual parameters, others incorporated into the measurement of physical parameters, such as surface area, substrate type, etc. Their study was initiated based on previous work indicating fish tend to use specific habitats generally based on cover type and depth. They provided descriptions of the various habitat types, and also attempted to sketch examples that would facilitate future use of their system. One important aspect of their system was the incorporation of cover types that provided a second level of classification beyond the traditional pool or riffle. The drawbacks of their systems when applied to later studies included the scale of their study streams (small, low order) and the geographic location (Pacific Northwest), where certain cover types were more prevalent. For instance, they found secondary channel pools were not utilized during the summer due to isolation from the main channel. In addition the fish in the study streams were dominated by Pacific Northwest salmonids (cutthroat trout, coho salmon, steelhead trout). However, they did note significant preferences of habitat unit types by both species and age classes of the fish in their study.

Other workers have utilized the hierarchical framework across the world, including the River Styles classification system used in Australia (Thomson et al. 2001). This method recognizes that in-stream habitat variability is determined by the interaction of channel morphology and substrate characteristics along with discharge, and hydraulics within the channel are influenced by channel cross-section shape, bed roughness and bed slope, among other variables. Basin factors such as sediment supply and flood history in turn influence all of the above. Beginning at the basin scale, streams are first characterized by valley type ("confined" (no floodplain), "partly confined" (discontinuous floodplain) or "alluvial" (continuous floodplain)), similar to Rosgen's Level I framework (1996). Classification then proceeds through the reach, geomorphic unit (riffle, pool, and glide) to the hydraulic unit. In follow-up research using Thomson et al.'s (2004) system, they found the variability of macroinvertebrate use among geomorphic units was best explained by variability in substrate and hydraulic variables, including Froude number, Reynolds number, shear velocity, and roughness. Substrate composition, as measured using the mean phi scale, provided the most consistent differences among classes. They theorized based on previous research this was due to the influence of stream power on particle size, with valley confinement in turn influencing stream power. They also recognized although macroinvertebrate assemblages were not strongly related to geomorphic units, the mobility of fish might provide stronger associations to these units. The overlap among some geomorphic units (such as pools with fast-flowing water to runs with margins of slow-flowing water) enhances the difficulty in separating some units, even based on quantitative variables such as the ones measured in their study. Runs may be merely extensions of adjacent pools (Rowntree and Wadeson 1999 in Thomson et al. 2004).

In classic geomorphological study, it has long been recognized pool areas are generally areas of scour while riffle area are depositional during flood events, while riffles are erosional areas during low flows and pools become depositional (Leopold et al. 1964, Frissell et al. 1986, Peterson and Rabeni 2001a). As such, physical characteristics of any identified channel unit will change with changing discharge. For instance, backwater pools can transition into secondary channel pools into main channel scour pools with increasing discharge. Other studies using some form of channel unit classification have noted these distinctions. In a hierarchical system, watershed variables influence the size and shape of channel units. For instance, Peterson and Rabeni (2001a) found the higher channel slope at one site translated into channel units with larger substrate sizes than the equivalent units on another site. In addition, they found the scale of channel units changed with watershed size. However, as discussed in the results of their study, they found no difference in fish densities within equivalent channel units between the two sites (Peterson and Rabeni 2001a).

Another hallmark paper on the hierarchical framework for stream studies was published by Frissell et al. (1986). They recognized stream slope might change drastically over geologic time, being influenced by climate, geology, initial relief, and time, but on a smaller temporal scale, stream slope can also significantly influence the potential pool/riffle morphology of a particular reach. They illustrated this hierarchy not only in a spatial scale (stream system, segment system, reach system, pool/riffle system, and microhabitat system), but also in a concordant temporal scale, indicating the rate of change expected of the preceding systems based on their persistence through time (ranging from 1 million years to less than 1 year, declining logarithmically). They defined a stream system as all the streams within a particular watershed with a linear scale of approximately 1,000 m, indicating all the stream systems within a particular physiographic province with similar geologic structure should have similar network structures. A segment system was the portion of a stream system flowing through a single bedrock type and delineated by tributary junctions or waterfalls. Reaches could be separated by breaks in channel slope, local sideslopes, valley floor widths, riparian vegetation, or bank materials, and could range in size from meters to hundreds of meters, depending on stream order. They used an amalgamation of previous studies to identify riffles (areas of deposition at high flow, erosion at low flow) and pools (areas of erosion at high flow, deposition at low flow). The persistence of a particular feature was dependent on the associated geomorphic structure (e.g., bedrock vs. boulder vs. woody debris), and the pools/riffles associated with less stable geomorphic features were less resilient and less resistant to flows approaching the mean annual flood level. They defined microhabitat as patches within pools or riffles with similar substrate types, waters depths, and velocity, and indicated the usefulness of studies at this scale for investigation of the behavioral ecology of fishes.

Frissell et al. (1986) recommended classification variables should be those that are the most general, invariant and causal to determine the behavior of any system. At the microhabitat scale, he indicated the classification scheme should recognize the habitat's origin and development as well as its present characteristics in addition to its larger-scale environment (pool vs. riffle). On a temporal scale, these microhabitats were usually disturbed once annually. The persistence of a substrate patch is the most important determinant of a microhabitat unit's capacity as a stream habitat. Although most microhabitat classification systems were geared primarily for third order or lower streams, the relative hierarchical relationships remain intact even in the largest rivers, although habitat in many large rivers may depend more on upstream influences and less on streamside characteristics.

Hawkins et al. (1993) also attempted to present the hierarchical stream classification system. However, their hierarchical system started at the analogous pool/riffle level, disregarding upper level geomorphic influences. They defined channel units as somewhat discrete areas with relatively homogeneous depths and flow, bounded by sharp physical gradients, formed by interactions among discharge, sediment load and channel resistance to flow. They asserted at this level, biota and their processes exhibited distinct patchiness. Identified habitat types should be discrete, equally accessible and recognizable by the organism(s) of interest in order to calculate selectivity. They used a three-level classification system to distinguish habitat units (termed "channel geomorphic units") based primarily on flow velocity, then turbulence, and then various distinguishing characteristics such as local slope, channel location, and structure influence. Fast water areas were separated from slow water areas at the first level. Fast water was subdivided into turbulent versus non-turbulent, while slow water was subdivided into scour pools and dammed pools. Turbulent fast water units were described as falls, cascades, rapids, riffles and chutes, and non-turbulent units were split between sheets and runs. Sheets were described as shallow water flowing over smooth bedrock. As has been discovered by many researchers using habitat unit classification, glides were often the most difficult to define, and were best described as extended transitional areas between fast and slow-water units. Scour pool slow water units were described mainly based on channel position: eddy, trench, mid-channel, convergence, lateral and plunge. Dammed pool slow water units were divided based on structure association: debris, beaver, landslide, backwater, and abandoned channel. An important observation by Hawkins et al. (1993) is the transition of habitat units based on flow. As discussed above, pools and riffles switch roles depending on flow stage, and habitat units change character, also often based on flow. They also indicated channel units in larger streams may comprise several smaller scale habitat patches that are physically and biologically similar to entire units in small streams.

Schlosser (1995) found certain landscape factors influenced fish populations in smaller, headwater streams. In an extensive literary review, he demonstrated portions of a landscape (or stream reach) where different habitat types are in close proximity would tend to support higher densities of fish than landscapes where they are farther apart. He provided evidence for including scale-dependent landscape attributes in developing conceptual fish models, including the effects of different life-stages of the particular fish under study.

McKenney (1997) used a multi-tiered classification system in her study of Ozark Plateau streams in Arkansas and Missouri. Streams were first classified by valley type, and valley types were classified by valley sinuosity. Valley sinuosity was calculated as the ratio of the length of valley meander to the straight-line distance between the two points. The hierarchical system is comparable with methods used by Rosgen (1996) and the present study. Most of her study focused on the common meandering valley streams present in the plateau region of the Ozarks. Interestingly, in her description of straight, narrow valleys, she indicated although the valleys are narrow, very few stream-valley wall collisions occur and the streams tend to flow down the center of the valley with well developed alternate bars (compare Figure A61 with Figures A5, A9, A11, etc.). Wide straight valleys tend to have the streams flowing along one valley wall, indicating channel patterns are apparently stabilized by the valley wall (Miller and Jacobson 1995 in McKenney 1997) (compare Figure A3).

McKenney (1997) classified Hydraulic Habitat Units (HHUs) based on position of unit at low flow: main flow versus marginal (analogous to secondary and side channels). Main flow HHUs were then subdivided based on gradient (high > 0.075%; low ≤ 0.075%) whereas marginal HHUs were subdivided based on persistence of flow (ephemeral versus permanent). For high gradient HHUs, she used particle size to flow depth relationship to separate “alluvial riffles” from “tributary riffles,” with tributary riffles dominated by cobble-boulder where alluvial riffles were dominated by gravel-cobble. She also added “bedrock riffle” and “race” to high gradient HHUs. She described race as a convergence of flow downstream of a riffle with particle size dominated by cobble and gravel. “Alluvial cutbank pools” were located on the outsides of bends, normally associated with coarse woody debris. “Mid-channel pools” were generally found to be bank-to-bank since these were mainly large, still pools in her work. “Obstruction pools” were the most general of her main flow pool types in that they were associated with scour around some channel obstruction. “Glides” were considered to have velocities similar to pools due to their low gradients which separated these areas from races. Glides were often difficult to separate from pool areas due to stage dependence of her depth and velocity criteria.

McKenney (1997) did not separate marginal habitats by indicating side channel versus secondary channels. She indicated marginal ephemeral units would dry up during extended low flow stages while at high flow stages they became part of the main channel. She separated both ephemeral and permanent HHUs by the entrance of flows: “forewaters” had flow enter only from upstream ends; “backwaters” had flow enter only from downstream ends; “oblongs” had flow enter from both ends. She added “edgewaters” as a separate marginal ephemeral habitat, indicating these HHUs were located adjacent to pools, glides, or riffles but characterized as low-velocity areas less than 10 cm in depth. Generally, permanent marginal HHUs were deep where ephemeral marginal HHUs were shallow. She did add “cut-off backwaters” as a permanent marginal HHU, in which flow could be cut off at lower flows but higher flows connected these habitats back to the main channel while still maintaining their “backwater” status.

In her study of hydraulic microunits, Sullivan (1987) found velocities in backwater pools did not change significantly between summer low flows and storm flows. She studied cascades as meso-units of pool-rapid combinations, and found 20-35% of the cascade meso-unit surface area was made up of pools, while 40-65% was in the mainstream of flow (the remaining surface area was comprised of the protruding rocks which characterized cascades). She theorized the small pool pockets were important as resting areas for fish in these meso-units. The velocities of the cascade pocket pools were similar to the larger eddy pools formed by obstructions in flow. Sullivan (1987) also found similar mean values for velocity and depth for similar order streams (in her case third and fourth order), despite differences in discharge between streams. She also found basin area did not affect the velocity and depth relationships. Velocities in all pools were similar at low discharge, but at moderate and high discharges drawdown and backwater pools were distinctly different. Secondary channels (both pool and riffles) had lower velocities than the main stream drawdown pools, but the velocities became more alike with increasing discharge. Scour and plunge pools declined significantly in usable area for fish as velocity increased, but total usable area within stream reaches did not change significantly from low flows to storm flows. Eddy pools also maintained low velocities even during storm flows, dramatically different than thalweg velocities.

Sullivan (1987) found velocity differences within cascade meso-units were consistent with particle size differences: larger substrates were present in areas of greater velocity. Large roughness elements (e.g., large boulders) anchored positions of riffles and pools in the channel, and fixed larger objects (such as boulders, stumps, or live trees) anchored these habitat types along banks as well. Leopold et al. (1964 in Sullivan 1987) found the median particle size of riffles eroded at 75% bankfull discharge. Grette (1985 in Sullivan 1987) indicated large obstructions may increase the number but not the area of pools within a stream reach. Sullivan (1987) stated both meso-units and micro-units owed their existence to obstructions that laterally constrict the walls of the channel. Channel wall constriction was found to increase the availability of meso-units. The amount of constriction is defined in Rosgen's (1996) classification scheme as entrenchment ratio. Sullivan (1987) found pool units deeper than riffle units; however, eddy pools and secondary channels were very shallow at most flows less than most storm flows.

In streams with similar slopes, Sullivan (1987) found longitudinal or mid-channel bars most often were located downstream of small obstructions in straight shallow reaches. Slopes (or channel gradients) between 2% and 4% might be a transition range where riffle meso-units become cascade meso-units formed by boulder steps. Zimmerman et al. (1967 in Sullivan 1987) found the greatest channel width variation in intermediate-sized watersheds (2 to 10 km^2) reflecting the importance of channel obstructions in channel development.

Sullivan (1987) did not find a consistent relationship between the proportion of channel area comprised by pools and the amount of large woody debris, especially in streams of steeper gradient (>4%). Grette (1985 in Sullivan 1987) noted no difference between bedload movement of large debris between streams in harvested and unharvested forests. Grette (1985 in Sullivan 1987) further found no differences in fish per unit area between large and small pools.

Mosley (1987) compared various river classification schemes using longitudinal zonation based on work by Illies and Botosaneanu (1993), Illies (1961), Ricker (1934), Huet (1954), Carpenter (1928), Pennak (1971), and Nevins (1969), and using Strahler (1952) stream order as the base classification. The weakness of stream order alone as a classification scheme was fairly apparent when comparing other physical characteristics (e.g., mean bankfull width, watershed area, etc.).

Wright et al. (1984 in Mosley 1987) and Furse et al. (1984 in Mosley 1987) classified British rivers using physical characteristics and macroinvertebrate species using multiple discriminant analysis (MDA) and found the first axis was most correlated with mean bed sediment size, alkalinity, and total oxidized nitrogen. The second axis correlated most with discharge, width, depth, slope and distance from source. Using the MDA, both authors found it correctly assigned 76% of the sites using environmental data, seeming to indicate those physical factors best predicted the observed macroinvertebrate community. Mosley (1987) also classified New Zealand rivers and found 70% of the variation in channel morphology among 72 rivers could be described by cross-sectional area, cross-section shape, and channel slope. Sinuosity correlated poorly with channel morphology ($R^2 = 0.34$).

Emery et al. (2003) used a habitat assessment model called PHABSIM to determine the usable area of a particular reach based on channel bedforms (riffles and pools). Their efforts focused on the hydraulic characteristics of the bedforms to classify them into hydraulic patches. They used topographical and velocity cross sections, combined with a spatial point kriging method of interpolation, to determine distinctive microhabitats. Six hydraulic patches were defined based on clustering algorithms: channel margins (low velocity at all flow stages); pools (increasing velocity with stage); head and tail riffle margins (increasing velocity with stage); riffle crest and downslopes (increasing velocity with stage; backwaters (decreasing velocity with stage); and steep riffle crests and downslopes (high velocity at all stages). It is important to note that the preceding habitat patches were found on one river; in the other river used in the study, different hydraulic patches were identified even though both rivers had similar slopes (0.0017 vs. 0.0036). Another observation by Emery et al. (2003) was that pools exist as discrete hydraulic patches only down to a certain size, at which point they merge with and hydraulically behave like riffle margins.

Beschta and Platts (1986) found nearly 90 % of the alluvial channel reaches studied had pool/riffle sequences between 3 and 9 channel widths in length. Pools as habitat patches were recognized often as forming near large boulders that deflected flows and increased velocities and turbulence around their bases.

Mosley (1987) indicated the weakness of using average conditions (mean depth, mean velocity, etc.) to determine the suitability of a river as habitat for a given organism since the suitability will be based on a given frequency distribution of several variables at all points in a river. He suggested using several closely spaced cross sections along a reference reach to derive an index of suitability. This suggestion compares favorably with the Rosgen reach approach.

Newson and Newson (2000) used flow types to separate “physical biotopes,” which they labeled as a “mesoscale” approach to habitat classification. They separated runs from glides based on flow types: runs had "rippled" flows where surface turbulence did not product waves but symmetrical ripples which moved downstream parallel to flow; glides had very little surface turbulence. Physical aspects of stream habitat dominate biotic responses in two types of rivers: headwater streams and river segments heavily impacted by engineering design for flood protection or water abstraction (assuming water quality is not limiting).

Poole et al. (1997) conducted a critical review of HCU classification stream habitat studies. They indicated the repeatability of visual HCU classification is directly linked to using actual measurements as opposed to subjective classification based on written descriptions. Transference of visual techniques from descriptions to field personnel is limited the user is trained in the methods. They cited studies that showed major differences between field crews classifying the same streams within one 24-hour period. One study indicated a "shift" of a pool/cascade-dominated reach to a riffle-dominated reach between two surveys (Ralph et al. 1991 in Poole et al. 1997). Poole et al. (1997) found when 15 habitat types were used, just over half of the habitat types were classified the same between two observers, dropping to 34% with four observers. Moreover, when two habitat types were used, four observers classified the types the same only 69% of the time. They found even personnel with prior training had similar problems agreeing on classification of 9 habitat types. However, they used only the two studies where the data was available to determine percentage agreement.

Peterson and Rabeni (2001a) also found channel unit classification to be imprecise and unrepeatable, but by making detailed measurements of the physical characteristics of each unit, classification was improved. Poole et al. (1997) further indicated monitoring of habitat structure alone (such as pool/riffle ratios) should be discouraged if it is not contained within a more holistic approach to characterizing fish habitat, such as direct measures of channel morphology. Cross sections, bed particle size distributions and velocity and depth distributions are better suited to documenting changes in habitat availability as opposed to measuring the surface area of particular habitat units. By contrast, however, Buffagni et al. (2000) determined how macroinvertebrate fauna from the same habitat type at different sites can be more similar than fauna from different habitats at the same site, and indicated habitat unit classification can be a valuable and meaningful description of in-stream conditions.

Studies applied at the habitat unit scale (even scales as coarse as "pool" and "riffle") without consideration of the reach or basin-scale conditions, cannot be compared to one another (Thomson et al. 2001). They indicated management strategies, such as returning degraded reaches to a "good" condition, require an understanding of how large-scale geomorphic processes influence and shape local habitat.

In order to resolve the lack of repeatability among observers using the visual channel unit classification, Stanfield and Jones (1998) found a point-transect method reduced differences among crews in classifying habitat unit types. Most differences among observers using visual methods alone occurred in transition habitats, such as flats and runs, differences among spatial scales chosen by the observers, and errors derived from creating and interpreting drawings made at the site. The streams were all "C" types (Rosgen 1996), and all habitat classifications occurred at baseflows, with age-0 rainbow trout as the target species for analysis among habitat preferences. The target species choice allowed for a qualitative rating between pool types; other habitat units included flats, marginal flats, plunge pools, runs, riffles and point bars. Their study supported the contention that visual methods alone tended to misclassify habitat types. Agreement between the visual methods and the point-transect method was only 37%, with the point-transect method exhibiting the most repeatability between crews. Sixty measurement points within each 100 m^2 reach was sufficient for interpreting typical habitat, taking 2 to 3 hours per site (2-person crews). As would be expected, the lower number of habitat types used in their study improved the agreement between visual methods and the point-transect method. In contrast to other studies reviewed here, they asserted Froude number was insufficient for habitat classification across a broad range of stream sizes, due to its characterization of flows across a larger section of river.

An important advancement that may increase the use of habitat unit classification is the use of aerial photography. Legleiter (2003) found unsupervised classification of in-stream habitat (based on a modified, smaller version of Bisson et al. 1982) increased total among to within-unit variability by an order of magnitude compared to field methods. In his study, habitat unit types were high-gradient riffles, low-gradient riffles, glides, runs, rough-water runs, pools, and eddy drop zones. He suggested short-wave-infrared bands may be especially useful (based on 1-m resolution aerial photography), and indicated the unsupervised classification method might potentially recognize a greater number of distinctive habitats than field methods, however both glides and runs failed to demonstrate spectral distinction, perhaps indicating these areas may not be biologically distinctive. His methods were better able to distinguish boundaries between units that were not distinguishable in the field using visual techniques. He did recognize the advantage of field methods in identifying the biological importance of the arrangement of habitat units, an aspect not captured in the spectral classification algorithms. Spatial arrangement of habitat patches has been shown to influence habitat quality (Dunning et al. 1992). The use of map-based geomorphic variables also was successful in identifying this spatial arrangement (Porter et al. 2000).

Whited et al. (2002) also used aerial photography to determine riverine habitats in a regulated stream in eastern Washington. Mean temperatures were found to be fairly consistent during high and low flows, and were consistent between main channel and off-channel habitats (25.2º C and 26.1º C, respectively). Water from the dam is used for both irrigation and power production, and reduction in flows due to regulation has resulted in loss of channel connectivity and habitat complexity. The authors defined habitats as riffles, back bar channels and ponds, springbrooks, slack waters (backwater), eddy and pools. Detailed cross sections were made using total stations, which along with Wolman pebble counts were used to ground truth the aerial classification data. The remotely sensed data were classified into categories defined as shallow-slow, shallow-fast (riffle), shallow-fast (non-riffle), deep-slow and deep-fast, and photos were taken during two flow stages ("high" and "low"). As might be expected, channel complexity, off-channel habitats, connectivity between main and off-channel habitats and riffle habitats were all greater during high flows. In one subset, available off-channel habitat decreased 86% from high to low flow, while overall decreases were determined to be 38% across the entire study reach.

Fish Habitat Studies

Many studies concerning particular species' habitat use have been undertaken. Most studies have indicated the general trend that fish prefer "pool" areas rather than shallower areas or areas with higher velocities. Mahon and Portt (1985 in Statzner et al. 1988) found size within and among fish species increased from riffles to raceways to pools, indicating larger fish prefer pool-type habitats. Beschta and Platts (1986) recognized that pools of all shapes, sizes and quality are needed: young-of-the-year fish used shallow, low-quality pools and as they grew, they compete for the high quality pools with better food supplies and winter rearing habitat. In addition, summer rearing pools were often relatively shallow and close to riffles; pools adjacent to high-velocity areas were utilized by fish to have better access to passing food and oxygen. During high flood events, fish find protection along stream margins with temporary pools (Beschta and Platts 1986). By contrast, riffles are important for generating food for many fishes, and riffles are utilized by some species as spawning habitat. Watson and Hillman (1997) found the highest relative densities of bull trout occurred in stream areas with the deepest pools, no matter the scale of analysis, and densities were more closely associated with depth than frequency of pools.

In a classic fish habitat study, Gorman and Karr (1978) indicated a general correlation between habitat characteristics and presence/absence of fish species, suggesting most small stream fish are habitat specialists. Three variables are most important for determining microhabitat specialization: depth, current (velocity), and substrate (silt < 0.05 mm, sand 0.05 mm – 2 mm, gravel 2 mm – 10 mm, pebble 10 mm – 30 mm and rock > 30 mm). The combination of all three variables significantly correlated with fish species diversity, indicating habitat complexity increases diversity, but each variable individually failed to correlate with diversity.

Grossman and Ratajczak (1998) conducted a long-term study of microhabitat use by many of the same fish historically found in the present study's streams (see Table 1.2), including mottled sculpin (*Cottus bairdi*), longnose dace (*Rhinichthys cataractae*), central stonerollers (*Campostoma anomalum*), greenside darter (*Etheostoma blenniodes*), northern hogsucker (*Hypentelium nigricans*), creek chub (*Semotilus atromaculatus*), rock bass (*Ambloplites rupestris*) and rainbow trout (*Oncorhynchus mykiss*). In their study (as has been done in many other microhabitat fish research) they focused on depth, velocity and substrate composition (estimated visually in randomly placed 20-cm X 20-cm quadrats). Substrate was categorized in the following manner: bedrock = embedded to the surface, boulders (unembedded particles) > 30 cm, cobble > 2.5 cm and ≤ 30 cm, gravel ≤ 2.5 cm and > 0.2 cm, sand ≤ 0.2 cm, silt was considered suspended particles. Many species exhibited seasonal changes in microhabitat use, both based on depth and substrate, but these responses were attributed to changing microhabitat availability rather than specific "choices." However, northern hogsuckers and mottled sculpins did not display non-random microhabitat use, although the hogsuckers did show some preferences for deep habitats with little bedrock or cobble and large amounts of boulders. There was an apparent lack of changing microhabitat use among the species caused by piscivorous fishes and interspecific competition also had little effect on influencing changes in microhabitat use.

Freeman and Grossman (1993) conducted a study on rosyside dace (*Clinostomus funduloides*). Dispersion of the species could not be predicted by the overall availability estimated from point measurements of depth or velocity, but rather the occurrence of a specific habitat type (eddies adjacent to high velocity currents) and seasonal differences in behavior. Total area of suitable habitat did not influence dispersion nor did the occurrence of the habitat type noted above. The largest groups of the species existed downstream of a boulder that created a mixing or depositional area in a location with high current velocity. Biotic interactions were weak in their study area.

Bart (1989) also found little evidence of significant interspecific associations at the habitat level (main channel riffles, backwater inlets and pools) in Ozark streams and most fish were generalized in their habitat-use patterns. Young-of-year fish favored pools during summer and fall (typically less stream flow), and most species used backwater pools as young and completed their life cycles in main channel habitats. Pools supported more species than inlets and riffles, due to their deeper nature. The minnow species in his study occurred in large multi-species schools and randomly used habitats, appearing to move among areas in search of food. He concluded the scale of habitats was too small for studying full lifetime requirements.

Gorman (1987) also conducted research in Ozark streams, focusing on microhabitat use by minnow assemblages. Adult minnows used the open-water pool habitats, while juveniles used near-edge shallow microhabitats in pools and raceways; substrate provided little information on segregation of species. He used three stream habitat classifications: pools, riffles, and raceways. The fish (stonerollers and bluntnose minnows (*Pimephales notatus*)) tended to avoid very shallow areas (looking at entire assemblage) and favored still-water areas, but juveniles of the species preferred the shallower, near-edge areas. In general, smaller fish used smaller, shallower habitats, and theorized it was to avoid predation by the larger fish. He concluded the relative lack of use of these habitats by the larger species was avoidance of terrestrial predators.

Ozark streams also were the focus of work done by Felley and Hill (1983) on the cyprinids: central stoneroller, bluntnose minnow, and creek chub. They focused on microhabitat units as defined by homogeneous patterns of water clarity, substrate type, current velocity and presence/absence of cover (vegetation or structure), debris (leaves and sticks) and emergent vegetation. Stream width and maximum depth (both stream at overall sample location and within specific unit) along with other water quality parameters also were measured. Central stonerollers and creek chubs consistently preferred gravel microhabitats, while bluntnose minnows preferred mud/sand microhabitats (though the authors did not specify the measure of those substrate). Interestingly, creek chubs tended to live in relatively narrow streams (1.8 m to 4.0 m), and were found in both slow and fast currents.

Ross et al. (1987) did not find significant spatiotemporal variation in fish assemblage, but did show changing patterns in microhabitat use. Their 4th-order study stream was low-gradient, and fish species included silverjaw minnow (*Ericymba buccata*), golden shiner (*Notemigonus crysoleucas*), northern hogsucker (*Hypentelium nigricans*), largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*) and green sunfish (*Lepomis cyanellus*). Microhabitat variables included substrate composition and other visually estimated parameters including amount of litter, vegetation and cover. Based on the three dominant families in their study (Centrarchidae, Percidae and Cyprinidae), they found the percids preferred swifter currents with coarser substrate. However, they found very few species exhibited temporally distinct associations with substrate, although some species did show spatial preferences. They concluded that a significant change in spatial or temporal change within a particular habitat variable may not be due to a species altering its position in niche space, but the variable in question may not have an ecological meaning to the species. In other words, if certain species are significantly observed over a certain substrate type, it may not mean the species actually "prefers" the substrate type if substrate is not an important component of its life history.

Angermeier (1987) studied spatial and temporal associations with habitat by fish (northern hogsucker, central stoneroller, silverjaw minnow, striped shiner (*Notropis chrysocephalus*), bluntnose minnow, creek chub, rockbass, green sunfish, bluegill and smallmouth bass (*Micropterus dolomieu*)) in relatively low-gradient Illinois streams. Although distinct associations between species and certain habitat features were found, these same preferences were not consistent among reaches in the same stream, among different streams, and over time on the same reach. Cyprinids were inconsistent in their habitat associations and degrees of selectivity, while centrarchids were consistently more abundant in relatively deep sites with slow current. Substrate classification was part of the habitat study, along with the presence of certain cover types (woody debris, undercut banks, submerged vegetation), and depth and current velocity. The presence of piscivorous fish increased the complexity of habitat selection by the fish.

Curry and Spacie (1984) studied habitat use by white suckers (*Catostomus commersoni*) and northern hogsuckers in low-gradient streams in Indiana. White suckers migrated to headwater streams to spawn and preferred spawning over medium gravel in riffles in depths from 20-25 cm. Northern hogsuckers spawned over medium gravel in riffles at depths from 30 cm to 60 cm, but did not appear to migrate for spawning purposes. Certain substrate sizes were preferred, but the authors indicated the surface arrangement of particles may not necessarily indicate these species' particular preferences.

In an earlier study of fish habitat, Pusey et al. (1993) found mean species richness was significantly and positively correlated to cover complexity, but not to physical habitat complexity expressed by depth, flow and substrate. They included watershed-scale variables (order, gradient, watershed area) in addition to several microhabitat parameters. Substrate diversity was related negatively to watershed area and stream order, but positively related to gradient. Total mean physical habitat complexity also was related negatively to watershed area and gradient. Species richness did not increase with order, and they hypothesized this lack of increase was due to the increased likelihood of anthropogenic disturbance downstream. Fish assemblage structure was not influenced by smaller scale habitat variables, but by watershed-scale effects, such as gradient, stream order, watershed area and the percentage of cleared watershed area.

De Jalon et al. (1996) used some geomorphic parameters and microhabitat variables to study fish community/habitat interactions in Spain. They measured mean width, mean depth, slope and pool/riffle ratio along with substrate characteristics (fines < 2 mm; gravel > 2 mm and

< 200 mm; cobble > 200 mm and < 1000 mm; boulders > 1000 mm; rocky surfaces (bedrock) > 4 m^2). Their target species was brown trout (*Salmo trutta*), although they also studied fish community patterns. They found brown trout biomass was correlated negatively with habitat diversity, but positively correlated with depth, while overall fish biomass was correlated with depth and pool/riffle ratio ($p < 0.1$).

In a study of a stream channel constrained with moderate to steep banks that channelizes and intensifies high-flow velocities and increases stream power, Bryant et al (1992) observed a low retention of woody debris. In addition to channel morphology, the nature of the riparian vegetation, in their case dominated by western hemlock and Sitka spruce, precluded retention in the channel since these trees tended to be less stable. They indicated a trend of higher mean densities of fish was observed associated with woody debris than other cover types (such as boulders, bedrock, etc.) but the differences were not significant. McKenney (1997) indicated coarse woody debris substantially altered the geomorphic and habitat characteristics of the channels in the Ozarks. Historical research has demonstrated the importance of woody debris in large rivers, including the Mississippi, which at one time had over 600 snags per river kilometer (Sedell et al. 1990).

The Instream Flow Incremental Methodology (IFIM) (Bovee 1982 in Sullivan 1987) has been a popular method for determining habitat quality for fish. IFIM has been criticized for assuming all habitat variables are equal and selected independently, which Sullivan (1987) indicated was not valid. De Jalon et al. (1996) also found very few features of the IFIM model for brown trout were correlated with their findings of habitat use by the species.

The species of fish traditionally found in the stream reaches used in the present study have all been previously researched to some extent, and regional fish fauna descriptions have provided their general habitat preferences (see Table 2.1). However, studies continue to focus on particular species' specific habitat preferences. For instance, Schlosser and Toth (1984) found species specific responses to fluctuations in discharge were related to subtle differences in microhabitat use between two species of darter. They also conducted samples at the macrohabitat level (pool, riffle and raceway) to determine differences in species' preferences. the fantail darter (*Etheostoma flabbelare*) preferred substrate sizes with crevices (25 mm to > 50 mm) and avoided areas without crevices. These preferences were consistent whether the other darter species was present or not, indicating interspecific competition was not a factor in their microhabitat choice. They speculated the fantail darter's apparent microhabitat preference was more the result of its morphology (body shape). This species seemed particularly resilient to variability in flow, especially compared with other species.

Table 2.1. Species-Specific General Habitat Descriptions[a].

Species	Habitat Description
Ambloplites rupestris[b]	Moderate gradient, pools & backwaters, strongly associated with shelter; lesser current; nests in shallows with coarse sand to large gravel and in moderate flow pools
Campostoma anomalum[b, c]	Slow parts of pools; hard bottom runs & riffles; spawns in runs & pool tails; nests in excavated pits
Catostomus commersoni[b, c]	Wide range of gradients, substrates; usually found in moderate and high gradient streams; pools (fairly deep) with structure shelter; spawns in riffles with large gravel or sluggish pools at low water in riffles

Species	Habitat Description
Cottus bairdi[b, c]	Moderate to high gradients; runs & riffles of rubble, gravel, & boulder; well-flowing pools; nests in cavities cleared under stones or anything with structure
Cottus girardi[c]	Moderate gradients; swift currents; slow, deep runs
Cyprinella spiloptera[b, c]	Runs, well-moving pools, backwaters adjacent to appreciable current; variety of substrates; eggs deposited in crevices of loose bark on fallen trees & stumps
Ericymba buccata[b, c]	Low to moderate gradients; bottom dwellers in open shallow runs & pools; variety of substrates, but mostly sands; spawns over sand & gravel
Exox niger[b, c]	Sluggish water with depths < 3 m; associated with plants & logs, vegetated pools & backwaters; spawns in calm stream shallows, usually among vegetation
Etheostoma blenniodes[b, c]	Riffles & runs of rubble & boulders; moderate gradients; associated with vegetation; spawns over fine sand in lee of boulders
Etheostoma flabbelare[b, c]	Riffles in shallow sections (juveniles found in shallow margins of riffles, runs, & pools); breeds under stone spaces; spawns in runs & slow riffles
Exoglossum maxilingua[c]	Pools & runs, occasionally riffles, associated with cover; nests in slow runs, backwaters with appreciable current exchange, & pools, under or against banks, boulders, or logs; nests made of pebbles
Hypentelium nigricans[b, c]	Runs & riffles, hard substrates; spawns in gravelly tails of pools, sometimes in shallows and medium gravel of riffles; bottom dweller
Ictalurus punctatus[b, c]	Pools, moderate current, variety of substrates; nests in sheltered areas
Lepomis cyanellus[b, c]	Moderate gradient; slow pools & backwaters; nests in pools & backwaters often near vegetation and in sunny areas
Lepomis gibbosus[b, c]	Pools & backwaters, over firm & soft bottoms, often near macrophytes/cover; nests in open shallow areas on sand & small gravel
Lepomis macrochirus[b, c]	Low to moderate gradient; pools & backwaters; nests in shallows on sand or gravel
Luxilus chrysocephalus[b, c]	Pools & backwaters with hard & soft bottoms (esp. gravel); spawns over other fish nests (gravel substrates in swift currents)
Luxilus cornutus[c]	Moderate gradient; primarily pools, current ecotones; open water and cover, firm & soft bottoms
Micropterus dolomieu[b, c]	Gravelly & rocky substrates; frequent succession of riffles, runs, & pools, typically runs & pools; likes submerged logs, stumps, or rock outcrops; nests on firm bottoms in slow current often adjacent to cover in coarse gravel < 1 m depth
Micropterus salmoides[b, c]	Pools & backwaters; nests in variety of substrates (mostly firm) in pools & backwaters, open or with logs, ledges
Nocomis micropogon[c]	Gravelly & rocky, moderate to somewhat high gradients; pools, runs, & riffles (rarely); rapid currents; nests in runs & pool tails; nests are gravel mounds 0.3 – 1 m in diameter
Notemigonus crysoleucas[b, c]	Low to moderate gradient; medium to large streams; sometimes spawns over Centrarchid nests
Notropis rubellus[b, c]	Swifter currents; runs & pools near current ecotones; firm & soft substrates; spawns in shallow runs & riffles, over gravel substrate or other minnow nests; also found in rubble, boulder, and bedrock substrates
Oncorhynchus mykiss[b, c]	Wide variety of substrates; calm pools, pockets within riffles; escape cover must be nearby; redds cut in gravel runs
Pimephales notatus[b, c]	Pools to backwaters; wide range of habitats; nests in cavities
Rhinichthys atratulus[b, c]	Gentle riffles & runs; backwaters & pools near current ecotones; hard bottoms; spawns in shallow gravelly to sand/gravel pool tails & slow to moderate runs, open & shallow; uses other fish nests
Rhinichthys cataractae[b, c]	Fast water on rubble, boulder & bedrock bottoms; chutes; spawns in relatively shallow areas with currents > 5 cm/sec, over fine to coarse substrate
Salvelinus fontinalis[b, c]	Moderate gradients, rocky streams; various substrates; redds cut in gravel, sometimes sand bottoms
Semotilus atromaculatus[b, c]	Scantily or unvegetated pools, backwaters & slow runs; moderate to somewhat low gradients; nests built in gravel & sand/gravel runs & pool tails

Species	Habitat Description
Semotilus corporalis[c]	Sandy to hard bottoms, low to moderate gradients; streams at least 0.5 m deep, 8 m wide; pools & slow runs; nests in gravel/rubble runs & glides above riffles, in open, along banks, or middle of gently flowing pools; nests with pit on downstream edge, with gravel-sized stones

[a] All descriptions partially based on Fishes of West Virginia (Stauffer et al. 1995)

[b] Description also based on the Fishes of Tennessee (Etnier and Starnes 1993)

[c] Description also based on Freshwater Fishes of Virginia (Jenkins and Burkhead 1994)

The importance of cover and substrate has been repeatedly stressed in numerous studied of fish habitat. Some studies have shown no single factor has greater influence of biological significance than the physical nature of the stream substrate (Cummins 1974 in Beschta and Platts 1986). Boulders have been recognized as important velocity refuges (Peterson and Rabeni 2001b). High velocities require fish to expend more energy to maintain position, but body shape may help some fish species (such as stonerollers with a fusiform shape) take advantage of areas with higher velocities. Smallmouth bass were three times as likely to use boulders as cover than any other cover type (Todd and Rabeni 1989 in Peterson and Rabeni 2001b). Beschta and Platts (1986) stated the optimum spawning substrate mix for their study species appeared to be gravel containing small amounts of fines sediments and small rubble. Sedell et al. (1990) demonstrated the size and porosity of stream substrate strongly influence the ability of the hyporheic zone to act as a refuge for fish and other aquatic species, and at times this zone can be ten times the volume of the in-channel habitat. Watson and Hillman (1997) indicated bull trout are highly substrate oriented, with larger substrates providing the necessary habitat complexity, velocity breaks, concealment cover, and visual isolation necessary for their life history requirements.

Meffe and Sheldon (1988) found most of the species in their study of South Carolina coastal plains streams preferred slow, deep habitats with depositional substrates and cover. They examined habitat use at the “mesohabitat” scale of pools, riffles and runs (Frissell et al. 1986). They found northern hogsuckers preferred deep and wide habitats with medium to high currents, while creek chubs tended to be found in small and deep habitats. Meffe and Sheldon followed up the preceding study with one where they intentionally defaunated a section of the stream to further determine habitat preferences (1990). There was little change in species composition, and no significant differences in individual species’ densities prior to and one year after a section of stream was defaunated. Recovery of the individual mesohabitats was non-random and largely predictable from habitat structure (Meffe and Sheldon 1990). Although this particular stream recovered after one year, the results seem to indicate predictions may be made at the mesohabitat scale. Further, recovery was not via diffusion from neighborhood sites, but by fish traveling through several habitat types to reach the chosen mesohabitat (however, the low gradients and presumably lack of natural or otherwise barriers of the study streams likely enhanced this method of migration).

Traditional work has led to the development of Habitat Suitability Indices (HSI) for certain common species of fish. These HSI compiled the existing research at the time into calculations based on streams’ ability to support all phases of a species life history and habitat preferences. Values are divided into a rating system that classifies quality of each parameter, and later combines all variables to come up with a single score that “rates” the stream. In addition to HSI, regional fish textbooks also combine prior individual species’ studies to come up with general habitat preferences. Using these descriptions, the fishes traditionally found in the present study's streams have general habitats described below in Table 2.1 (habitats in relation to factors measured in the present study).

Habitat descriptions (for habitat parameters in the present study) for above fish species contained in HSIs are included below in Table 2.2. Further examination of select HSI variables will be discussed in Chapter IV.

Table 2.2. Habitat Descriptions for Selected Fish Taken from Habitat Suitability Indices.

Species	"Optimal" Habitat Description*	Source
Catostomus commersoni	Migrate from lentic areas to spawning riffles; found in inlets, outlets, small creeks, rivers w/swift shallow water over gravel; spawn over clean coarse sand or gravel, near lower ends of pools, quiet water, or where current quickens; low to medium stream gradients; adults in pools (w/flow) or slow runs w/cover; fry over sand/gravel substrate; young in eddies and backwaters; juveniles in shallow backwaters, riffles, sand/rubble runs	Twomey et al. (1984)
Ictalurus punctatus	Streams w/diversity of velocities, depth & structure (40-60% pools); cover of boulders & debris in deep water for overwintering; deep pools w/>40% suitable cover; riffles & runs in important for night feeding; nest in dark, secluded areas in cavities, burrows, under rocks; spawn in shallow, flooded areas; fry found in low-velocity areas of rocky riffles, debris-covered gravel, sand bars; fry overwinter under boulders in riffles or cover in deep water	McMahon & Terrell (1982)
Lepomis cyanellus	Pool areas of streams, optimal at least 50% of total; vegetative cover; low range of gradients (0.02-0.6%); small – medium-sized streams (<30 m width); nest on firm substrate of gravel/sand, near rocks, logs, vegetation; adults in low current velocity areas; optimal spawning substrate (≥50% sand + gravel)	Stuber et al. (1982b)
Lepomis macrochirus	Areas of low velocity, backwaters; high % pool area (>60); optimal stream gradient (0.05%); cover in form of submerged vegetation, logs, brush	Stuber et al. (1982a)
Luxilus cornutus	Small/medium-sized streams w/moderate current, unvegetated gravel/rubble bottoms; pools immediately below cascades, not in deadwater or long pools; spawning substrate (5-60 mm), use creek chub nests, or nest in riffles in sand depressions or gravel in eddy currents; fry move to pools typical of moderate gradient streams;	Trial et al. (1983b)
Micropterus dolomieu	Midorder streams >10.5 m width w/abundant shade & cover (variety); deep pools, moderate current, gravel/rubble substrate; stream gradients (0.075-0.47%) w/alternating pools/riffles; spawn in river shallows, backwaters, w/stone, rock or gravel substrate; adults in pool or deep areas behind rocks, near edge of current; nests built in gravel or broken rock, near boulders, logs or other cover, in shallows or stream backwaters; fry in shallow areas w/rocks and vegetation; juveniles in quiet water under dark shelter, low velocities near current	Edwards et al. (1983)
Micropterus salmoides	Large, slow-moving rivers; pools of streams w/soft bottoms, aquatic vegetation; high %(60) of pool & backwater areas; low gradient (0.1%); prefer spawning over gravel substrate, silty, mucky bottoms unsuitable; adults most abundant w/vegetation & other cover; flooded vegetation access important for fry	Stuber et al. (1982c)
Oncorhynchus mykiss	Silt-free rocky substrates in riffles/runs; 1:1 pool/riffle ratios; areas of slow, deep water, well-vegetated stream banks, abundant instream cover; redds constructed in gravel substrates at heads of riffles or downstream edges of pools; spawning in gravel areas w/≤5% fines, optimal substrate (15-60/100 mm); interstitial spaces important for fry, overwinter in shallow stream margins w/rubble	Raleigh et al. (1984)

Species	"Optimal" Habitat Description*	Source
Rhinichthys atratulus	Small stream pools; rocky, gravelly streams w/gravel-cobble substrates; stream gradients (1.1-2.3%); spawn over sand, gravel, cobble; fry in shoals and pool margins over sand/silt substrate; juveniles over sand, gravel, small rocks, boulders	Trial et al. (1983a)
Rhinichthys cataractae	Swift, steep gradient headwater streams w/strewn boulders and gravel and rock beds; stream gradients (0.19-1.87%); very shallow waters; spawn in riffles, gravel/rock substrate (<200 mm); prefer riffle areas, in pools w/o competitors present, crannies between stones; juveniles in riffles	Edwards et al. (1983)
Salvelinus fontinalis	Silt-free rocky substrate in riffles/runs; 1:1 pool/riffle ratio w/areas of slow, deep water; well-vegetated stream banks; abundant instream cover (low stream bottom visibility, suitable depth, low current velocity); optimum embryo substrate (3.4-50.5 mm), overall (30-80 mm); overwinter in shallow low-velocity areas w/rubble (cobble)	Raleigh (1982)
Semotilus atromaculatus	Small, streams w/moderate to high gradients (0.3-2.3%), gravel substrate, well-defined riffles, pools w/abundant cover; streams w/small widths (0.5-7 m); alternating pools/riffle-runs; rubble (cobble) substrate in riffles; deep pools & runs w/abundant cover (all types); deep pools w/cover near larger streams important for overwintering; all types of substrate; spawn in gravel in shallow areas above/below riffles; embryos highest in gravel substrate in riffles/runs; fry in shallow areas along edges of pools	McMahon (1982)
Semotilus corporalis	Gravel-bottomed streams; found near cascades & falls; nest in areas w/overhanging vegetation or brush, or in pools w/suitable substrate; adults seek pools & deep runs; young more frequent in rapid waters	Trial et al. (1983c)

*As indicated in each species' HSI for geomorphically related parameters; does not include other water quality parameters such as T, pH ranges, suspended particle effects, food preferences, lacustrine preferences, etc.

Studies Combining Fish Habitat with Stream Classification

In order to maximize data recovery while conserving funding to determine fish habitat needs for management strategies, studies have attempted to combine known fish habitat preferences with studies of broad geographic and geomorphic features. The ultimate goal of these studies has been to make predictive models of particular fish (or other biotic criteria) species associated with physically similar in-stream habitats. In a cluster analysis study of Missouri fish, Pflieger et al. (1981) found significant associations between common fish species and four distinct physiographic areas in Missouri: River, Lowland, Ozark and Prairie. By contrast, McCormick et al. (2000) found local physico-chemical parameters influence fish assemblages more strongly than broad geographic features, but fish may respond to physical parameters such as stream order and slope that do not reflect ecoregion boundaries. They found little separation at ecoregion or watershed scales except in those separated by very broad spatial scales, and theorized the long history of human disturbance has masked any fine-scale structure in fish assemblages.

McKenney (1997) acknowledged the relative lack of studies using habitat classification schemes on warmwater streams compared to the rich amount of data on western, steep, coldwater streams (e.g., Bisson et al. 1982). Difficulties arise when using the large amount of data gathered from cold-water stream systems and attempting to apply results to warm-water stream systems (Grossman et al. 1982 in Bowlby and Imhof 1989). Cold-water stream systems tend to be more stable over time (Moyle and Vondracek 1985 in Bowlby and Imhof 1989).

Graham et al. (1982) found significant correlations between bull trout (*Salvelinus confluentus*) redd frequency and watershed and microhabitat variables. Channel gradient, stream order, D_{90} pebble size, and percent boulder were the most significant variables, with redd frequency being negatively correlated with all but stream order (positively correlated). However, when they used the resultant redd frequency classes to classify the same stream sites, only 58.5% of the stream sites were successfully classified using their method.

In another study involving bull trout, Watson and Hillman (1997) measured a multitude of geomorphic variables across streams in three western states. Their used stream classification method, an earlier version of Rosgen's (1993 in Watson and Hillman 1997) stream classification method, combined elements of habitat type used in Hawkins et al. (1993). In their study, a recorded habitat unit had to be equal to or longer than the average width of the wetted channel, perhaps eliminating subtle differences in hydraulic unit use at smaller scales. Their main goal was a model which would detect bull trout presence/absence, but they used relative densities of none, sparse, many, and numerous to distinguish sites. Although other studies have indicated the difficulty in applying species models across spatially distant areas, they found significant differences in many of the geomorphic variables for sites with and without bull trout. These variables ranged from valley width to percentage boulder cover, and included Rosgen channel types. When comparing the scour pool habitat unit between sites with and without bull trout, significant differences were noted between channel type, subdominant substrate, valley width, gradient and number of log jams. Significant correlations also were found between some variables and bull trout relative density, but not at the basin- or watershed-scales. They concluded watershed-scale physical processes are the most important factors determining this species distribution and occurrence in third and fourth order streams.

Parsons et al. (1982) also used geomorphic parameters to develop a predictive fish habitat model. One beneficial aspect of their model was their ability to develop independent indices for each landtype association. Although they used flow, pool/riffle ratio and stream surface shading as measured parameters, they also included subjective qualitative ratings for the available pools and riffles as part of the local habitat quality rating system. They used a rich amount of other geomorphic, watershed- and basin-scale variables to distinguish between stream types. They found no significant differences between undisturbed basins and disturbed (timbered) basins.

Bryant et al.. (1992) used a classification system whereby units were hierarchically arranged into macrounits (pools, fast water, and side channels), mesounits (pools: backwater vs. drawdown; fast water: riffle, glide/run, cascades, or rapids/falls), and microunits. However, considerable overlap occurred between the meso- and microscale in that the statistical analysis used for the study compared units classified at the mesoscale with habitat units classified at the microscale.

Bryant et al. (1992) found coho salmon fry were found in higher densities in eddy pools compared to riffles and glides. However, they did not find any other significant differences of mean densities for the other fish (fry, juvenile, or adults) at the microhabitat level. At the mesohabitat level (pool, glide, riffle, side channel), there were significant differences in densities for coho salmon fry and parr, but not for the other two species (fry, juvenile, or adults). The highest density of all salmonids were in pools, but side channels were significantly important for coho salmon parr, even though this habitat unit comprised only 1% of the total habitat surveyed.

Recently emerged salmonids have been found to emigrate downstream from the emergence site, and generally move to the shallow stream margins to feed in low velocity areas (Mason and Chapman 1965 in Sullivan 1987). Bachman (1984 in Sullivan 1987) found brown trout juveniles spend 86% of their time in a sit-and-wait mode and 14% of their time was spent in high-energy activities. This behavior underscores the importance of low-velocity areas, whether within or outside of the main channel, as resting areas for fish. Sullivan (1987) found cutthroat trout occupied plunge and scour pools during the winter, verifying the preference of this fish species for deeper portions of streams with good cover. However, she also found age 2+ trout only inhabited channel units with average depths greater than 0.02 m and avoided secondary channels and low-gradient riffles.

Bisson et al. (1988) were able to use differences in fish body shape morphology to predict use of particular hydraulic habitat units, classified using an earlier method (Bisson et al. 1982). Similar to Inoue and Nakano (1999) and Inoue and Nunokawa (2003), Bisson et al. (1988) established grids to determine hydraulic variable values within each as a classification method, and found use of channel units with different hydraulic patterns varied consistently according to species and age group.

In a study of brown trout (*Salmo trutta*) in California, Kershner and Snider (1992) developed a three-tiered hierarchical system for habitat study. They based their study at the reach, mesohabitat and microhabitat scales to determine fish preferences for microhabitat and based habitat classification on Bisson et al. (1982). Reach classification was based on Rosgen (1985 in Kershner and Snider 1992). The majority of the streams ranged in gradient from 1.5 to 4%, with width/depth ratios of 8 to 20 (Type "B" in Kershner and Snider 1992). Although they found a high degree of variability among each reach type, low-gradient riffles, lateral-scour pools, dam pools, glides and runs dominated type "B" streams. However, only low-gradient riffles were significantly different in mean percentage area among the three stream types in Kershner and Snider's study. Brown trout yearlings associated strongly with lateral scour pools with complex woody cover, similar to adult brown trout. In fact, 90% of adult brown trout were found in less than 2% of total habitat available (by percentage area), indicating a very strong preference for the lateral pools with woody cover.

In a follow-up study, Kershner et al. (1992) cautioned against using "representative reaches" to describe stream habitats due to their dynamic nature. In this particular study, they examined the relationship between a stream classification based on Rosgen (1985 in Kershner et al. 1985) and their identified mesohabitat scale (glides, main pools, lateral pools, riffles, and runs). They based their smallest individual channel unit classification on Bisson et al. (1982) on their study streams in northern California, which were relatively unregulated. They determined lateral pools were more prevalent (based on surface area) in "B" channel types as opposed to the "C" types. Their results demonstrated a wide range of percent compositions of simple habitat categories (pools, riffles and glides) among channel types. Another important observation made in their research was that "optimal" habitat for fish appeared to be sequences of food-producing habitat (riffles) followed by good pool habitat.

In a study of the same streams of the Ozark Plateau as McKenney (1997), Peterson and Rabeni (2001b) determined the relationship of fish assemblages to hydraulic channel units. They found most of the variation in channel units was based on depth and current velocity. In their study, they found races had greater amounts of cobble and boulder substrates than glides, perhaps a reflection of their greater mean velocities (Peterson and Rabeni 2001a). However, although transitional units were able to be distinguished from other mesoscale habitats (scour, riffle, and slackwater), races and glides were often misclassified (33.4% and 22.2%, respectively). They found greater amounts of boulder and cobble substrate in the high-gradient riffles than the low-gradient ones.

Peterson and Rabeni (2001b) found most of the warmwater species they studied in scour and slackwater units in both summer and winter. Species found in slackwater units in summer moved to different scour units in winter, depending on whether it was backwater units or forewater units. Centrarchid species were most often found in the scour units primarily comprised of woody debris and boulders. Most species age-0 fish used the shallow slackwater units in summer. They surmised that small-bodied fish moved to shallow areas to avoid the large aquatic predators, whereas the larger fish preferred deeper areas of the channels to avoid terrestrial predators. Therefore the predator/prey interactions of specific stream systems may influence the habitat use of certain species, depending on size. During winter, however, most species (all age groups) moved to deeper areas associated with woody debris and/or boulders, and were found in bluff pools and backwater units (with depth). Their study indicated seasonal channel unit use might be an important factor when describing fish habitat in streams.

In a smaller scale study of fish habitat/channel unit preference in Japan, Inoue and Nakano (1999) found significant associations between juvenile masu salmon and a deep-moderate “subunit”. They started at the channel unit scale, which they referred to as riffles, pools, cascades, rapids, or glides (based on Bisson et al. 1982), while they used the “subunit” scale to describe their individual habitat units based on depth, current velocity, current variability, and substrate. Study reaches ranged from 22 m to 30 m. Pools had higher densities than other channel unit types and there were significant differences among the eight subunit types used based on the variables used. Small fish selected shallow water while the larger fish used the deeper water subunits, as shown in other studies (Schlosser 1995). They found certain subunit types occurred in specific arrangements within the overall structure of the entire channel unit. However, certain subunits were found across different channel units as well (Inoue and Nakano 1999).

Inoue and Nunokawa (2002) followed up with a similar study and found a distinct subunit preference by the masu salmon and rosyface dace. Masu salmon preferred pool heads while the dace species preferred slow-current edge units. Longitudinal variation existed at the subunit scale and concordant variation in fish species abundance existed based on the species’ preferred subunit habitat. Areal percentage of a subunit type was dependent on longitudinal variation of its composition as a function of distance from stream mouth. Significant correlations between species densities and preferred habitats (subunit) were found in their study, which were not apparent at the channel unit scale.

Tsao et al. (1996) conducted a study where habitat unit availability was the most limiting component on the salmon population. They found run habitats were important as spawning habitat for their target species, and an equal combination of run and pool habitat was indicated favorable habitat at the mesohabitat scale. At the microhabitat scale, salmon fry preferred quiet waters along stream margins. Barriers separating lengths of channel (Formosan salmon are not anadromous) were represented by a set of check dams. Between these dams, unless an individual section was connected to other sections providing sufficient pools as refuge from floods and runs for spawning habitat, the section itself had to have a sufficient quantity of both habitat types in order to have self-sustaining salmon populations.

Modde et al. (1991) also used Bisson et al.'s (1982) method of habitat classification to separate streams and categorize trout biomass in South Dakota. At the upper end of their hierarchy, they found significant differences among all but four of the 24 physical and water quality variables when comparing land-type associations. They found the highest biomass of brown trout in plunge pools, while the highest biomass of brook trout was in pool habitats and glide habitats. Habitat composition was independent of land-type association although significant differences among the quantitative variables were found among land-types. As a result, although the greatest brook trout biomass was in lateral scour pools, the land-type association with the largest amount of lateral scour pools was relatively low in brook trout biomass. They admitted some form of negative interaction between the two species might have partially explained this observation.

Another study that demonstrated the importance of a hierarchical framework was completed by Pusey et al. (2000) on rivers in Australia. In their study, they concluded regional and watershed factors determined which species would be present at individual sites, whereas local factors were important in determining abundance of the species. Watershed-scale variables used in their study were elevation, distance of site from stream source and from the sea, stream order, riparian cover and watershed area. Local factors measured included site gradient, mean depth, mean water velocity, composition of the substrate, and other variables describing cover, such as large woody debris, overhanging banks and root masses. They also found significant correlations between the local factors measured and the watershed-scale variables. Streams with lower flow variability had fish assemblages more strongly controlled by habitat variation. There were no strong associations between inter-site differences in assemblage structure and inter-site differences in habitat structure, although the associations were significantly better than random. Density data of particular species actually reduced the ability to discriminate between sites, and indicated spatial variation in the fish assemblage structure were influenced more at the watershed scale.

Porter et al. (2000) found a fish species model based on macrohabitat variables in one river failed to predict species distributions in one river, but succeeded in a geographically distant river. Of the 13 fish species habitat models used in the study, 11 of the models were better at classifying sites without individual species than identifying sites with the species when only using the map-based variables (such as drainage area and sinuosity) (i.e. sites without the preferred habitat parameters were more accurately classified than those with them). Inclusion of the field-generated variables improved the classification rates for the models. However, when the successful models were applied to the distant river, poor classification rates were observed for all seven species in common between both drainages. When models were developed specific to the distant drainage, these classification rates were improved. As might be expected, significant differences were found between the streams based on some (but not all) of the measured variables, both map- and field-based.

Nelson et al. (1992) also found brook trout and cutthroat trout distributions at specific sites were related to geologic district (subunit of ecoregion) and landtype association (subunit of geologic district) in Nevada streams. The most important attributes for characterizing habitat were stream width, abundance of large substrate and streamflow. Their streams were subject to extremely dry conditions on some occasions (and hence the importance of streamflow). In addition, they used $\alpha = 0.10$ as their significance level. In their hierarchical classification, glides and runs were lumped into pools based on their relatively similar velocities and depths, in addition to unbroken surfaces. There were significant differences among sites with and without trout based on elevation, rubble-boulder % (> 76.2 mm), gravel % (4.8 mm – 76.2 mm), embeddedness % and pool % across all geologic districts.

In a study of golden trout (*Oncorhynchus mykiss aquabonita*) in California, Knapp et al. (1998) observed significant increases in spawning habitat availability and densities of age-0 trout with increases in stream width. They also demonstrated the role of streamside vegetation and livestock access to the stream in influencing local channel dynamics, which also influenced redd density.

Hicks and Hall (2003) investigated possible salmonid densities between rock types (basalt and sandstone) and found no significant differences when all salmonid species were combined. Rock type was shown to influence stream morphology, including substrate composition, and they found significant differences between dominant substrate sizes in the two rock types (basalt > sandstone). However, the basalt streams also had significantly greater gradients, which influence substrate sizes.

However channel units are described, fish considered habitat generalists may not be correlated with specific channel units (Porter et al. 2000), and frequent or long-term disturbances usually tip the balance from habitat specialists to habitat generalists (Peterson and Rabeni 2001b).

One aspect of associating fish habitat with hydraulic channel units is the role of particular units to act as refugia from disturbance or predation by other fish or terrestrial predators. For instance, Thomson et al. (2001) recognized shallow backwaters as refugia for small fish to avoid the larger piscivorous fish species. The ephemeral nature of most backwaters may enhance their importance for some species. Buffagni et al. (2000) found backwater habitats, although they were subjected to higher amounts of temporal variability due to changing discharge levels, were separable from other habitat units based on a combination of physical parameters and macroinvertebrate use. Bisson et al. (1982) also found backwater pools to be heavily utilized by age 0+ coho salmon, and smaller fish generally used these habitat types.

Sedell et al. (1990) examined refugia in depth, defining them as habitats or environmental factors conveying spatial and temporal resistance and resilience to communities impacted by disturbances. The hierarchical system used in their study described channel units as those longer than one channel width with characteristic slopes, turbulence and degree of supercritical flow. Riffles, pools, rapids and other features shorter than one channel width were considered subunits. They again recognized as flow increases, channel units attain uniform surfaces and definitions, blurring the distinctions between subunits. Increased flow also increased the necessity for maximum interaction between the stream and its floodplain, where the greatest diversity and extent of refugia was found to occur. As other research has shown in this review, during flood events, pools, side channels and backwaters provided refugia for fish. In addition, they demonstrated increased channel complexity also increased the likelihood these channels served as refugia to different disturbance types (e.g. droughts). As such, they recommended river managers assess the importance and frequency of identified refugia types via flows and lateral linkages. Schlosser (1995) asserted the spatial distribution of refugia is likely to be a fundamental factor controlling fish population dynamics. Graham et al. (1982) also observed large numbers of bull trout redds in streams with abundant side channels and braided channel areas.

Other units also are recognized by their particular function as fish habitat, such as waterfall units as barriers to upstream migration (Thomson et al. 2001). Schlosser (1995) also found connectivity between habitat units appeared to be important in some natural streams.

McGarrell (1997) found Rosgen Level I (1996) 1st to 3rd order type B streams had significantly higher macroinvertebrate taxa richness than type C streams, but no significant difference in taxa richness based solely on stream order. Most macroinvertebrate communities were predominantly influenced by percent cobble substrate, dissolved oxygen, percent riffle and acidity. Taxa richness was significantly negatively correlated with entrenchment ratio, while it was significantly positively correlated with D_{50} pebble size.

Channel hydraulic influence on freshwater aquatic communities was studied extensively in research by Statzner et al. (1988). Substrate characteristics were less important as determinants of macroinvertebrate distribution than mean velocity and other complex hydraulic factors. They did not discount the influence of substrate on the complexity of local stream velocities. They reported stream fish show spatial segregation based on depth and velocity, but rarely substratum type. Channel slope and width could be used as rough indicators for shear stress, which they found significantly separated habitat use by fish.

Buffagni et al. (2000) also used channel hydraulic criteria to classify habitat units based on macroinvertebrates, using Froude number, flow velocity, depth, substratum composition and bed roughness. No single physical parameter explained the resulting functional habitat classification. In many cases, intra-habitat variability exceeded the inter-habitat variability of many parameters. They indicated their results are cautionary evidence against using physical factors alone to classify in-stream habitats as predictors of biological assemblages.

Rabeni et al. (2002) found community structure similarity (measured at the family level) increased as the hierarchical scale proceeded from three flow groups to the 11 channel units used in their study, showing consistency spatially and temporally. This consistency failed, however, using traditional community-scale variables (taxon richness, abundance, and diversity). There were no significant differences in the common taxa among channel units. Although their results suggested a strong biological relationship between family-level community structure and identified channel units, they cautioned against applying their results to broad scale comparisons among different streams, and suggested the utility of the relationship was best assessed within single streams.

Young (1993) performed research on the near-bed zone of streams and determined the terms “pool,” “riffle” and “run” were not necessarily relevant when studying this particular microhabitat. However, the author used a visual method when defining these habitats, and indicated runs were intermediate between riffles and pools in the description. The results of the study indicated although pools were appropriate, riffles and runs may not be ecologically relevant in studying benthic species.

Sheldon (1985) used some basin-scale watershed parameters to map invertebrate communities in a Tennessee river of the Appalachian Mountains. He looked at stream gradient, elevation, and stream size indexed by a linkage system (number of 1st-order tributaries to a particular stream are summed to get value). He found gradient did not influence stonefly distribution, but rather elevation and stream size exerted significant controls. Hawkins et al. (1982), however, found gradient, substrate size and current velocity strongly controlled macroinvertebrate communities in his study of Oregon streams.

In addition to many studies of hierarchical and geomorphic influences on macroinvertebrates, many resource agencies are incorporating these variable types into rapid stream bioassessment methods. In a review by Osborne et al. (1991) almost fifteen years ago, all but one of the states surveyed were using substrate size and type among many other geomorphic parameters, including sinuosity, gradient, and channel morphology (Rosgen-type classifications). Recently, Ward et al. (2003) showed the three most popular stream assessment methods significantly correlated with Level I Rosgen (1996) stream types. Assessment scores decreased significantly from boulder-dominated streams to silt-dominated ones and from streams with high entrenchment ratios to those with low entrenchment ratios (incised). Level I stream types A, B and C (Rosgen 1996) typically scored higher and had a more diverse set of habitat niches than the other types (E, F and G). The Proper Functioning Condition method (Bureau of Land Management—BLM) (Prichard et al. 1993) best incorporated morphological parameters into the assessment, and found no significant differences in scores between Level I types. They recommended using either the RBP (Barbour et al. 1999) or the NRCS method (NRCS 1998) along with the BLM method as the best rapid assessment technique of stream habitat quality.

Chapter III. Methods

Reach Locations

As discussed previously and in Rosgen (1996), reference reaches should encompass at least two meander wavelengths or 20 – 30 channel widths. In the case of the reaches chosen in this study, a reach length of two meander wavelengths was deemed too long logistically. This method of using the channel-width-length reach has been used in other studies due to the greater ease of comparing reaches on a quantitative scale (Kershner et al. 1992). Therefore reaches were chosen to accommodate as much meander wavelength as possible, while still remaining approximately 30 channel widths in length. Reaches were first chosen using ESRI ArcMap© GIS software. Bankfull width was estimated from aerial photographs and a mean bankfull width was calculated. Note this bankfull width "mean" is not the same bankfull width mean discussed in the results and in the Pebble Counts, Cross Sections and Rosgen Data sections of Methods. The former means were multiplied by a factor of 30 in order to develop reach lengths required. The upstream and downstream bounds were generated using this method and maintained throughout the study. Corrected bankfull width means resulted in reach lengths ranging from 26.2 to 33.2 bankfull widths (see Table 1.1). This reach length was used as the basis for all data. At various places throughout this text, "Rosgen reach" refers to these particular reaches.

Reach locations were based on criteria developed in the following discussion. For SR3 (refer to Table 1.1 for reach abbreviation explanations) and SR4M, the hydrolabs used by Dominion Power were used as the basic midpoints of each reach. For SR4, the US 50 bridge was used as the basic midpoint. For SR1, a reach was chosen based on a reach within the upper 1.2 miles of the Stony River below the Mt. Storm Lake dam where a complex of main channel and backwater pools led into a good-sized pool. The larger reach is also referred to as the Upper Stony River Reach and is discussed separately below. This reach was part of the river possibly targeted for future fish habitat restoration/rehabilitation.

For the comparison reaches, streams were chosen within the West Virginia portion of the North Branch of the Potomac River watershed (Figure 1.1). Two of the streams, Difficult Creek and Abram Creek, were chosen because they morphologically resembled the majority of the Stony River. The other two comparison streams were chosen based on their historic ability to support a fairly stable and diverse fish community and occurring in the same watershed. Reach locations were chosen based on accessibility and therefore were associated with either roadsides or bridges. The streams in this study ranged from 2nd (Difficult Creek) to 3rd (Stony River, Abram Creek, and New Creek) to 4th (North Fork of Patterson Creek).

The upper Stony River reach was bounded on the upstream end by the outfall of the catch basin below the dam on Mt. Storm Lake (Figure 3.1 and 3.2). This reach ended at the Dominion hydrolab at MSR-SR1. This reach was pre-determined for study as a possible location for fish habitat restoration/rehabilitation. The data for this reach was recorded separately from all other reach data. The only data recorded for the Upper Stony River reach were habitat maps and one fish survey.

Figure 3.1. Upper Stony River Reach Location

Figure 3.2. Upper Stony River Reach Aerial Photo

Reach areas were determined to be the reach length multiplied by the mean bankfull channel width. This did not account for side channels in the DC and SR3 reaches (Figures A7-A8 and A13-A14, respectively), however. Reach area for the upper Stony River reach was based on length and the mean bankfull width of the SR1 reach.

Although the sites on the Stony River may not be considered "independent" samples, other studies using sites on the same streams have found appropriate distance separation between sites was sufficient to consider each site independent. In the case of Stoneman and Jones (2000), they determined a minimum of 1 km between sites on the same stream was sufficient to treat sites independently. In the current study, the closest sites on the same stream are SR1 and SR4M, with a separation distance of approximately 1.9 km.

Discharge

Discharge values were obtained from daily mean values taken at USGS gaging stations with available data. For the Stony River reaches, discharge values were recorded from the station located at the US 50 bridge over the Stony River at the approximate midpoint of reach SR4. For the PC reach (North Fork Patterson Creek), the discharge data was obtained from the station located on the main stem of Patterson Creek at Headsville, Mineral County, West Virginia. For New Creek (NC reach), discharge data was taken from the station located on North Branch of Potomac River at Pinto, Allegany County, Maryland. For the Abram Creek (AC) and Difficult Creek (DC) reaches, discharge data was taken from the North Branch of Potomac River at Barnum, Mineral County, West Virginia (located downstream of Jennings Randolph Lake).

In order to approximate the expected discharge from New Creek and Abram Creek, historic discharge data were taken from the previously operating USGS stations at Keyser, Mineral County, West Virginia and Oakmont, Mineral County, West Virginia, respectively. All of these data were taken prior to the installation of Jennings Randolph Lake in 1981. Historic discharge data were also taken from the two stations on the North Branch of Potomac River on the equivalent dates to the New Creek and Abram Creek stations. The daily mean discharge values for the real-time discharge taken at the surrogate stations (N. Branch Potomac R.) were then found on all dates where data was gathered at these stations and the stations on New Creek and Abram Creek. By taking the mean values of the daily mean discharge values recorded on New Creek and Abram Creek on the same dates as the equivalent historic discharge values on the North Branch of Potomac River, an approximation for the expected discharge on these creeks was obtained. For instance, on August 20, 2004, the daily mean discharge at the North Branch of Potomac River USGS station was 304 cfs. This discharge value was recorded seven previous times at this station during the time when the New Creek station was recording data. The mean daily mean discharge for the New Creek station was determined to be 10.9 cfs (SDEV = 4.9 cfs). Sullivan (1987) found excellent correlation of discharge between an existing gaging station and study streams located even 50 miles from correlated streams.

The discharge data were used only as reference data and were taken on every date of habitat mapping and fish surveys (see Table 3.2).

Table 3.2. Discharge Values for Dates of Habitat Mapping and Fish Surveys

Reach	Date	Gathered Data	Discharge[a] (cfs)	Historic Discharge[b] (cfs)
AC	21-Aug-04	General Habitat Determination	216[e]	27.8
AC	22-Aug-04	Habitat Mapping	217[e]	37.0
AC	27-Aug-04	Fish Survey	256[e]	32.2
AC	4-Sep-04	Fish Survey	251[e]	30.7
AC	24-Sep-04	Fish Survey	295[e]	38.8
AC	11-Oct-04	Habitat Mapping	311[e]	44.7
AC	23-Oct-04	Habitat Mapping	253[e]	39.3
DC	22-Aug-04	General Habitat Determination	217[e]	N/A
DC	28-Aug-04	Fish Survey	257[e]	N/A
DC	5-Sep-04	Fish Survey	247[e]	N/A
DC	25-Sep-04	Fish Survey	401[e]	N/A
DC	11-Oct-04	Habitat Mapping	311[e]	N/A
DC	24-Oct-04	Habitat Mapping	256[e]	N/A
DC	5-Nov-04	Habitat Mapping	908[e]	N/A
NC	20-Aug-04	General Habitat Determination	304[d]	10.9
NC	21-Aug-04	Habitat Mapping	289[d]	11.3
NC	27-Aug-04	Fish Survey	312[d]	13.3
NC	4-Sep-04	Fish Survey	316[d]	8.9
NC	24-Sep-04	Fish Survey	591[d]	22.6
NC	10-Oct-04	Habitat Mapping	924[d]	33.4
NC	23-Oct-04	Habitat Mapping	385[d]	12.1
PC	20-Aug-04	General Habitat Determination	20	N/A
PC	20-Aug-04	Habitat Mapping	20	N/A
PC	27-Aug-04	Fish Survey	16	N/A
PC	4-Sep-04	Fish Survey	13	N/A
PC	24-Sep-04	Fish Survey	53	N/A
PC	10-Oct-04	Habitat Mapping	50	N/A
PC	23-Oct-04	Habitat Mapping	110	N/A
SR1	7-Aug-04	General Habitat Determination[c]	21	N/A
SR1	28-Aug-04	Fish Survey	8.6	N/A
SR1	5-Sep-04	Fish Survey	6.7	N/A
SR1	25-Sep-04	Fish Survey	40.0	N/A
SR3	28-Jul-04	General Habitat Determination	110	N/A
SR3	29-Aug-04	Fish Survey	7.6	N/A
SR3	5-Sep-04	Fish Survey	6.7	N/A
SR3	26-Sep-04	Fish Survey	43.0	N/A
SR3	8-Oct-04	Habitat Mapping	18	N/A
SR3	24-Oct-04	Habitat Mapping	110	N/A
SR3	12-Nov-04	Habitat Mapping	68	N/A
SR4M	29-Jul-04	General Habitat Determination	25	N/A
SR4M	29-Aug-04	Fish Survey	7.6	N/A
SR4M	5-Sep-04	Fish Survey	6.7	N/A

Reach	Date	Gathered Data	Discharge[a] (cfs)	Historic Discharge[b] (cfs)
SR4M	26-Sep-04	Fish Survey	43.0	N/A
SR4M	11-Oct-04	Habitat Mapping	19	N/A
SR4M	11-Nov-04	Habitat Mapping	33	N/A
SR4M	14-Nov-04	Habitat Mapping	96	N/A
SR4	27-Jul-04	General Habitat Determination	217	N/A
SR4	28-Aug-04	Fish Survey	8.6	N/A
SR4	4-Sep-04	Fish Survey	7.8	N/A
SR4	25-Sep-04	Fish Survey	40.0	N/A
SR4	11-Oct-04	Habitat Mapping	19	N/A
SR4	11-Nov-04	Habitat Mapping	33	N/A
SR4	14-Nov-04	Habitat Mapping	96	N/A
Upper Stony R.	4-Jun-04	Habitat Mapping	50	N/A
Upper Stony R.	12-Jun-04	Habitat Mapping	356	N/A
Upper Stony R.	8-Aug-04	Habitat Mapping	19	N/A
Upper Stony R.	15-Oct-04	Fish Survey	17	N/A
Upper Stony R.	13-Nov-04	Habitat Mapping	76	N/A

[a] Recorded as daily mean value at real-time USGS stations (see Methods: Discharge)

[b] Recorded as mean historic daily mean values (see Methods: Discharge)

[c] Determination of riffles, pools, and glides/runs (see Methods: Pebble Counts)

[d] Values recorded at N. Br. Potomac R. at Pinto, MD (see Methods: Discharge)

[e] Values recorded at N. Br. Potomac R. at Barnum, WV (see Methods: Discharge)

Pebble Counts

The pebble count data reach was used as the basic reach length upon which all other data were gathered. Based on methods discussed in Rosgen (1996), reaches were approximately 30 channel widths in length (see above). Reach bounds were field corrected using the approximate middle of the channels on each reach. After establishing the bounds, each reach was paced to determine the approximate percentages of pools, riffles, and glides/runs. In contrast to Rosgen (1996), glides/runs were added as a third general habitat type as glides/runs represented a significant portion of the lower gradient stream reaches (SR4 and New Creek). In addition, glides were recognized as a habitat type representing the intermediate condition between riffles and pools in Bisson et al. (1982). In determining general habitat types, the dominant type was determined for each stream length unit. For instance, in a lateral view of a typical stream, riffle complexes can contain small pools or runs between the steps of the riffle. However, these areas were paced as riffles only as long as riffle habitat was the dominant type in a lateral view and in association with immediate upstream and downstream views. If general habitat types varied across the cross section of the channel, the type comprising the greatest percentage was chosen. Paces were previously determined to be approximately 0.82 m (2.7 ft) in length. Pace totals were used to determine percentages of each general habitat type.

Upon determining the percentages of each general habitat type, pebble count locations were chosen based on these relative percentages. Percentages were rounded to the nearest 10%, with each reach having ten pebble count locations. For instance, SR1 had approximately 42.3% riffle habitat, 37.7% glides/runs, and 20.1% pool on the date of the reach walk (see Table 3.3). Therefore the resulting pebble counts were located in four of the riffle habitats, four of the glide/run habitats, and two of the pool habitats for a total of ten pebble counts. Pebble counts locations were, as much as possible, spread across the each reach's entire length to maximize the ability of the data to represent the reach.

Table 3.3. General Habitat Types per Reach

Reach	Date	Riffle %	Pool %	Glide/Run %
AC	21-Aug-04	37.5	13.1	49.3
DC	22-Aug-04	53.2	15.7	31.1
NC	20-Aug-04	33.2	5.9	60.9
PC	20-Aug-04	43.2	17.4	39.4
SR1	7-Aug-04	42.3	20.1	37.7
SR3	28-Jul-04	58.2	27.2	14.6
SR4M	29-Jul-04	42.5	12.1	45.4
SR4	27-Jul-04	42.4	28.7	28.8

For each pebble count location, a 25-m tape was used to measure the bankfull width to the nearest 0.1 m. A total of twenty pebbles were measured at each pebble count location. As suggested in Rosgen (1996), the location of each measurement was determined by dividing bankfull width by the number of measurements (20), then taking a measurement at every equal interval. Each reach therefore had 200 measurements. Measured particles were determined by the first "blind" touch. Calipers were used to measure each particle along its intermediate axis to the nearest 0.1 mm. For particles determined to be less than 0.1 mm, particle size was assumed to be 0.09 mm. Many of these particles were likely less than 0.09 mm; however, this value was chosen as conservative for estimation purposes. Values for very fine material/clay were arbitrarily assigned a value of 0.009 mm. In the analysis section of this report, "bedrock" was arbitrarily assigned a value of 8,000 mm for histogram purposes.

After recording all values, data were later grouped based on general habitat type (pools, riffles, glides/runs) and also combined to generate overall reach values. The D_{50} value represents the diameter of the particle of which 50% of the values are less than and 50% of values are greater than. In other words, this particle represented the median pebble count size.

Pebble sizes were classified according to the modified Wentworth scale as described in Rosgen (1996) and as indicated below in Table 3.4. For statistical purposes, general descriptions were further classified using the numeric values contained in third right column in Table 3.4.

Table 3.4. Pebble Count Sizes

Description	Size (mm)*	Wentworth
Silt/Clay	<0.062	1
VF Sand	0.062 - 0.125	2
Fine Sand	0.125 - 0.25	2
Medium Sand	0.25 - 0.50	2
Coarse Sand	0.50 - 1.0	2
VC Sand	1.0 - 2	2
VF Gravel	2 - 4	3
Fine Gravel	4 - 6	3
Fine Gravel	6 - 8	3
Med. Gravel	8 - 12	3
Med. Gravel	12 - 16	3
Coarse Gravel	16 - 24	3
Coarse Gravel	24 - 32	3
VC Gravel	32 - 48	3
VC Gravel	48 - 64	3
Sm. Cobble	64 - 96	4
Sm. Cobble	96 - 128	4
Lg. Cobble	128 - 192	4
Lg. Cobble	192 - 256	4
Sm. Boulder	256 - 384	5
Sm. Boulder	384 - 512	5
Med. Boulder	512 - 1024	5
Lg. Boulder	1024 - 2048	5
VL Boulder	2048 - 4096	5
Bedrock	>4096	6

*As measured on the intermediate axis

Cross Sections

To generate values for entrenchment and width/depth ratios, cross sections were used at each reach. Cross sections were located in relatively straight stretches, avoiding riffles and pools. In general, these locations corresponded to glide/run locations determined during the general habitat walks discussed above. Three cross sections were used at each reach, with attempts to spread these locations across the length of the reach. Mean values obtained for Rosgen variables are discussed below.

At each cross section, a 25-m tape was used to determine bankfull width, and the tape remained in place to ensure rod readings (equipment described below in Methods: Slope) were recorded perpendicular to flow across the stream. Readings were taken arbitrarily across the reach; however, breaks in stream bottom elevation were targeted. Cross sectional area was determined by multiplying measured bankfull width by mean bankfull depth.

Slope

Slope was determined with a Berger Instruments level and rod along each Rosgen reach. The rod was placed at the water surface elevation, in this case on the right bank (looking downstream) for each reading. The first reading at each location (whether starting downstream or upstream) was arbitrarily assigned a value of 1,000 ft. Each value was measured to the nearest 1/8 in. Slope is defined as the change in elevation over a distance; therefore actual elevation values are not necessary for determination of slope. Slope was recorded for the entire length of each reach, and therefore can be considered a mean elevation change for the entire reach. Local, within-reach elevation changes will influence habitat within the reach. However, these data were not recorded for this study.

Fish Surveys

Fish surveys were based upon methods discussed in Doloff et al. (1993). Fish surveys were completed in teams of two and three (except for the upper Stony River reach where a team of four was used). Surveys began at the downstream end of each reach and proceeded upstream. Each team spaced themselves laterally across the reach to maximize the ability to count fish. Prior to starting the survey, each team would wait a period of five minutes to ensure fish disturbed during preparation were relatively settled into “normal” behavior. Surveys would proceed upstream, maintaining a steady pace (roughly equivalent to pacing for land-based survey purposes), moving in a zigzag pattern laterally within each team member’s “zone.” One team member would be assigned recording of all data, whereas another team member would record time. During the survey, each team would pause approximately every 10 to 25 meters longitudinally, depending on breaks in habitat type. For instance, in areas of quick changes between riffle to pool or glide/run habitat, pauses would be closer to every 10 meters. Areas of relatively homogeneous general habitat would involve pauses after approximately 25 meters, for instance. At each pause position, the team would wait for one minute while continuing to record data. These data were kept separate during each survey, but totals for the entire reach were combined.

In recording data, each team member counted fish in terms of three general groups: “ones” were sightings of single fish; “twos” were sightings of groups of fish, with counts of numbers within the group; “threes” were sightings of schools of fish, with estimations of the numbers of fish within the school. Schools of fish were rarely encountered during this study.

During the first survey at each reach, three pools were also videotaped for fish density and habitat. These pools were snorkeled during this and subsequent surveys to enable more accurate counting of fish and to disturb fish from under rocks and other cover.

While surveying, attempts were made to approximate 100-meter intervals. These approximate intervals will be used as possible sub-samples for data examination. For statistical purposes, however, these “sub-samples” involve pseudo-replication in that they are not independent of each other. Therefore these intervals were labeled as "Psuedo-SubUnits," or "PSUs". Fish survey dates, approximate PSU length, numbers of pauses, and mean interval length are recorded in Table 3.5.

Table 3.5. Fish Survey General Information (PSU = Pseudo SubUnit—see text for details)

Reach	Date	PSU Length (m)	Number Pauses	Mean Interval Length (m)
AC	27-Aug-04	115	23	25.0
AC	4-Sep-04	115	29	19.8
AC	24-Sep-04	115	22	26.1
DC	28-Aug-04	110	21	20.9
DC	5-Sep-04	110	25	17.5
DC	25-Sep-04	110	20	21.9
NC	27-Aug-04	107	20	21.4
NC	4-Sep-04	107	22	19.5
NC	24-Sep-04	107	18	23.8
PC	27-Aug-04	102	27	15.1
PC	4-Sep-04	102	15	27.3
PC	24-Sep-04	102	22	18.6
SR1	28-Aug-04	100	25	24.0
SR1	5-Sep-04	100	26	23.1
SR1	25-Sep-04	100	26	23.1
SR3	29-Aug-04	113	25	22.6
SR3	4-Sep-04	113	24	23.5
SR3	26-Sep-04	113	22	25.7
SR4M	29-Aug-04	103	28	22.0
SR4M	5-Sep-04	103	26	23.7
SR4M	26-Sep-04	103	23	26.8
SR4	28-Aug-04	110	34	22.6
SR4	4-Sep-04	110	30	25.6
SR4	25-Sep-04	110	26	29.5

For the upper Stony River reach fish survey, a total of four team members were used. GPS positioning was recorded at the start of the survey, and at the end of each subsequent interval (pause). In addition to density, the species of each fish was identified. Previous information on this study reach indicated a low number of species; therefore species identification could be achieved. Four team members were used to increase the accuracy of the density data. No attempt was made to sub-divide this reach into PSUs.

General Habitat Assessments

Using EPA standard methods for physical habitat (Barbour et al. 1999), general habitat was taken at four or five 100-meter reaches per Rosgen reach. Members of a graduate-level course independent of this study gathered some of these data. The reaches used for physical habitat assessment were spread across the Rosgen reach and later combined for mean values. Low-gradient sheets (Barbour et al. 1999) were used at NC and SR4, while high-gradient sheets were used on the remaining sites.

Riparian Cover

In order to approximate the riparian cover available at each Rosgen reach, a GRS densitometer was used to record percentage riparian cover at various locations along each reach. Values were recorded at the water's edge on the left-descending and right-descending banks and in mid-channel at each location. A total of ten to twelve locations were recorded at each Rosgen reach.

Habitat Mapping—Hydraulic Channel Units

Mapping conventions were based on Bisson et al. (1982), and modified to suit the reaches in this study. Habitat types are discussed in detail in Table 3.6. Habitat mapping was completed a total of three times at each Rosgen reach, and four times for the upper Stony River reach. Habitat mapping was not completed on reach SR1 separately, however, as it was a subunit of the upper Stony River reach. Although depth was not a variable measured in the present study, most of the backwater pool and secondary channel pool habitat in these stream reaches would be considered shallow (< 0.5 m).

Table 3.6. Hydraulic Channel Units and Descriptions for Study.

Hydraulic Channel Unit	Numbering System	Description
Riffle	1	Associated with turbulent flow/fast water; <2% gradient; substrate generally exposed
Rapid	2	Associated with turbulent flow/fast water; 2 – 4% gradient; substrate exposed
Cascade	3	Associated with turbulent flow/fast water; > 4% gradient
Lateral Scour Pool (general)		Have distinct heads and toes; max. depth gen. ≥ reach mean; borders variable; flow directed both laterally and down from main channel flow direction
Lateral Scour Pool associated with Root wad	4	See general description above; associated with exposed root wad(s) on bank; always found along stream margins
Lateral Scour Pool associated with Boulders	5	See general description above; associated with boulders; found from stream margins to mid-channel
Lateral Scour Pool associated with Bedrock	6	See general description above; associated with bedrock; mostly found along stream margin
Lateral Scour Pool associated with Large Woody Debris	7	See general description above; associated with large woody debris; generally little eddy current

Hydraulic Channel Unit	Numbering System	Description
Obstruction Pool	8	Completely blocked by obstruction; scouring action caused by eddying, little lateral flow as compared to main channel flow
Plunge Pool	9	Located immediately below large obstruction; majority of flow scours in a downward direction as compared to main channel flow
Secondary Channel Pool	10	Separated from main channel by obstructions large enough to severely limit or completely obstruct both lateral and/or upstream/downstream head by adult piscivorous fish; can be found in transition between tributary and main channel; generally experience lateral interstitial flow; experience surface flow at head and foot; depth variable, enough to support cyprinids (generally shallower than main channel pools)
Backwater Pool (general)		Separated from main channel such that surface flow limited to one head; depth variable, enough to support cyprinids (depth similar to secondary channel pools)
Backwater Pool associated with Boulders	11	See general description above; associated with boulders
Backwater Pool associated with Large Woody Debris	12	See general description above; associated with large, woody debris
Backwater Pool associated with Root wad	13	See general description above; associated with large, woody debris
Backwater Pool associated with Bedrock	14	See general description above; associated with bedrock
Isolated Pool	15	Separated completely from main channel via surface flow; may experience interstitial flow (mostly); depth variable, enough to support cyprinids (similar to secondary channel pools and backwater pools)
Run/Glide	16	Broadest category of classification scheme; generally less flow than riffles, more flow than pools based on depth and turbulence; exposure of substrate in some cases (but without turbulent flow); depth variable, mostly uniform (lacking distinct head and/or toe)
Pool (Unclassified)		Generally larger pools; may be associated with more than one cover/substrate type (usually); dominate main channel (mostly bank to bank)

Hydraulic Channel Unit	Numbering System	Description
Side Channel		Separated from main channel; further subdivided using above classification scheme; experience surface flows from main channel at higher discharge; extremely little to nonexistent lateral interstitial flow from main channel (may receive surface flows from tributaries)

Each map was initiated at the upstream bound of each reach, and mapping proceeded downstream. Maps were completed for the within-bankfull stage in most instances; however, occasionally small isolated pools or connected backwater pools were mapped even if they continued beyond the observed bankfull stage. In generating the maps, numbers were used to identify habitat types on the map in lieu of drawing every rock. However, large boulders that served as anchors for riffles, rapids or cascades, structure for pools, or otherwise separated habitat types were recorded. Large woody debris, whether submerged or resting above the water surface, was also mapped. An exception to the numbering system was glides (numbered as 16 in Table 3.6). In general, glides/runs are transitions from riffles to pools and vice-versa (Bisson et al. 1982). Therefore, in the generated habitat maps, unbounded blank areas were assumed to be glide/run areas unless otherwise noted. On occasion (SR4), glides served as large-sized habitat types and these areas were recorded on the maps.

Mapping was completed to show areas that at a minimum were sufficient to support Cyprinid fish. It is important to note habitat types varied according to discharge. For instance, an area that was mapped as a “secondary channel pool” at low discharge could be later mapped as a “lateral scour pool” at a higher discharge.

The standard area used for presentation of results was a squared dekameter (dam^2), equivalent to 100 m^2. This unit was chosen arbitrarily to present HCU density numbers close to 1.

Rosgen Data

In order to classify each of the study reaches, Rosgen (1996) Level II classification was used. Entrenchment was determined from the cross section data using maximum depth and flood-prone area width and elevation. Flood-prone area width is found at the elevation equivalent to twice the maximum bankfull depth. Entrenchment is equal to the flood-prone area width divided by bankfull width. Three entrenchment values were recorded at each location and combined to give a mean entrenchment value for the reach.

Width/depth ratios (Rosgen 1996) were determined from the cross-section data using the mean bankfull width divided by mean bankfull depth. Similar to entrenchment, three values were determined for each reach and combined to generate a mean width/depth ratio for each reach.

Sinuosity was recorded as stream length divided by valley length (Rosgen 1996). In contrast to the other Rosgen values, however, this value was generated by measuring stream length for two meander wavelengths, with the reaches identified for this study used as approximate midpoints for this measurement. These values were determined based on aerial photography and ESRI ArcMap© software.

In addition to data used to generate Level II classifications for each reach, meander width ratio was determined from aerial photography and field-generated data for each reach. Similar to sinuosity, this value was determined by using two meander wavelengths with the reaches used for this study as approximate midpoints. Belt width is determined as the width of meanders within the valley, while bankfull width was determined as the mean bankfull width recorded during the pebble count and cross section measurements. Meander width ratio is equal to belt width divided by the mean bankfull width.

Upper Stony River Reach

As the main focus of this study, this reach encompasses the approximate 1.2 miles from the dam outfall (actually starting at the outfall of the catch basin located below the dam at Mt. Storm Lake) to the Dominion hydrolab at MSR-SR1. This reach was mapped a total of four times and one fish survey was completed for the entire reach. Rosgen reach SR1 occurred at the approximate midpoint of this reach, as indicated in Figure 3.2.

In addition to habitat mapping and fish surveys, an approximate 100 meter reach was identified within the SR1 reach for detailed cross section analysis. These data were recorded on a Nikon Total Station and may be used later to generate surfaces representing water elevations at different discharges and available habitat based on the mapping conventions used for this study. Cross sections were taken at approximately every meter for the entire 100-m reach. In contrast to cross sections used for the Rosgen data, these cross sections were detailed analyses of the bottom elevation. In addition, water surface elevation was recorded at various intervals across the reach. These data may be used to predict the availability of habitat based on discharge.

Statistics

Substrate values were transformed into the following numeric categories based on a modified Wentworth scale: silt/fines/clay = 1, sand = 2, gravel = 3, cobble =4, boulder =5 and bedrock = 6. This method of transformation has been successfully used in other studies (Inoue and Nakano 1999, Inoue and Nunokawa 2002, and others). This allows pebble sizes of widely varying sizes to be more easily analyzed with traditional statistical tests, including bedrock.

For comparisons among sites, one-way ANOVA followed by Student-Newman-Keuls multiple t-test comparisons were used for the following single variables: bankfull depth at cross sections by site, bankfull widths (measured at pebble count locations) by site, bankfull widths at riffle pebble count locations by site, flood prone area width by site, cross sectional area by site, mean entrenchment ratio by site, mean width/depth ratio by site, select hydraulic channel unit densities by site, modified Wentworth pebble size, mean RBP values per site, mean riparian shading per site, mean overall stream shading, fish density per site and HSI variable comparisons. These same tests were used on the Criteria groups (the five categories described in Introduction: Purpose) on all of the above except pebble counts, RBP values, shading values, and HSI variables. Alpha levels for significance of individual variables were set at 0.05 and tests were completed using the SPSS package for Windows (Version 13.0).

In addition, a Pearson correlation test was run on all of the geomorphic variables and hydraulic channel unit variables by site to determine those variables significantly correlated with each other. Due to the high correlations between many of these variables, Principal Components Analysis, although completed for both geomorphic variables and hydraulic channel units separately and together by site, are not reported here.

Chapter IV. Results

For this report, the results will be separated based on three main themes: Rosgen data, habitat mapping, and fish surveys.

Fish Surveys

Three fish surveys were completed for each comparison reach in the study. These surveys were done in summer (2) and fall (1) 2004, at various discharges (Table 3.2). The single survey completed on the upper Stony River reach in fall 2004 identified all species.

Noted differences in fish counts were observed at most reaches during subsequent surveys of the same reach (Table 4.1). These differences occurred despite the addition of one team member on the third survey at each reach. These differences may be attributable to changes in season and fish activity, or to post flood population recovery as the watershed experienced high rainfalls from the remnants of Hurricanes Frances and Ivan in September 2004. As expected, New Creek and North Fork Patterson Creek had the highest fish densities across all discharges. However, Abram Creek also had a fairly healthy fish population. The SR1 reach had the highest fish density of all Stony River reaches, and its density was comparable to Difficult Creek (Table 4.1).

Table 4.1. Fish Survey Results

Site	Date	Team Members	Total Fish	Density (per 100 m)	Density (per 100 m^2)
AC	27-Aug-04	2	601	105	4.98
AC	4-Sep-04	2	638	111	5.29
AC	24-Sep-04	3	108	19	0.89
DC	28-Aug-04	2	86	20	1.47
DC	5-Sep-04	2	72	16	1.23
DC	25-Sep-04	3	46	11	0.79
NC	27-Aug-04	2	1113	260	16.21
NC	4-Sep-04	2	705	165	10.27
NC	24-Sep-04	3	397	93	5.78
PC	27-Aug-04	2	1122	280	20.55
PC	4-Sep-04	2	860	214	15.75
PC	24-Sep-04	3	420	105	7.69
SR1	28-Aug-04	2	251	42	1.82
SR1	5-Sep-04	2	66	11	0.48
SR1	25-Sep-04	3	51	8	0.37
SR3	29-Aug-04	2	1	0.2	0.01
SR3	5-Sep-04	2	0	0.0	0.00
SR3	26-Sep-04	3	36	6.4	0.33
SR4M	29-Aug-04	2	62	10	0.48
SR4M	5-Sep-04	2	14	2	0.11
SR4M	26-Sep-04	3	9	1	0.07
SR4	28-Aug-04	2	9	1.2	0.05
SR4	4-Sep-04	2	10	1.3	0.06
SR4	25-Sep-04	3	3	0.4	0.02
Upper Stony	15-Oct-04	4	91	5	N/A

An important finding of the fish surveys on Difficult Creek and SR3 was the presence of fish in side channels. A total of one fish was found in the main stem of SR3 out of all three surveys (Table 4.2). However, during the third survey of this reach, 36 fish were found in the side channel on the left side (looking downstream) of the large mid-reach island, outside of the main channel. Whether this side channel normally serves as a refuge for stream fish or whether these were a consequence of wash-ins from flooding is unknown. However, these side channels may be important as additional habitat, especially pool habitat, for the overall reach.

Table 4.2. Fish Survey Results for PSUs by Reach (SC = Side Channels).

Site	Date	PSU 1	PSU 2	PSU 3	PSU 4	PSU 5	PSU 6	PSU 7	SC
AC	27-Aug-04	50	155	152	86	80	78		
AC	4-Sep-04	62	91	147	153	114	71		
AC	24-Sep-04	10	22	49	5	17	5		
DC	28-Aug-04	17	20	13	36				*
DC	5-Sep-04	19	13	13	27				16
DC	25-Sep-04	14	10	13	9				6
NC	27-Aug-04	171	225	445	272				
NC	4-Sep-04	46	138	322	199				
NC	24-Sep-04	23	36	151	187				
PC	27-Aug-04	227	192	247	456				
PC	4-Sep-04	175	162	372	151				
PC	24-Sep-04	53	159	123	85				
SR1	28-Aug-04	12	97	9	71	32	30		
SR1	5-Sep-04	1	17	4	21	3	20		
SR1	25-Sep-04	3	6	8	24	5	5		
SR3	29-Aug-04	1	0	0	0	0	0		*
SR3	5-Sep-04	0	0	0	0	0	0		0
SR3	26-Sep-04	0	0	0	0	0	0		36
SR4M	29-Aug-04	0	0	10	36	13	3		
SR4M	5-Sep-04	1	0	2	2	9	0		
SR4M	26-Sep-04	1	0	0	1	6	1		
SR4	28-Aug-04	0	1	0	0	1	3	4	
SR4	4-Sep-04	1	0	0	3	0	6	0	
SR4	25-Sep-04	0	1	0	0	0	2	0	

*Side channels not surveyed

Mean values of fish density per length (100 m) and per area (100 m^2) of all surveys are presented below in Table 4.3. Individual fish survey data are contained in Table A3 (Appendix). Figures A49 to A51 show comparative histograms of each survey based on total fish, total fish density per 100 m, and total fish density per 100 m^2, respectively.

Table 4.3 Mean Fish Density per Site (SDEV = Standard Deviation; SEM = Standard Error)

Site	Mean Density (per 100 m)	SDEV	SEM	Mean Density (per 100 m^2)	SDEV	SEM
AC	78.2	51.5	29.8	3.72	2.45	1.42
DC	15.5	4.6	2.7	1.16	0.35	0.20
NC	172.5	83.9	48.4	10.75	5.23	3.02
PC	199.7	88.5	51.1	14.66	6.50	3.75
SR1	20.4	18.5	10.7	0.89	0.81	0.47
SR3	2.2	3.6	2.1	0.11	0.19	0.11
SR4M	4.6	4.8	2.7	0.22	0.22	0.13

Site	Mean Density (per 100 m)	SDEV	SEM	Mean Density (per 100 m^2)	SDEV	SEM
SR4	1.0	0.5	0.3	0.04	0.02	0.01

Table 4.4 indicates the results of the single fish survey completed on the Upper Stony River reach identifying species and total numbers.

Table 4.4. Results of Upper Stony River Reach Fish Survey.

BD*	CC	WS	SM	Total
27	33	15	16	91

* BD = blacknose dace; CC = channel catfish; WS = white sucker; SM = smallmouth bass

Habitat Mapping

As indicated in Table 4.5, Difficult Creek and SR3 had the highest amount of riffle habitat, while SR3 and SR4 had the highest amount of overall pool habitat. However, SR4 had a relatively small number of hydraulic channel units compared to the other reaches (Table 4.6). This may be the result of the low gradient of the channel; the other low-gradient channel (New Creek) also had a relatively low number of specific hydraulic channel units compared with the other reaches (Table 4.6).

Table 4.5. General Habitat Types per Reach

Reach	Date	Riffle %	Pool %	Glide/Run %	Pool/Riffle Ratio
AC	21-Aug-04	37.5	13.1	49.3	0.349
DC	22-Aug-04	53.2	15.7	31.1	0.295
NC	20-Aug-04	33.2	5.9	60.9	0.178
PC	20-Aug-04	43.2	17.4	39.4	0.403
SR1	7-Aug-04	42.3	20.1	37.7	0.475
SR3	28-Jul-04	58.2	27.2	14.6	0.467
SR4M	29-Jul-04	42.5	12.1	45.4	0.285
SR4	27-Jul-04	42.4	28.7	28.8	0.677

Table 4.6. Hydraulic Channel Units per Reach.

Site	Date	1*	2	3	4	6	7	8	9	10	11	12	13	14	15	16	UC Pool
AC	22-Aug-04	77	5	0	2	17	1	0	0	2	29	24	0	2	0	14	1
AC	11-Oct-04	111	3	0	3	55	1	0	0	8	44	48	0	0	0	7	1
AC	23-Oct-04	123	42	1	2	45	1	0	0	14	65	19	0	1	0	6	1
DC	11-Oct-04	120	6	0	5	38	0	0	0	7	33	27	0	6	0	3	2
DC	24-Oct-04	113	4	0	1	29	0	0	0	5	22	20	3	5	0	0	0
DC	5-Nov-04	117	14	0	7	34	0	0	0	11	32	15	0	6	0	5	0
NC	21-Aug-04	27	0	0	6	4	0	0	0	0	2	2	0	2	0	5	1
NC	10-Oct-04	45	0	0	13	6	0	0	0	0	14	4	0	4	0	1	2

Site	Date	1*	2	3	4	6	7	8	9	10	11	12	13	14	15	16	UC Pool
NC	23-Oct-04	64	1	0	4	9	0	0	0	0	38	6	0	1	0	3	1
PC	20-Aug-04	63	4	0	1	5	2	0	1	4	15	1	1	0	0	2	1
PC	10-Oct-04	66	9	1	3	30	2	1	7	15	27	0	0	2	2	2	7
PC	23-Oct-04	100	18	0	1	36	2	0	9	38	18	0	3	3	6	2	9
SR3	8-Oct-04	68	15	0	0	27	0	0	0	4	33	15	0	0	0	20	0
SR3	24-Oct-04	110	13	1	3	34	0	0	0	12	70	25	0	1	0	6	2
SR3	12-Nov-04	140	22	0	2	38	0	0	0	6	77	38	0	0	0	14	3
SR4M	8-Oct-04	75	13	1	0	28	1	0	0	3	32	18	0	0	0	16	1
SR4M	24-Oct-04	104	24	3	1	38	1	0	0	12	41	32	0	0	1	2	1
SR4M	14-Nov-04	127	13	0	0	38	1	0	0	6	79	24	0	0	1	7	1
SR4	11-Oct-04	45	0	0	1	8	0	0	0	0	7	19	1	0	0	3	11
SR4	11-Nov-04	41	0	0	1	4	0	0	0	0	17	5	1	0	0	4	9
SR4	14-Nov-04	42	0	0	3	13	0	0	0	0	18	11	1	0	0	0	8
Upper Stony	4-Jun-04	198	23	4	3	40	5	0	3	3	74	32	0	0	2	12	20
Upper Stony	12-Jun-04	163	25	2	3	29	4	0	0	6	31	18	1	0	0	0	15
Upper Stony	8-Aug-04	206	10	0	2	18	5	0	1	3	37	41	1	0	0	4	30
Upper Stony	13-Nov-04	355	20	2	8	128	6	0	0	16	141	64	1	0	3	3	10

*See Table 3.6 for HCU types

Two morphologically similar reaches on the Stony River, SR4M and SR3, had similar numbers of backwater pools, and these reaches along with Abram Creek had the highest number of backwater pools. All of the reaches with high numbers of backwater pools also had larger D_{50} sizes, seeming to indicate large obstructions, especially boulders, tend to be important for developing these channel units. This phenomenon was consistent with the habitat mapping, where backwater pools were often found adjacent to large boulder obstructions.

Mapping showed the total numbers of pool habitats tended to increase over time across all reaches. This increase may be the result of increasing familiarity with stream reaches over subsequent fish surveys and habitat mapping. However, the basis for identification of habitats was consistent throughout the study. Table 4.7 contains mean densities of habitat units combined over all discharges. Densities were based on dekameters^2 as these units provided numbers that did not have either extremely large or small values (1 dekameter = 10 meters; 1

dam^2 = 100 m^2). The high discharge level of Upper Stony on June 12, 2004 was not included in the Upper Stony values.

Table 4.7. Total Mean Select Hydraulic Channel Unit Density (per dam^2) Over All Discharges[a]

(Values in parentheses are standard error; LSP=Lateral Scour Pools, all associations; SCP=Secondary Channel Pools; BKP=Backwater Pools, all associations; PPL=Plunge Pools; NPL=Total Pools[b])

Site	Total LSP Density	SCP Density	Total BKP Density	PPL Density	NPL Density
AC	0.351 (0.096)	0.381 (0.086)	0.260 (0.071)	0.066 (0.029)	1.141 (0.192)
DC	0.651 (0.069)	0.497 (0.060)	0.468 (0.060)	0.131 (0.030)	1.804 (0.182)
NC	0.204 (0.039)	0.262 (0.154)	0.092 (0.017)	0.000 (0.000)	0.621 (0.168)
PC	0.507 (0.181)	0.348 (0.183)	0.427 (0.064)	0.047 (0.020)	1.471 (0.465)
SR3	0.322 (0.037)	0.558 (0.127)	0.245 (0.062)	0.068 (0.022)	1.333 (0.217)
SR4M	0.277 (0.027)	0.389 (0.111)	0.195 (0.023)	0.054 (0.020)	0.986 (0.022)
Upper Stony	0.173 (0.086)	0.203 (0.074)	0.116 (0.025)	0.018 (0.010)	0.577 (0.175)

[a]See Table 3.2 for discharges; [b]See Table 3.6 for HCU descriptions

Rosgen Data

As indicated in Table 4.9 and using Level I values from Table 4.8, differences between Level I classifications were observed at different cross section locations within each reach. Of all of the study reaches, only Difficult Creek seemed to be consistently classified at Level I ("C"). These differences may be the result of not identifying "reference" reaches prior to study initiation. In contrast to Rosgen (1996), this study used three cross sections for each reach where Rosgen methods indicate one. However, in using three sites, the resulting mean values represent the overall reach classification. The mean values for each reach seemed to indicate the Stony River is a "B" type stream between the Mt. Storm Lake dam and the US 50 bridge. As described in Rosgen (1996), narrow valleys where these channel types are found limit the development of a wide floodplain. They tend to be influenced by debris constrictions and local confinement, and produce scour pools and characteristic "rapids" (Rosgen 1996). This seems to be consistent with the habitat mapping results found in Table 4.6. The low entrenchment ratio (high entrenchment) observed in the SR4M reach, especially upstream of Fourmile Run, classified this reach as an "F" channel type that are found in low relief type III valleys, similar to "B" channels (Rosgen 1996). Table 4.8 includes some of the Level I Rosgen (1996) values used to classify the stream reaches in Table 4.9.

Table 4.8. Level I Rosgen (1996) Values per Reach.

Site	Channel Width (m)[a]	Mean Bankfull Width (m)	Meander Belt Width Ratio	Valley Length (m)[b]	Stream Length (m)[b]	Sinuosity[b]
AC	98.94	21.03	4.705	1985	2293	1.16
DC	24.86	13.33	1.865	1009	1089	1.08
NC	33.18	16.04	2.069	1460	1472	1.01
PC	32.40	13.35	2.427	1186	1641	1.13

Site	Channel Width (m)[a]	Mean Bankfull Width (m)	Meander Belt Width Ratio	Valley Length (m)[b]	Stream Length (m)[b]	Sinuosity[b]
SR1	36.20	22.95	1.577	1075	1203	1.12
SR3[c]	206.9	17.73	11.67	1423	1645	1.16
SR4M	41.59	21.12	1.969	1337	1480	1.11
SR4	214.5	23.07	9.298	1909	2453	1.28

[a]Widest part of meander wavelength (Rosgen 1996); [b]As measured from approximately two meander wavelengths with sample reach in middle; [c]These values included the large island at the approximate middle of the reach

Table 4.9. Individual Cross-Section and Select Level II Rosgen (1996) Data.

Reach	Cross Section	Mean Bankfull Depth (m)	Bankfull Width (m)	Flood Prone Area Width (m)	Entrenchment Ratio	Entrenchment	Width/Depth Ratio	Level I Stream Type*
AC	ACCX1	1.20	23.46	29.42	1.25	Entrenched	19.58	"F"
AC	ACCX2	2.44	23.70	101.5	4.28	Slightly Entrenched	9.72	"E"
AC	ACCX3	1.06	26.74	36.40	1.36	Entrenched	25.27	"F"
DC	DCCX1	0.741	12.1	41.2	3.40	Slightly Entrenched	16.36	"C"
DC	DCCX2	0.405	12.55	32.1	2.56	Slightly Entrenched	30.93	"C"
DC	DCCX3	0.814	13.49	42.6	3.16	Slightly Entrenched	16.59	"C"
NC	NCCX1	0.820	17.96	33.17	1.85	Moderately Entrenched	21.93	"B"
NC	NCCX2	1.21	17.75	72.95	4.11	Slightly Entrenched	14.71	"C"
NC	NCCX3	0.646	14.35	29.26	2.04	Moderately Entrenched	22.22	"B"
PC	PCCX1	0.582	14.00	29.44	2.10	Moderately Entrenched	24.09	"B"
PC	PCCX2	0.573	12.75	78.04	1.87	Moderately Entrenched	22.21	"B"
PC	PCCX3	0.491	11.21	14.31	1.28	Entrenched	22.85	"C"
SR1	SR1CCX1	0.787	21.46	30.06	1.40	Entrenched	27.25	"F"
SR1	SR1CCX2	0.576	28.43	33.28	1.17	Entrenched	49.30	"F"
SR1	SR1CCX3	0.869	18.35	39.30	2.14	Moderately Entrenched	21.14	"B"
SR3	SR3CCX1	0.665	25.66	35.75	1.39	Moderately Entrenched	38.54	"B"

Reach	Cross Section	Mean Bankfull Depth (m)	Bankfull Width (m)	Flood Prone Area Width (m)	Entrenchment Ratio	Entrenchment	Width/Depth Ratio	Level I Stream Type*
SR3	SR3CCX2	0.750	24.65	35.72	1.45	Moderately Entrenched	32.86	"B"
SR3	SR3CCX3	0.738	23.77	56.09	2.36	Slightly Entrenched	34.70	"C"
SR4M	SR4MCCX1	0.726	20.83	25.74	1.24	Entrenched	28.68	"F"
SR4M	SR4MCCX2	0.692	14.04	20.81	1.48	Moderately Entrenched	20.32	"B"
SR4M	SR4MCCX3	0.643	26.24	30.54	1.16	Entrenched	40.75	"F"
SR4	SR4CCX1	0.744	19.41	25.09	1.29	Entrenched	26.04	"F"
SR4	SR4CCX2	0.610	28.39	32.91	1.16	Entrenched	46.59	"F"
SR4	SR4CCX3	1.27	23.98	41.75	1.74	Moderately Entrenched	18.81	"B"

*Includes sinuosity values taken from Table 4.8

Pebble count data indicated significant differences among reaches based on mean modified Wentworth pebble sizes, both among entire reaches and among mesohabitat types per reach. Table 4.10 contains the results of the modified Wentworth pebble counts sizes; see Figures A17 through A48 for histograms of pebble count sizes and cumulative percent of each pebble size. Table A2 contains values for each pebble count location. Figures 4.1 to 4.4 show box and whisker plots for the values contained in Table 4.10.

Table 4.10 Results of Modified Wentworth Pebble Counts by Site and Mesohabitat Type

Site	Overall		Glide		Pool		Riffle	
	Mean*	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**	**Mean**	**SEM**
AC	3.78^{a}	(0.08)	$3.63^{a,b}$	(0.11)	$3.05^{a,b}$	(0.34)	4.15^{a}	(0.11)
DC	3.98^{a}	(0.07)	$3.75^{a,b}$	(0.14)	$4.15^{b,c}$	(0.24)	4.04^{a}	(0.10)
NC	3.26^{b}	(0.06)	$3.31^{b,c}$	(0.02)	$3.00^{a,b}$	(0.15)	3.23^{b}	(0.11)
PC	3.53^{c}	(0.08)	$3.31^{b,c}$	(0.12)	$3.15^{a,b}$	(0.15)	3.93^{a}	(0.10)
SR1	3.98^{a}	(0.08)	$3.80^{a,b}$	(0.12)	$4.10^{b,c}$	(0.24)	4.09^{a}	(0.11)
SR3	3.86^{a}	(0.08)	4.05^{a}	(0.17)	$3.60^{b,c}$	(0.16)	3.99^{a}	(0.10)
SR4M	3.90^{a}	(0.08)	$3.70^{a,b}$	(0.12)	$3.50^{b,c}$	(0.22)	4.30^{a}	(0.12)
SR4	3.26^{b}	(0.08)	2.90^{c}	(0.13)	2.72^{a}	(0.13)	3.94^{a}	(0.09)

*Mean values with same letters are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$) among sites; SEM = standard error of the mean

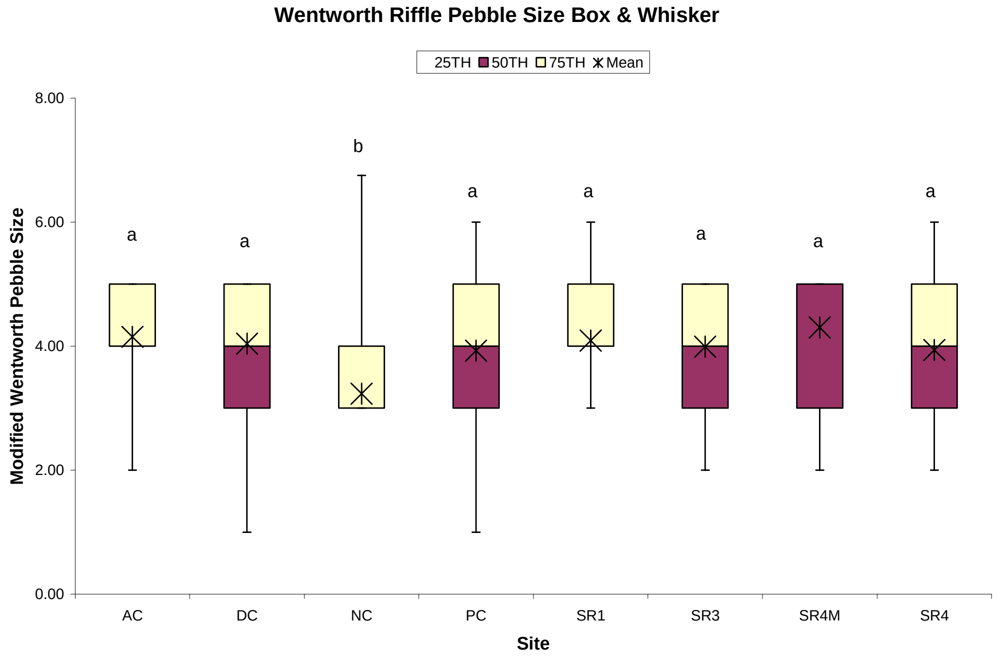

Figure 4.1. Box and Whisker Plot of Riffle Modified Wentworth Pebble Count Data
(Boxes with the same letter are not significantly different as determined using Student-Newman-Keuls ($\alpha = 0.05$); see Table 3.2 for pebble count sizes)

Figure 4.2. Box and Whisker Plot of Glide Modified Wentworth Pebble Count Data
(Boxes with the same letter are not significantly different as determined using Student-Newman-Keuls ($\alpha = 0.05$); see Table 3.2 for pebble count sizes)

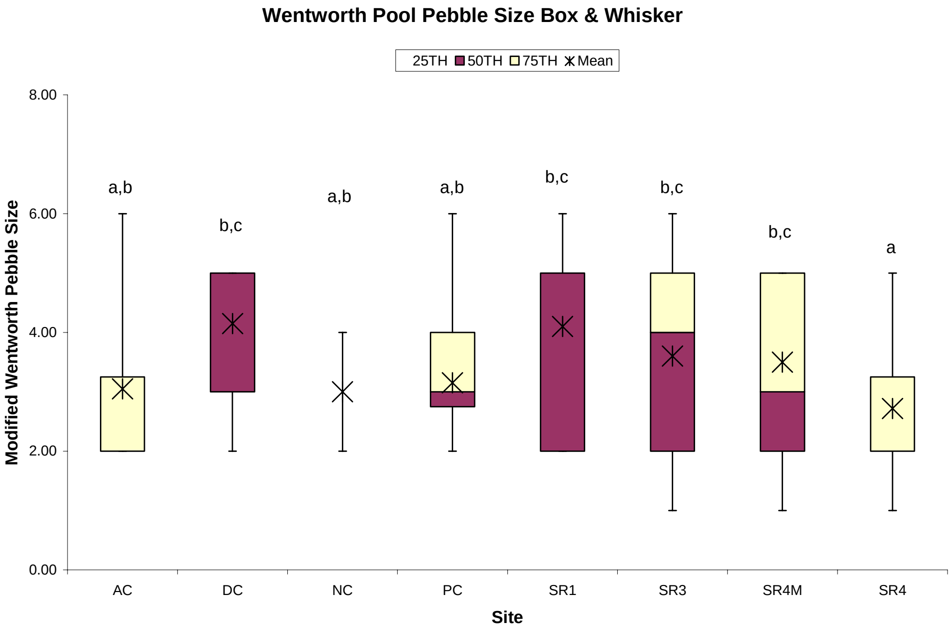

Figure 4.3. Box and Whisker Plot of Pool Modified Wentworth Pebble Count Data
(Boxes with the same letter are not significantly different as determined using Student-Newman-Keuls (α = 0.05); see Table 3.2 for pebble count sizes)

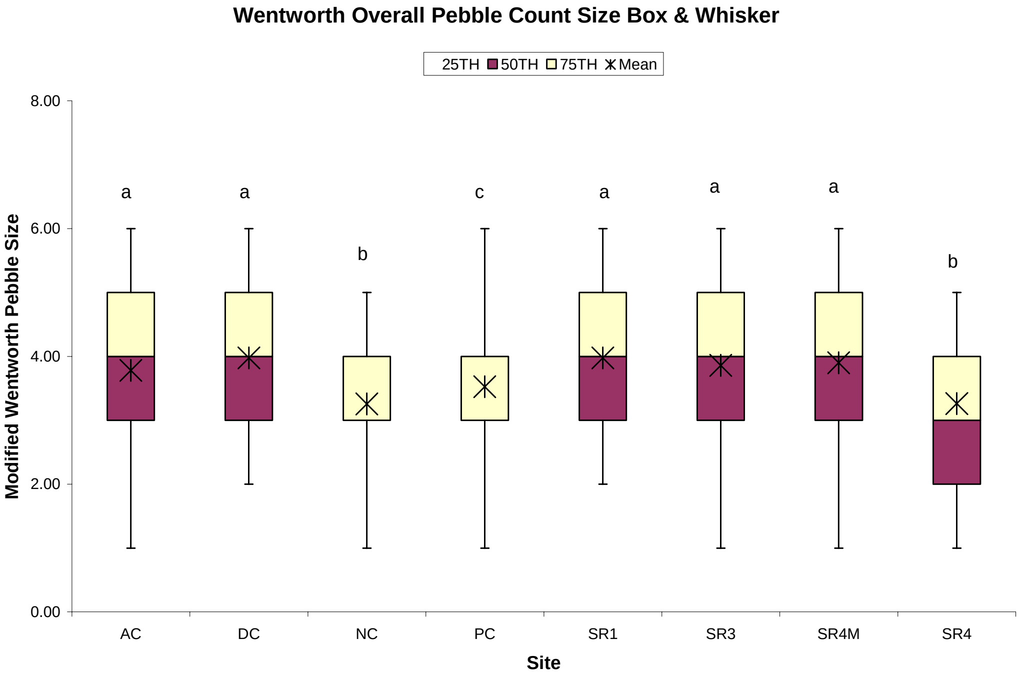

Figure 4.4. Box and Whisker Plot of Overall Modified Wentworth Pebble Count Data
(Boxes with the same letter are not significantly different as determined using Student-Newman-Keuls (α = 0.05); see Table 3.2 for pebble count sizes)

The data in Tables 4.8, 4.9, and 4.10 were combined to determine Level II reach types (Rosgen 1996). Rosgen cautioned against using combined values to make basin-wide classifications; however, this combination reflects the approximate 2 meander wavelength values Rosgen requires for making most classification decisions. Rosgen (1996) also indicated reach types may be tens to thousands of meters in length. However, pebble count data is required to be taken across two meander wavelengths (Rosgen 1996); thus, at Level II, a reach class type of tens of meters may not be an accurate characterization. The values and reach classifications in Tables 4.11 and 4.12 provide evidence of the nature of each reach as an approximate 30-channel-width unit.

Table 4.11. Cross Section Totals and Level II Rosgen (1996) Data per Reach.

Reach	Mean Bankfull Depth (m)[a]	Mean Entrenchment Ratio[b]	Cross Sectional Area (m^2)[c]	Entrenchment	Mean Width/Depth Ratio[b]	Level I Stream Type
SR1	0.723	1.57	176.52	Moderately Entrenched	32.56	"B"
SR4M	0.683	1.29	149.63	Entrenched	29.92	"F"
SR3	0.698	1.73	185.96	Moderately Entrenched	35.37	"B"
SR4	0.878	1.40	223.53	Moderately Entrenched	30.48	"B"
PC	0.524	1.75	75.15	Moderately Entrenched	23.05	"B"
NC	0.884	2.67	162.81	Slightly Entrenched	19.62	"C"
AC	1.46	2.30	409.56	Slightly Entrenched	18.19	"C"
DC	0.631	3.04	89.69	Slightly Entrenched	21.29	"C"

[a]Mean value of all recorded bankfull depths at all cross sections; [b]Mean value of three cross section determined values; [c]values not used for classification purposes

Table 4.12. Level II Rosgen Classification.

Reach	Mean Entrenchment Ratio*	Mean Width/Depth Ratio*	Sinuosity	Slope (%)	D_{50} Size (mm)	D_{50} Class	Stream Type
SR1	1.57	32.56	1.12	1.30	187	Cobble	B3c
SR4M	1.29	29.92	1.11	1.80	142	Cobble	F3
SR3	1.73	35.37	1.16	1.80	142.5	Cobble	B3c
SR4	1.40	30.48	1.28	0.25	36.5	Gravel	B4c
PC	1.75	23.05	1.13	2.05	47	Gravel	B4
NC	2.67	19.62	1.01	0.52	39	Gravel	C4
AC	2.30	18.19	1.16	1.70	120	Cobble	C3

Reach	Mean Entrenchment Ratio[*]	Mean Width/Depth Ratio[*]	Sinuosity	Slope (%)	D_{50} Size (mm)	D_{50} Class	Stream Type
DC	3.04	21.29	1.08	2.90	187	Cobble	C3b

[*] Mean value of three cross section determined values

Other Habitat Results

In addition to fish surveys and geomorphic parameters, general habitat assessment and riparian and stream cover was determined at each site. Table 4.12 indicates the results of the mean values of each site's RBP physical habitat assessment (Barbour et al. 1999). Figure 4.5 show the data in a bar chart. See Tables A4 through A6 in the Appendix for values by habitat parameter per location within each site.

Table 4.13. Physical Habitat Quality Assessed Using RBP (Barbour et al. 1999)

Site	Description	Reach Mean**	Reach SEM
AC	Optimal	161.8[b,c]	3.3
DC	Optimal	177.0[b,c]	2.5
NC*	Sub-optimal	122.5[a]	9.6
PC	Sub-optimal	155.0[b]	8.4
SR1	Optimal	183.0[c]	2.7
SR3	Optimal	174.8[b,c]	3.6
SR4M	Optimal	175.3[b,c]	4.2
SR4*	Sub-optimal	130.8[a]	7.2

*Assessed using low-gradient parameters; all other assessed using high-gradient; **values with same letters not significantly different using Student-Newman-Keuls ($\alpha = 0.05$); SEM = standard error of the mean

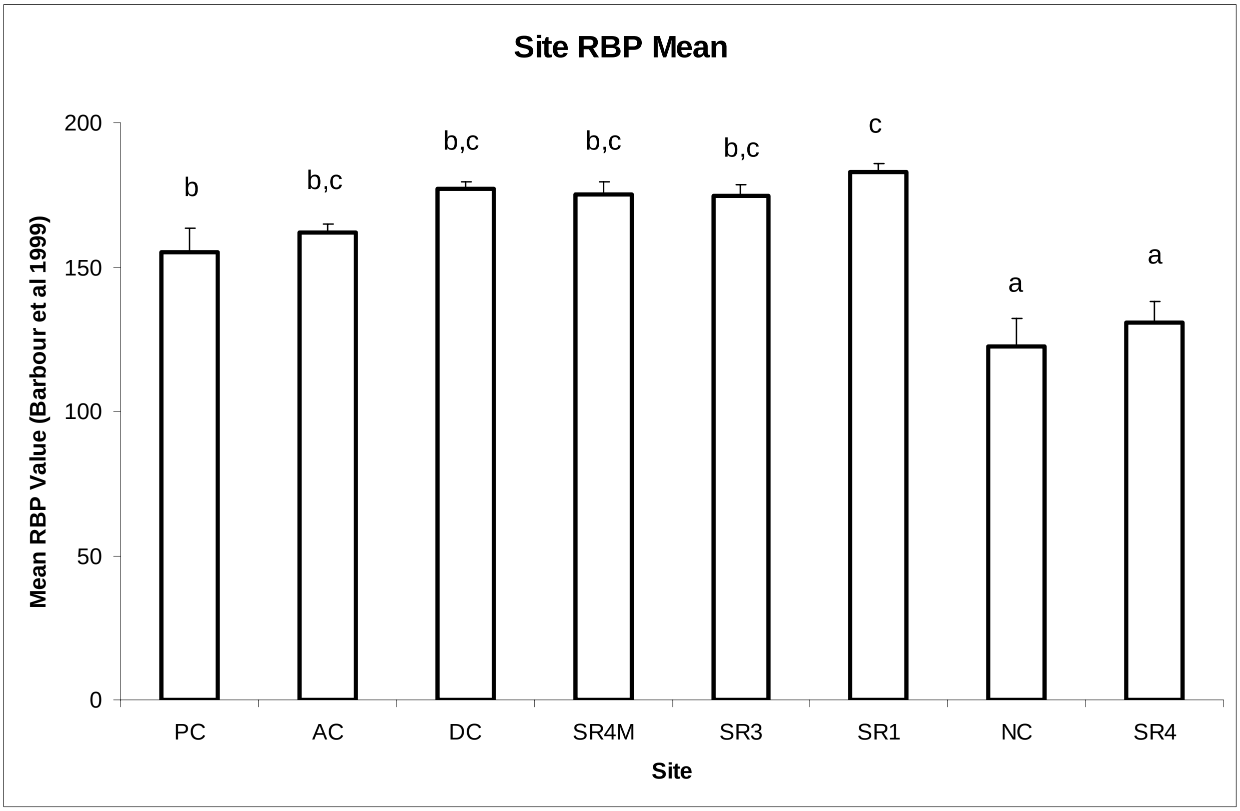

Figure 4.5. Mean RBP Values (Barbour et al. 1999) per Site

(NC and SR4 Assessed using low-gradient parameters; all other assessed using high-gradient; values with same letters not significantly different using Student-Newman-Keuls ($\alpha = 0.05$); error bars are 1 standard error)

The values of both riparian stream shading and overall stream shading indicate some differences among sites, but not many are significant. Table 4.13 presents the values of each per site. Figures 4.6 and 4.7 indicate the same values in a bar chart (riparian shading and overall stream shading, respectively). Table A7 in the appendix contains individual values per site.

Table 4.14. Riparian and Overall Stream Shading Mean per Site.

Site	Riparian		Overall	
	Mean*	SEM	Mean*	SEM
AC	$53.1^{a,b}$	7.8	$40.1^{a,b}$	6.6
DC	$72.5^{a,b}$	6.4	$62.5^{b,c}$	5.4
NC	79.0^{b}	5.6	68.6^{c}	5.3
PC	$76.3^{a,b}$	6.4	66.1^{c}	6.0
SR1	$58.2^{a,b}$	8.8	$39.2^{a,b}$	7.5
SR3	$61.5^{a,b}$	8.3	$45.2^{a,b,c}$	7.0
SR4M	$70.2^{a,b}$	7.4	$46.9^{a,b,c}$	7.4
SR4	46.5^{a}	8.3	34.2^{a}	6.7

*Values with same letters are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$); SEM = standard error of the mean

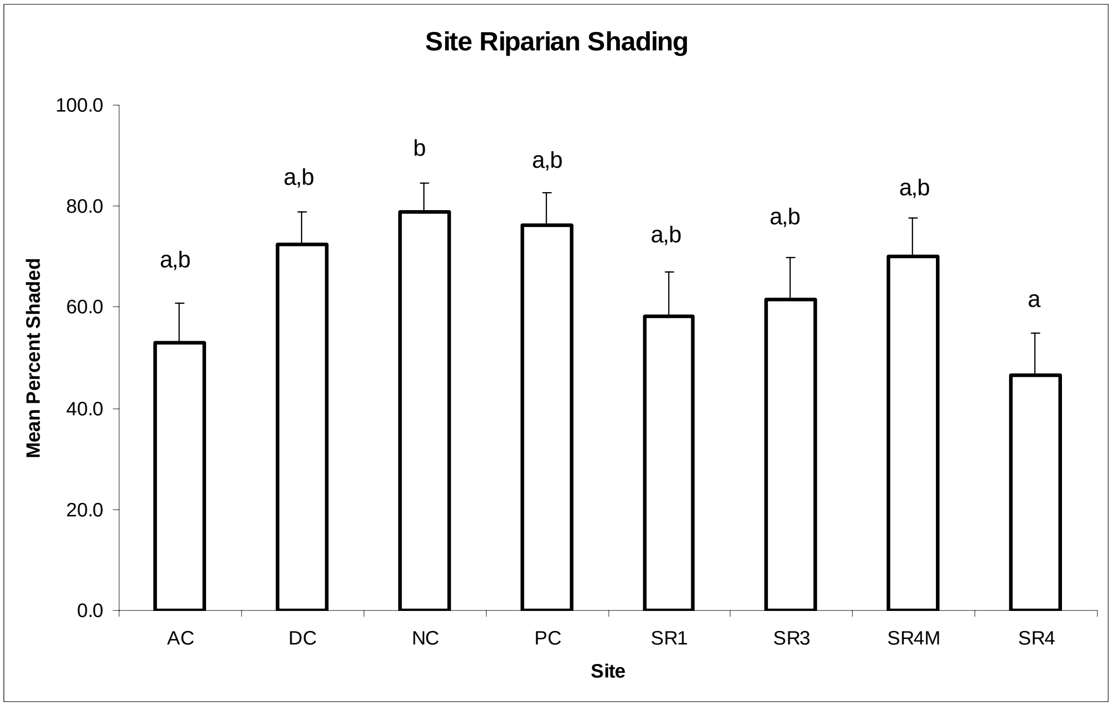

Figure 4.6. Riparian Shading Means by Site.
(Values with same letters are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$); error bars represent one standard error)

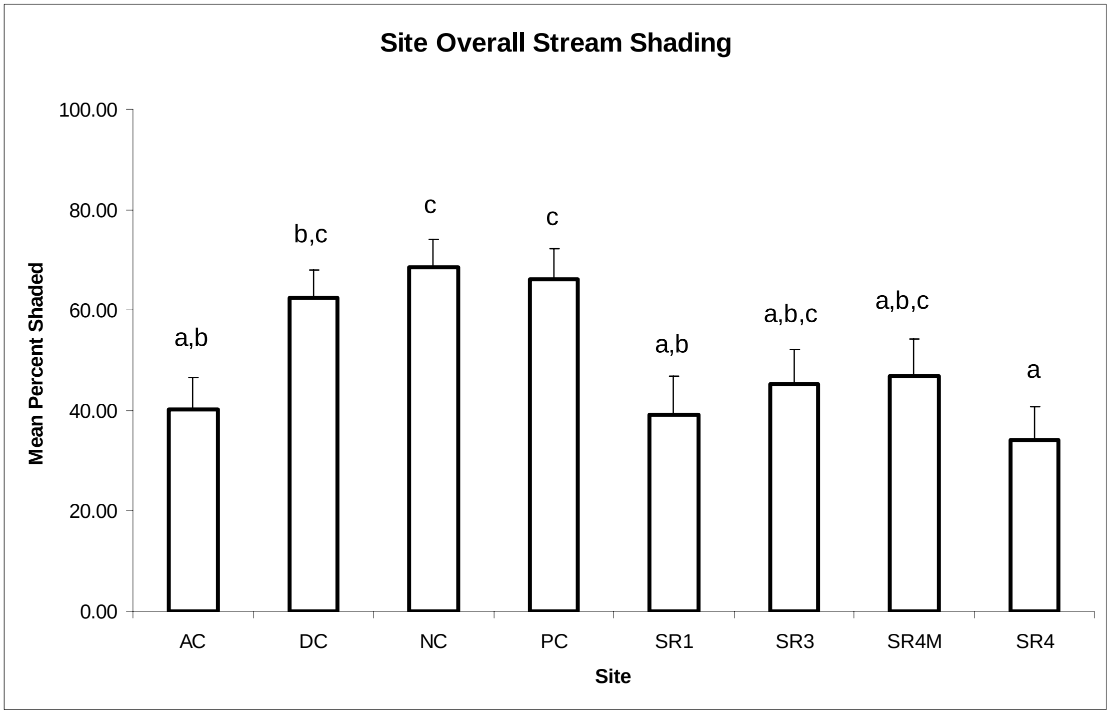

Figure 4.7. Overall Stream Shading Means by Site.
(Values with same letters are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$); error bars represent one standard error)

HSI Values

In using select Habitat Suitability Index variables related to the data gathered for this study, very little differences existed between sites, whether using individual species' variables or a combination of all HSI variables. A value of 1.0 is the highest score possible for these data. It is important to note the HSI models use other physical habitat variables (such as temperature, % aquatic vegetation, and others), combine the variables into categories, such as reproduction, food, adult habitat, etc., and then combine category scores into a final metric. In this study, all variables able to be determined from the recorded data were equally weighted and not separated by category. Therefore the results of the comparisons between sites should be viewed with caution, and are not substitutable for actual HSI determinations. However, the values compared here do provide some insight into particular physical habitat structure for the examined species. The individual species' comparisons are contained in the Appendix in Figures A52 to A60. Figure 4.8 below provides a comparison of all species' HSI variables from Table 2.2. Table 4.14 demonstrates the mean values of each site used to generate Figure 4.8

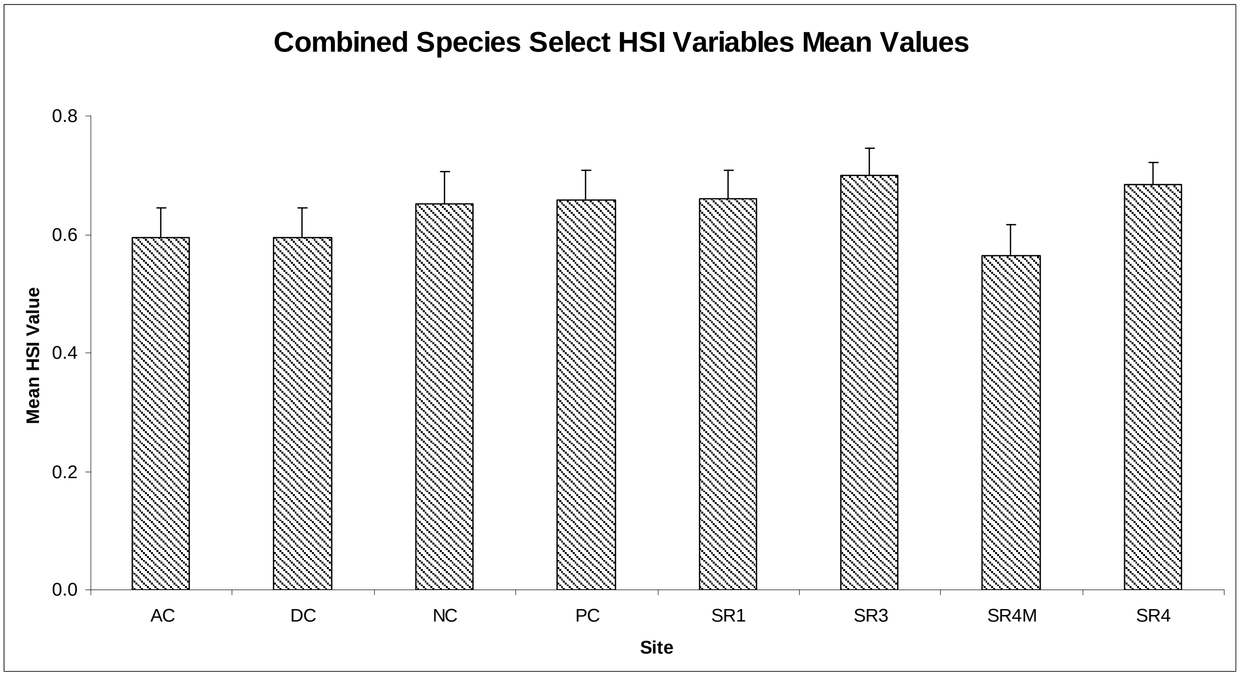

Figure 4.8. Bar Chart of Mean Values of Combined Select HSI Variables by Site
(See Table 2.2 for species used; see Tables A6 – A15 in the Appendix for individual variable scores by species; error bars represent one standard error)

Table 4.15. Mean Values of Combined Select HSI Variables by Site

Site	HSI Mean+	HSI SDEV	HSI SEM
AC	0.60	0.33	0.048
DC	0.60	0.34	0.049
NC	0.65	0.38	0.056

Site	HSI Mean+	HSI SDEV	HSI SEM
PC	0.66	0.34	0.050
SR1	0.66	0.33	0.047
SR3	0.70	0.32	0.046
SR4M	0.56	0.36	0.053
SR4	0.68	0.25	0.037

(SDEV = standard deviation; SEM = standard error); +No significant difference using ANOVA (α = 0.05)

Comparison of Sites

As indicated in the Introduction to this report, the main focus site of the study was the upper approximate 1.2 miles of the Stony River below the Mt. Storm Lake dam. The following tables and figures demonstrate significant differences among sites based on specific fish habitat types, along with difference among the sites previously described in the Purpose subsection of the Introduction, and reproduced here:

4. Below dam outfall with minimal mine impairment;
5. Mid-reach mine-impaired;
6. Lower reach with reduced gradient with

- Two structurally similar streams with similar gradient and geology and
- Two streams sustaining diverse fish faunas.

The figures below show the densities of specific and grouped hydraulic channel units as described in Table 3.6. Figures 4.9 through 4.14 show the differences in HCU densities between sites, while Figures 4.15 through 4.20 show these same difference based on the criteria above. In the latter figures, the following key refers to the categories on the X-axis: Minimal = SR1; Impaired = SR3 & SR4M; Low Grad = SR4; Similar = AC & DC; Diverse = NC & PC. Total pool density was not examined statistically as this category included unclassified pools, most of which were large in area compared to the classified HCUs. Surface area was not determined for pool types; however, the classified pools were all less than the channel width in width and often in length. Therefore inclusion of unclassified pools in total pool analysis could indicate reaches with large pools would seem to have less diversity of fish habitat. Table A18 in the Appendix contains mean values of the select HCUs per site, while Table A19 contains these same values by criteria.

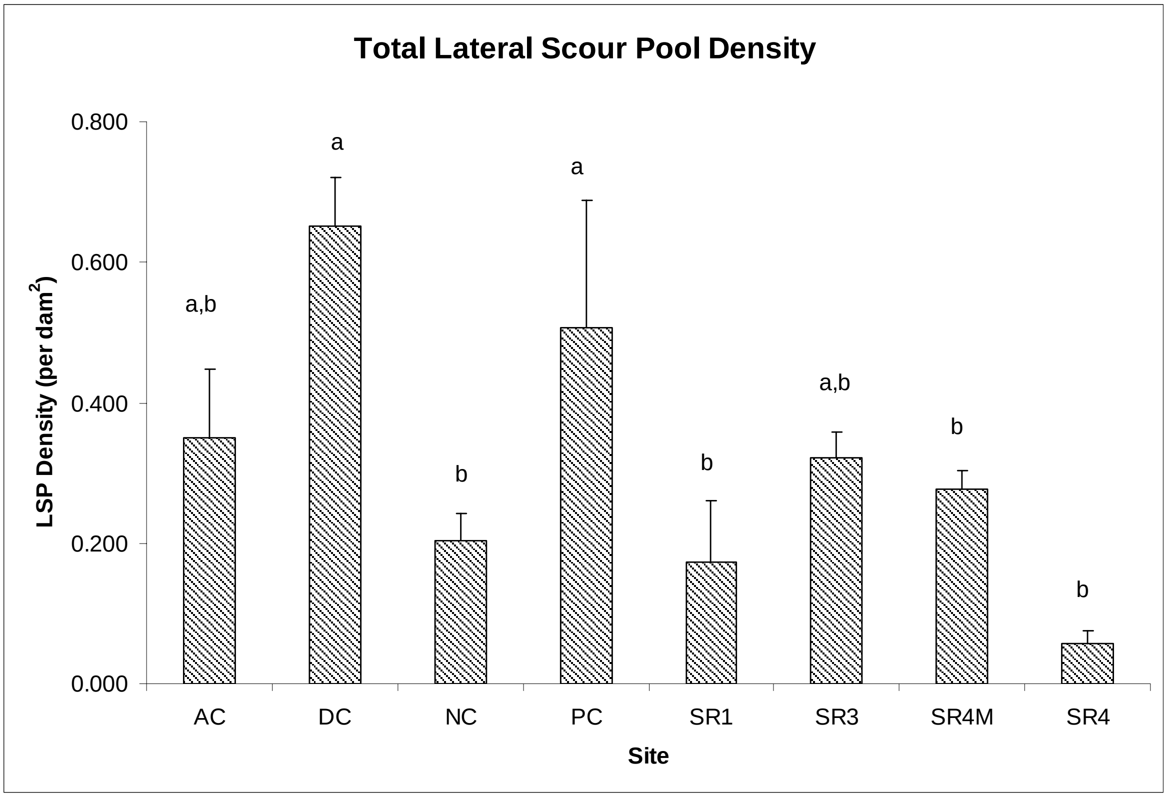

Figure 4.9. Total Lateral Scour Pool Density per Site

(See Table 3.6 for HCU description; graph combines all lateral scour pool (LSP) types; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

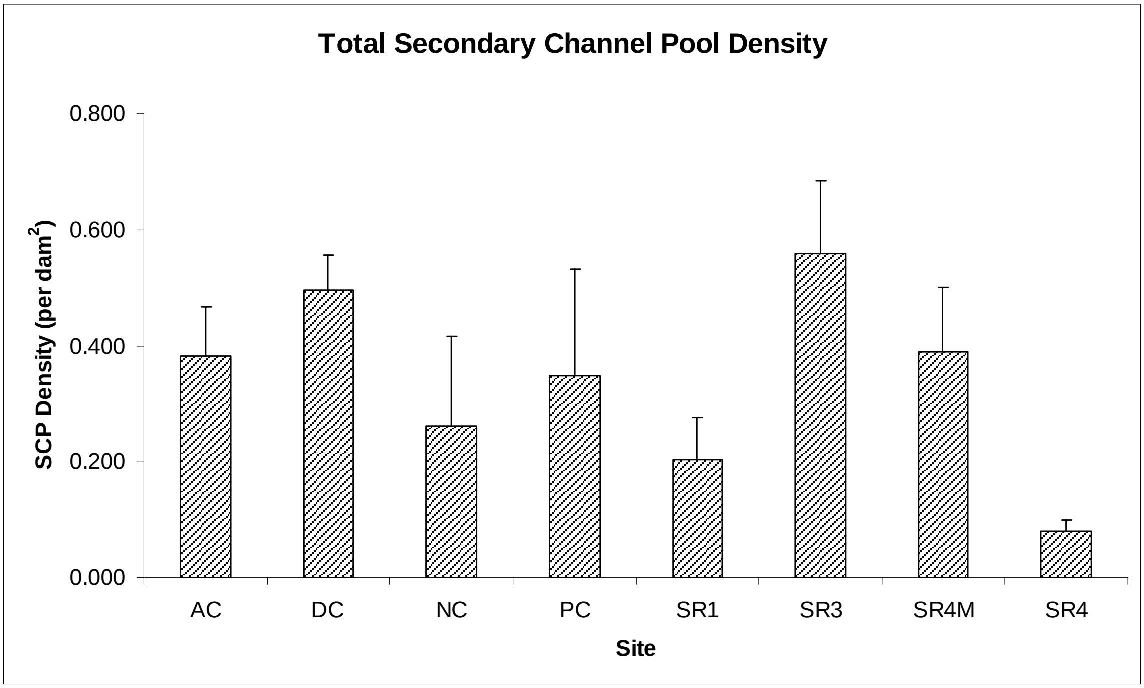

Figure 4.10. Total Secondary Channel Pool Density per Site

(See Table 3.6 for HCU description; SCP = secondary channel pool; bars represent one standard error; sites were not significantly different using ANOVA ($\alpha = 0.05$))

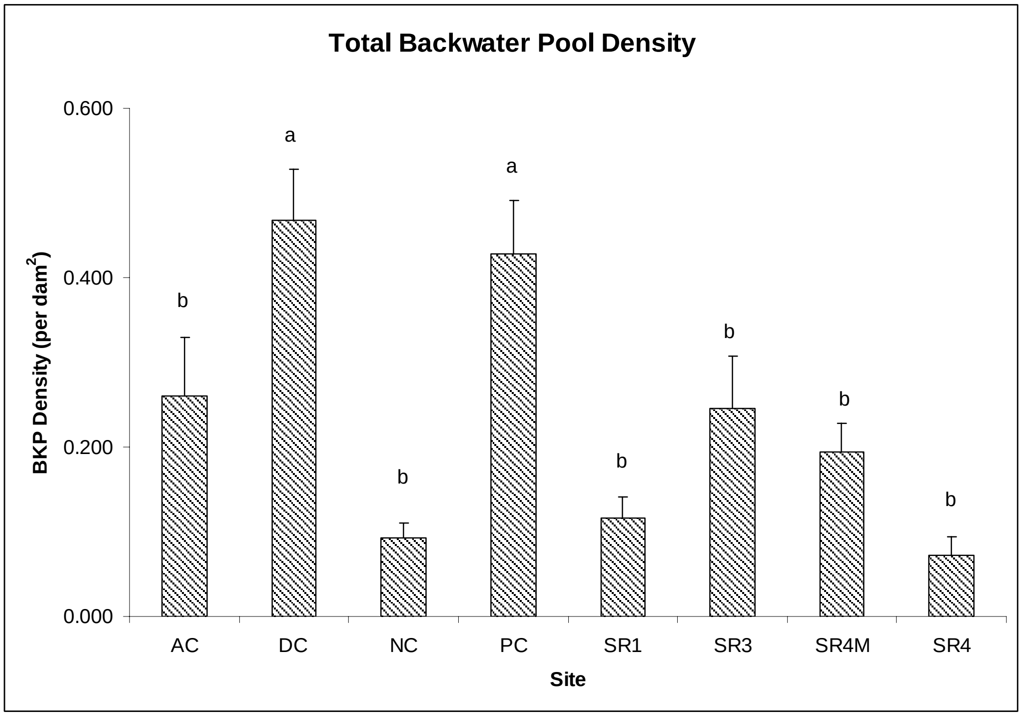

Figure 4.11. Total Backwater Pool Density per Site

(See Table 3.6 for HCU description; graph combines all backwater pool (BKP) types; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls (α = 0.05))

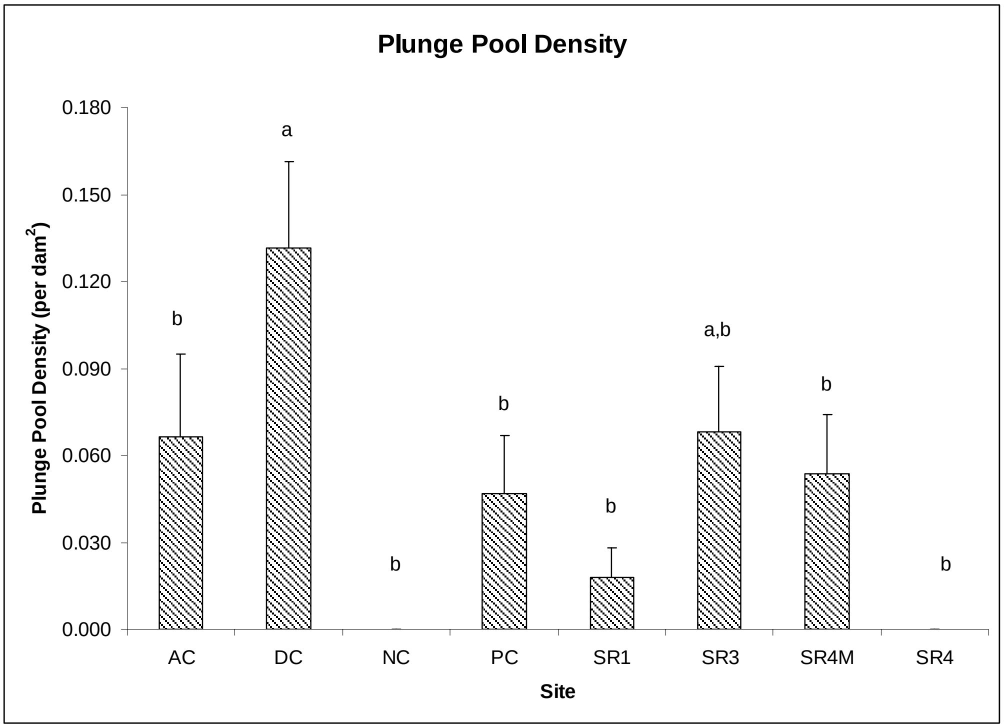

Figure 4.12. Plunge Pool Density per Site

(See Table 3.6 for HCU description; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls (α = 0.05))

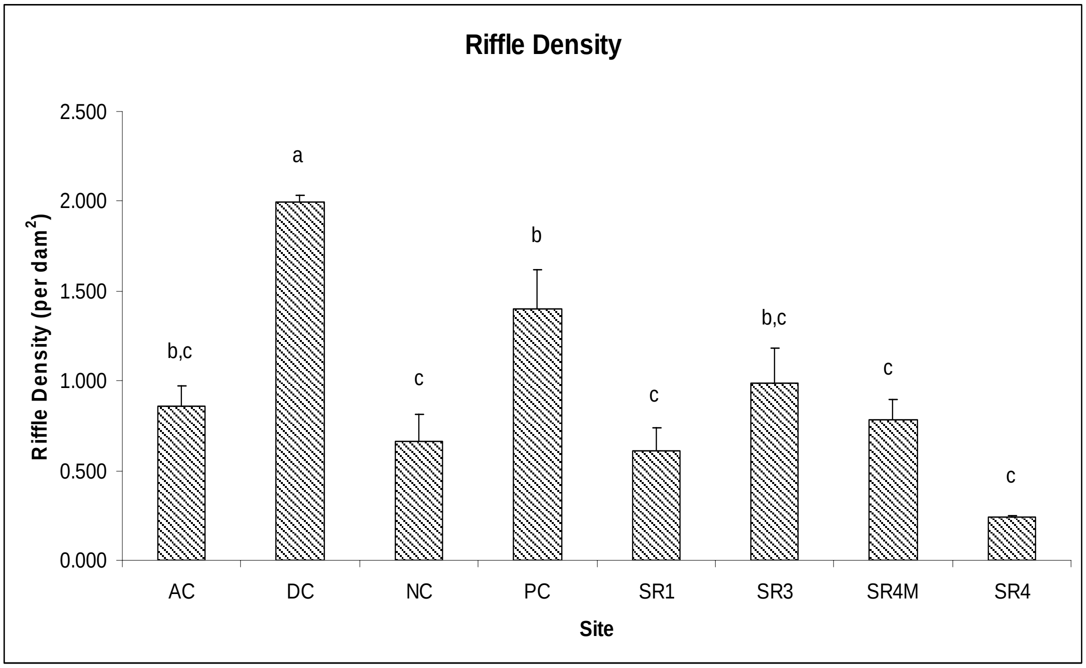

Figure 4.13. Riffle Density per Site

(See Table 3.6 for HCU description; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

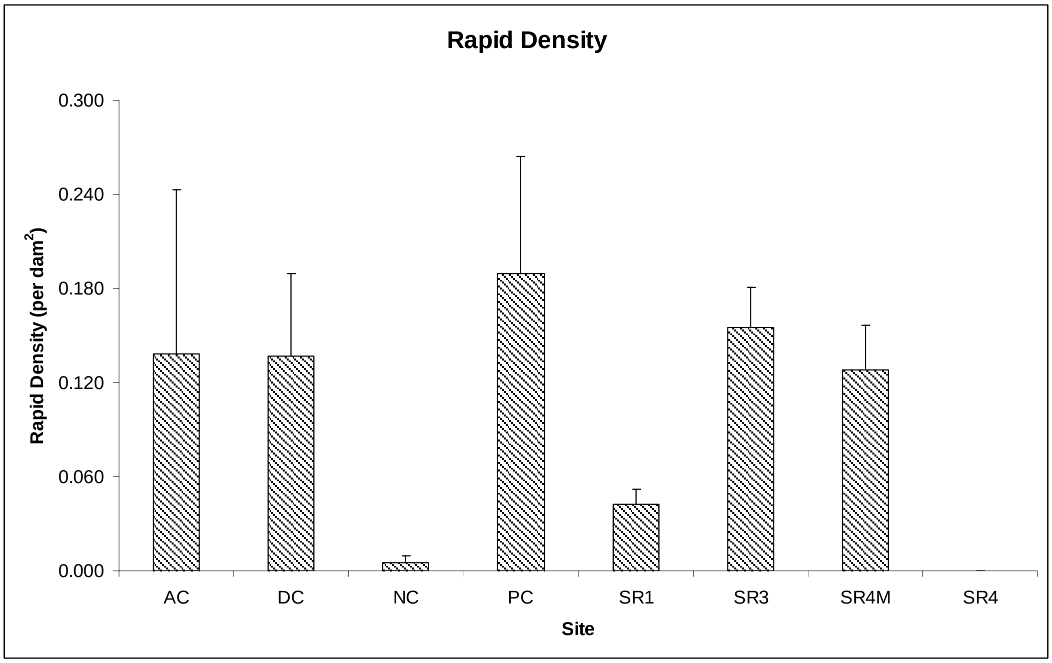

Figure 4.14. Rapid Density per Site

(See Table 3.6 for HCU description; bars represent one standard error; sites were not significantly different using ANOVA ($\alpha = 0.05$))

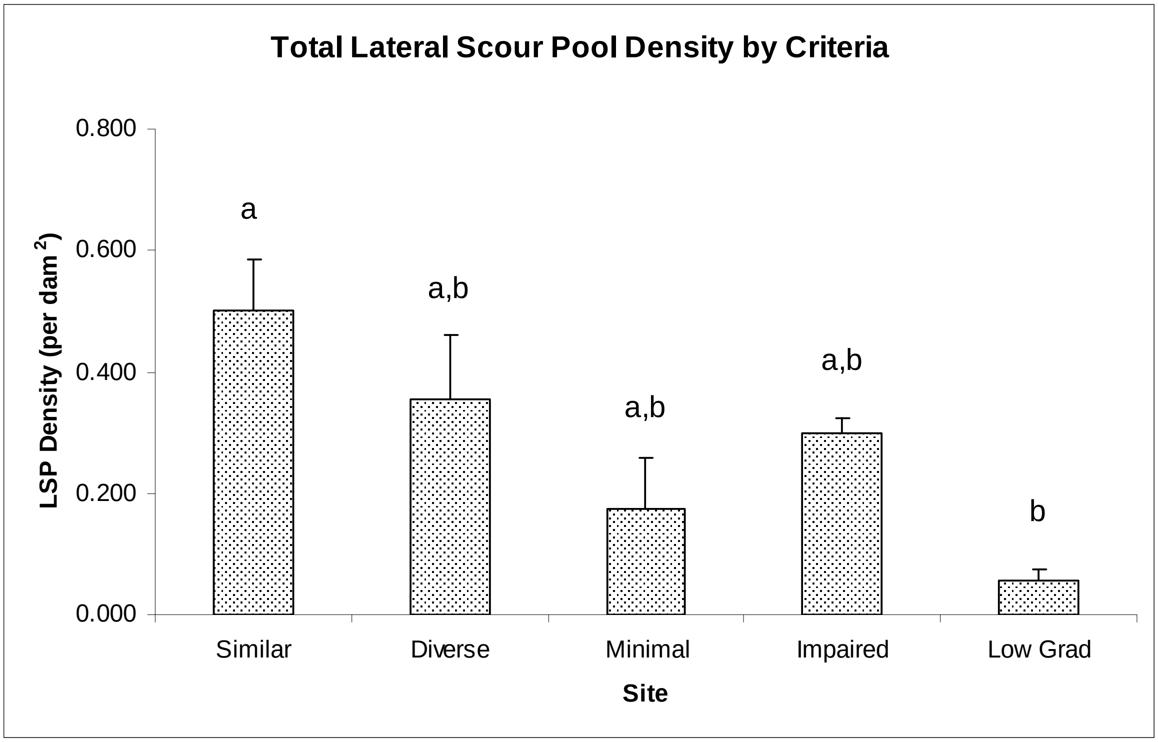

Figure 4.15. Total Lateral Scour Pool Density by Criteria
(See Table 3.6 for HCU description; graph combines all lateral scour pool (LSP) types; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls (α = 0.05))

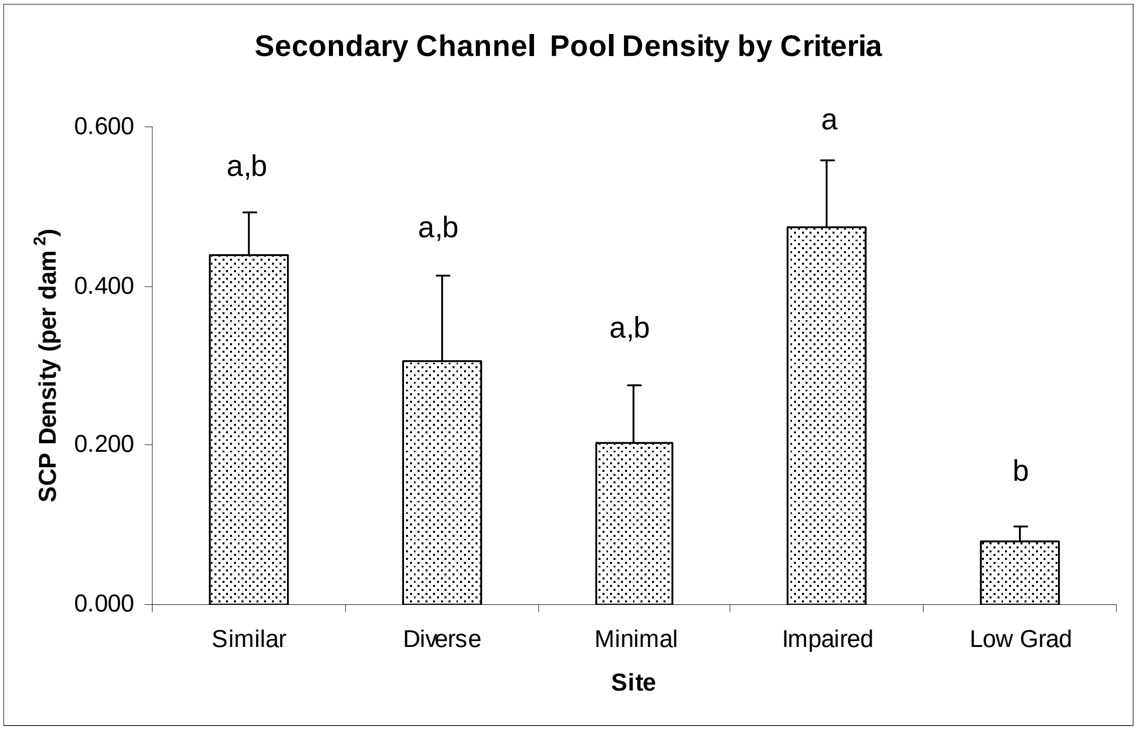

Figure 4.16. Secondary Channel Pool Density by Criteria
(See Table 3.6 for HCU description; SCP = secondary channel pool; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls (α = 0.05))

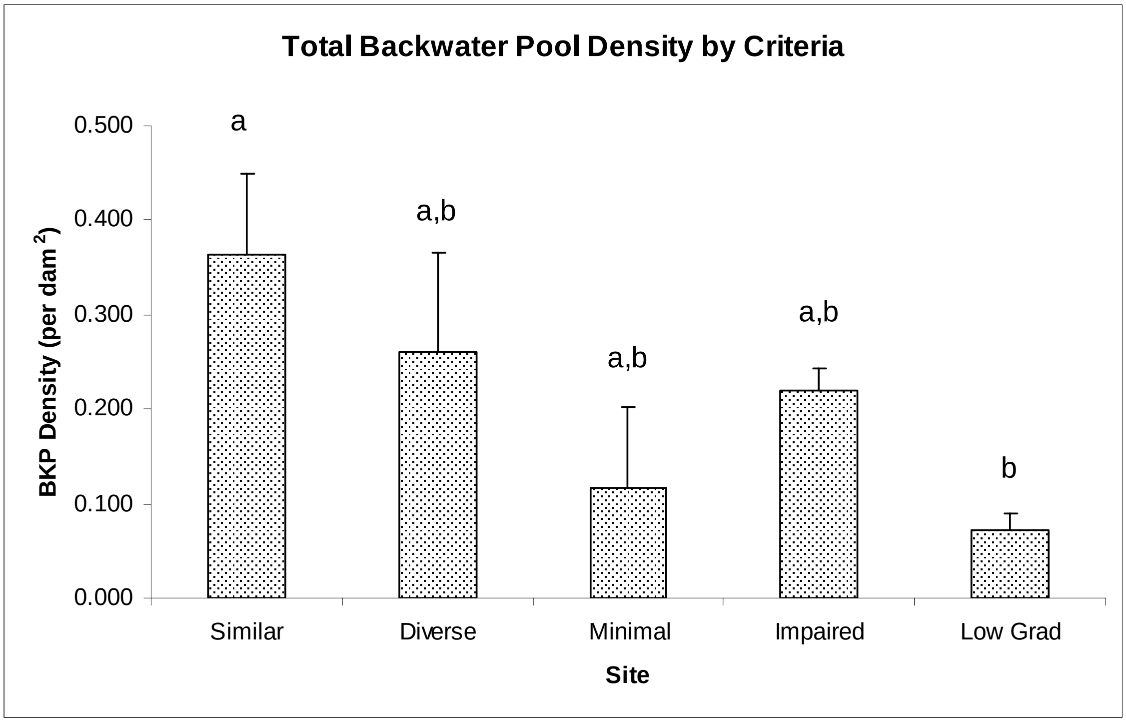

Figure 4.17. Total Backwater Pool Density by Criteria

(See Table 3.6 for HCU description; graph combines all backwater pool (BKP) types; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

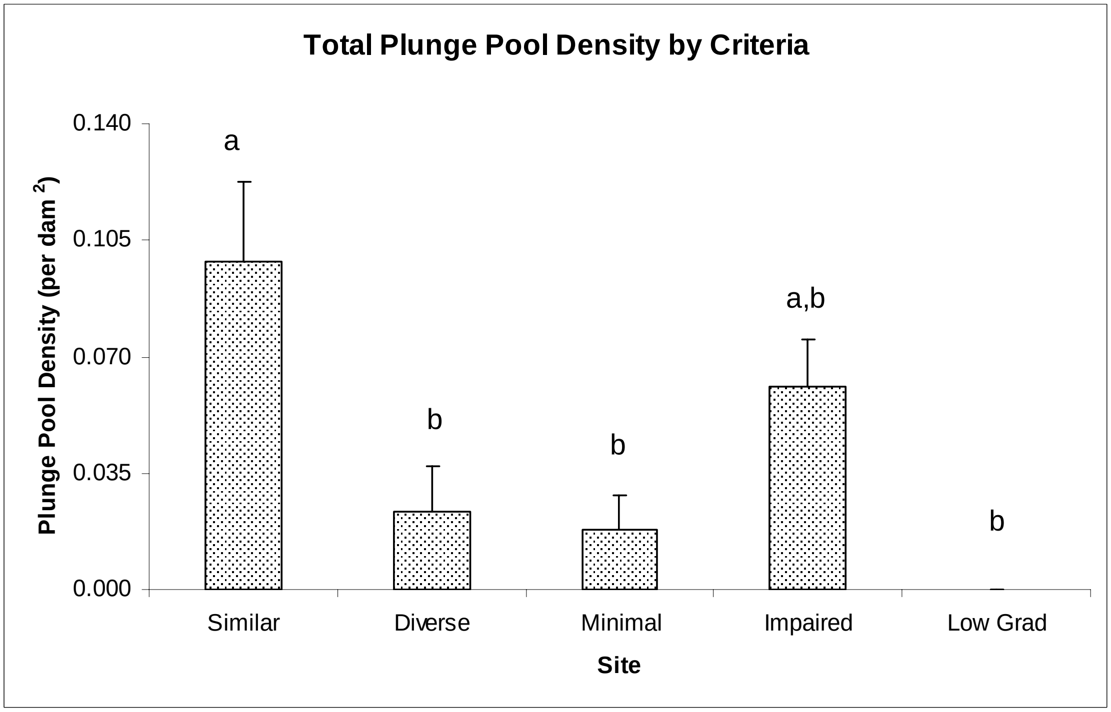

Figure 4.18. Plunge Pool Density by Criteria

(See Table 3.6 for HCU description; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

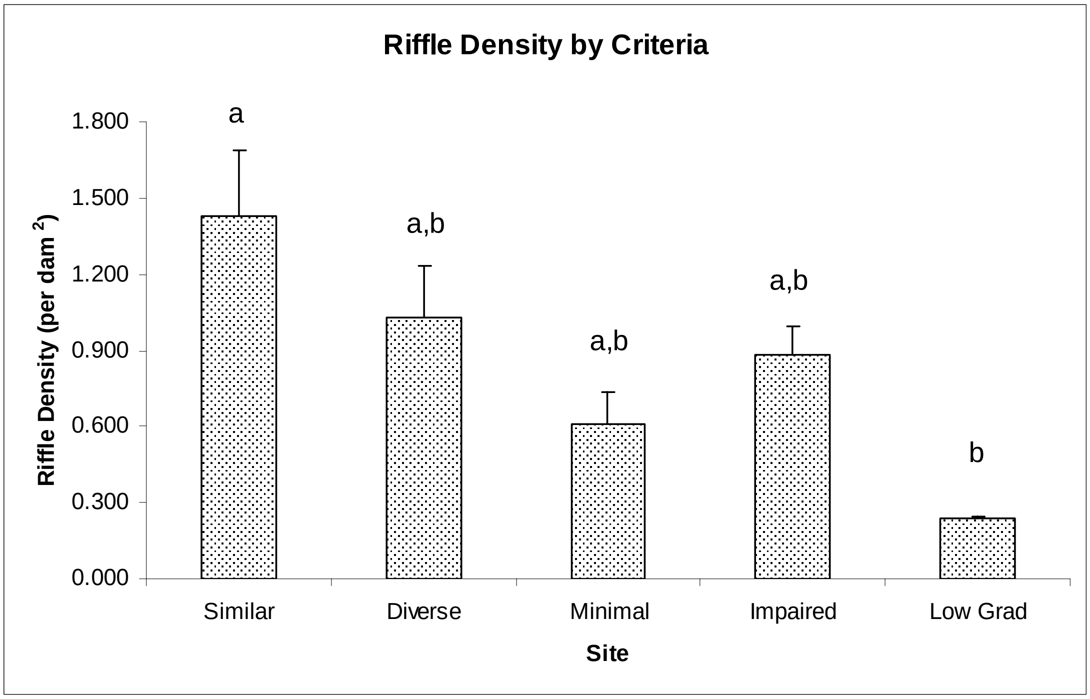

Figure 4.19. Riffle Density by Criteria
(See Table 3.6 for HCU description; bars represent one standard error; sites with same letter are not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

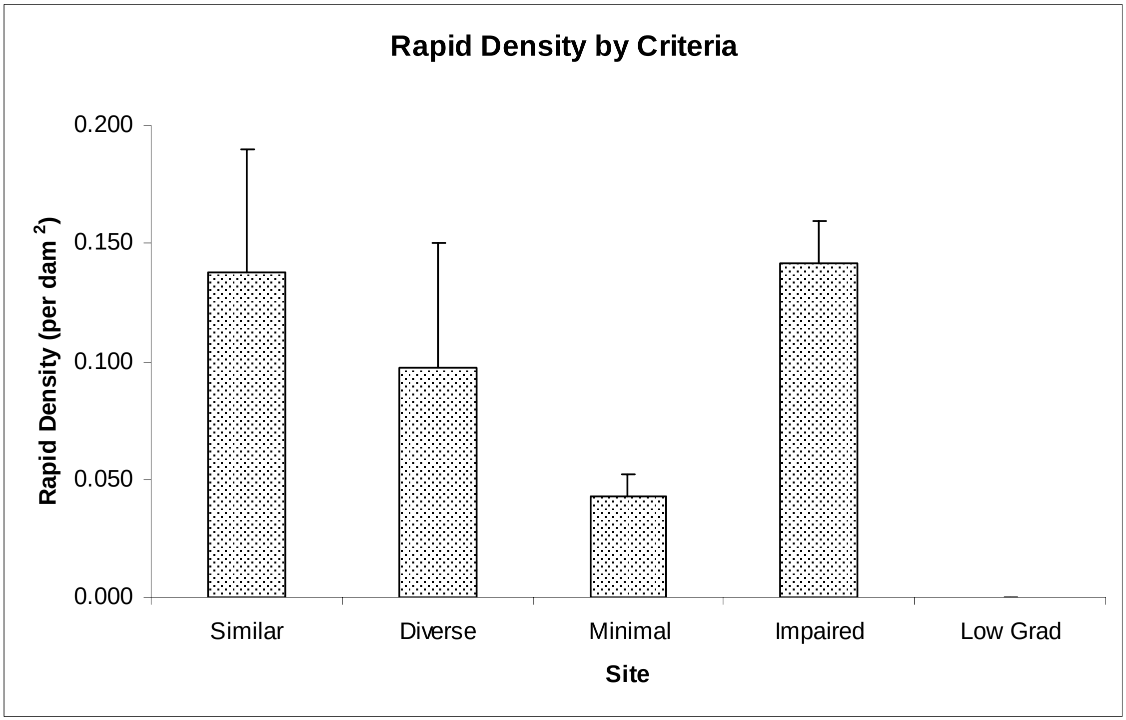

Figure 4.20. Rapid Density by Criteria
(See Table 3.6 for HCU description; bars represent one standard error; sites were not significantly different using ANOVA ($\alpha = 0.05$))

In comparing some of the geomorphic variables measured at each site, some significant differences were found among sites and among criteria. Figures 4.21 through 4.27 demonstrate these data and significant differences by site. Figures 4.28 through 4.30 show these same data by criteria. Criteria refer to same sites as noted above for hydraulic channel unit density. No significant differences were noted between mean values of entrenchment, flood prone area width, cross sectional area, or width/depth ratios by criteria (using ANOVA). These graphs are shown in the Appendix as Figures A62 through A65. Table A20 contains the values of geomorphic variables by criteria.

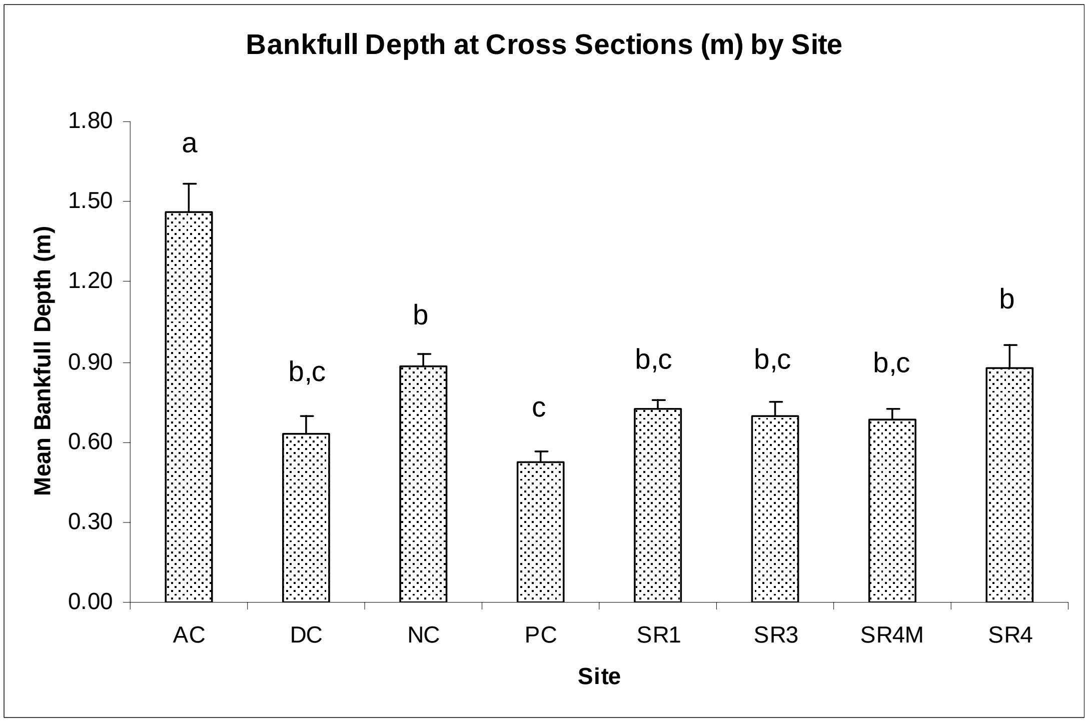

Figure 4.21. Mean Bankfull Depth at Cross Sections by Site

(Bars represent one standard error; see Table 4.11 for mean values; sites with same letter not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

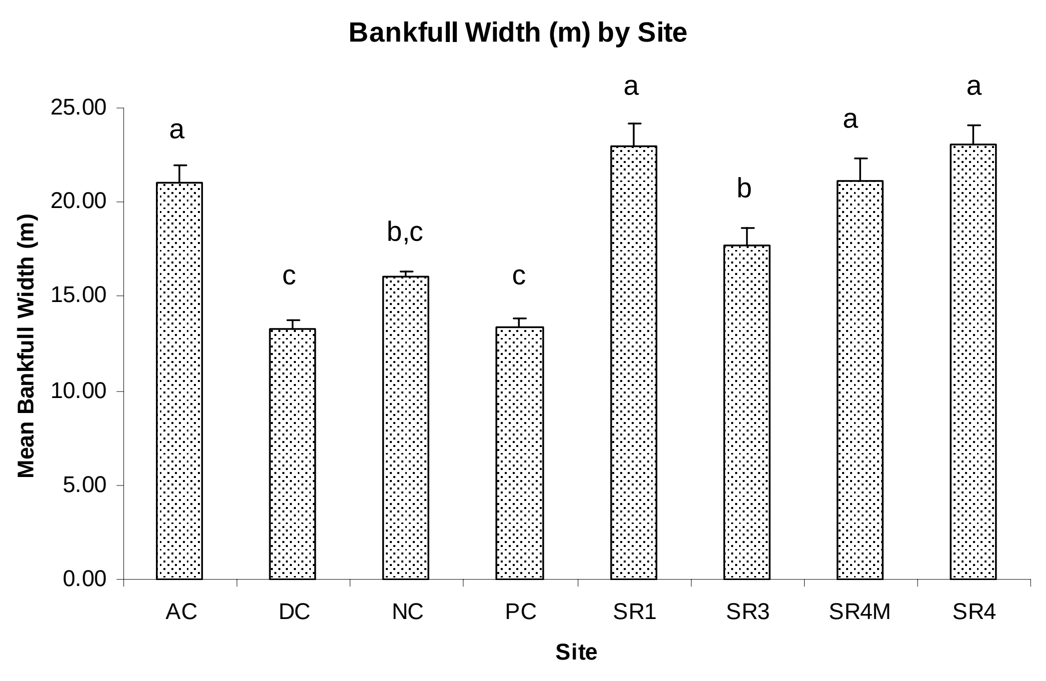

Figure 4.22. Mean Bankfull Width by Site

(Bars represent one standard error; see Table 4.8 for mean values; widths measured at pebble count locations; sites with same letter not significantly different using Student-Newman-Keuls (α = 0.05))

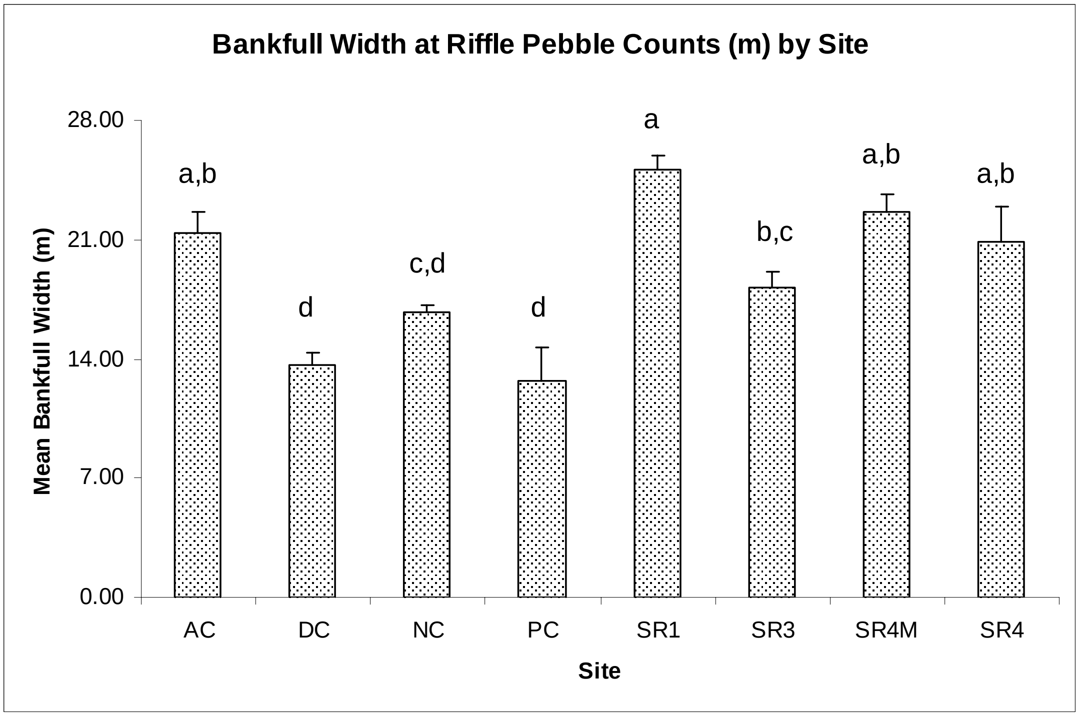

Figure 4.23. Mean Bankfull Width at Riffle Pebble Count Locations by Site

(Bars represent one standard error; widths measured at riffle pebble count locations; sites with same letter not significantly different using Student-Newman-Keuls (α = 0.05))

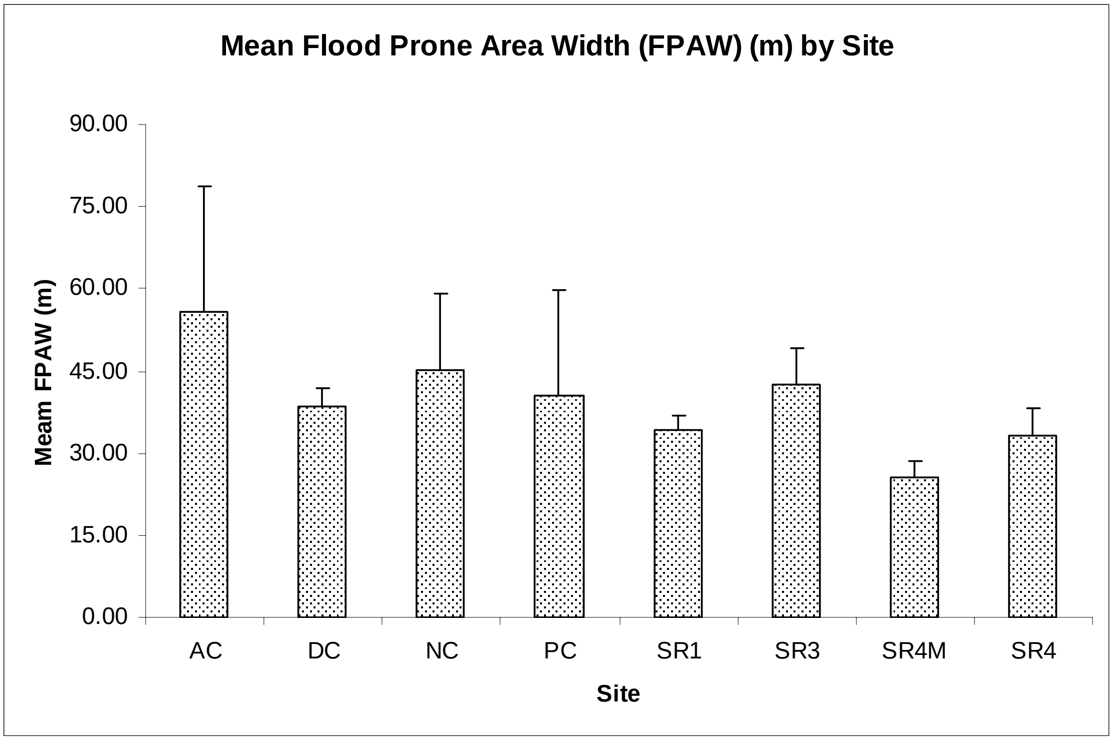

Figure 4.24. Mean Flood Prone Area Width by Site

(Bars represent one standard error; see Table 4.12 for mean values; sites not significantly different using ANOVA (α = 0.05))

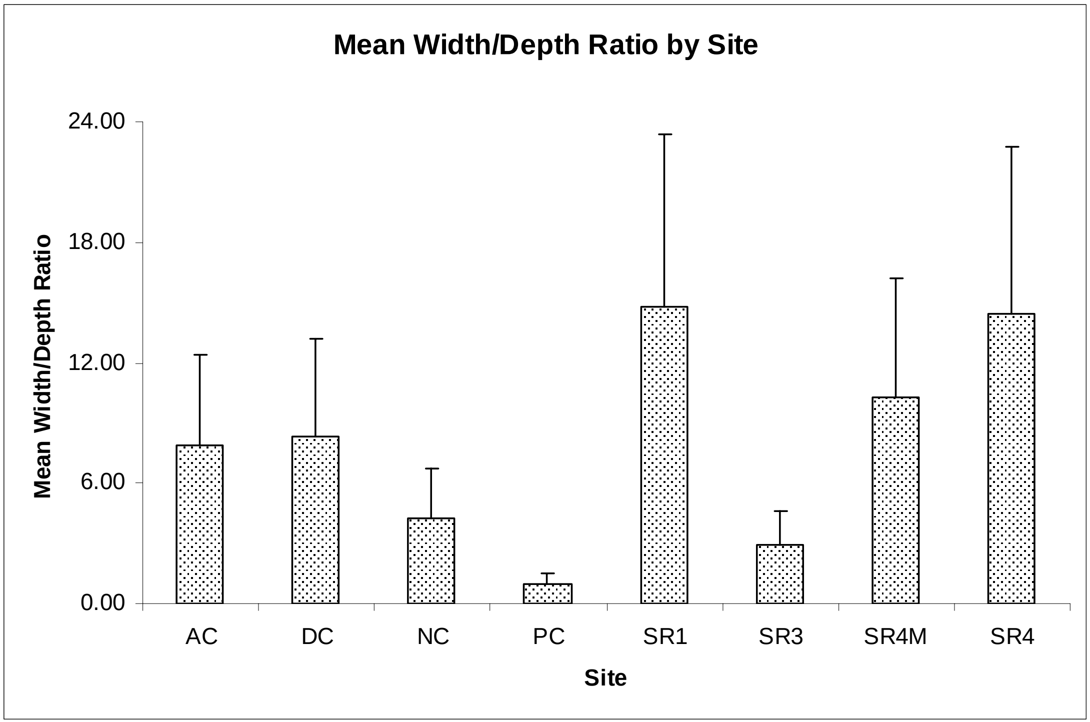

Figure 4.25. Mean Width/Depth Ratios by Site

(Bars represent one standard error; see Table 4.12 for mean values; sites not significantly different using ANOVA (α = 0.05))

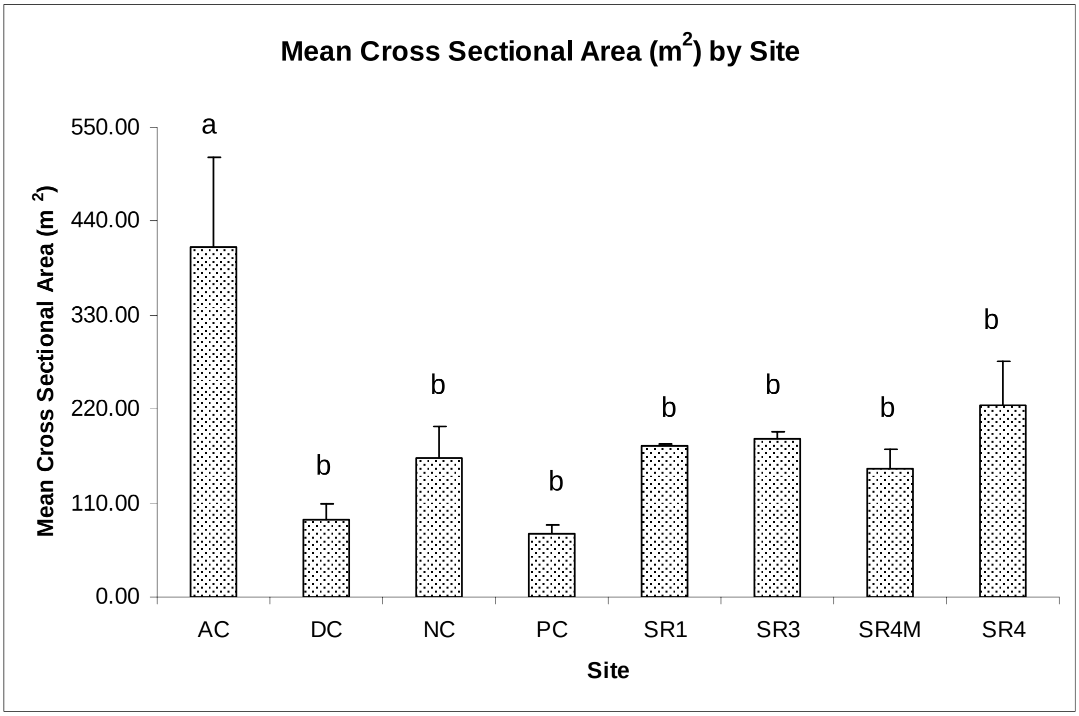

Figure 4.26. Mean Cross Sectional Area by Site

(Bars represent one standard error; sites with same letter not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

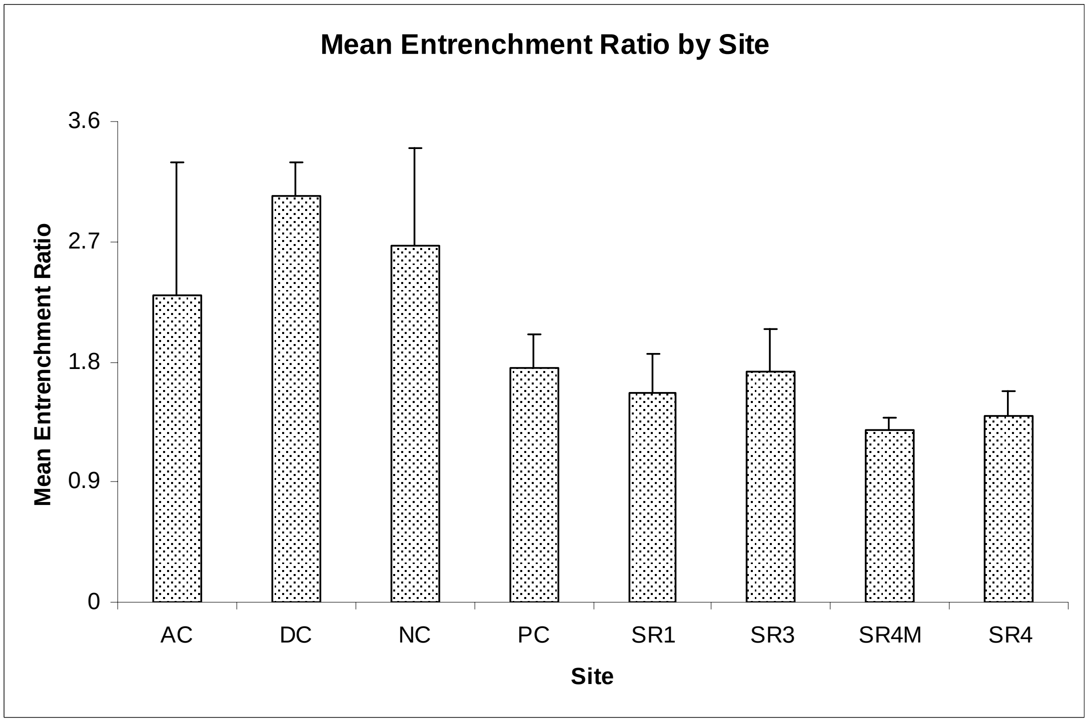

Figure 4.27. Mean Entrenchment Ratios by Site

(Bars represent one standard error; see Table 4.12 for mean values; sites not significantly different using ANOVA ($\alpha = 0.05$))

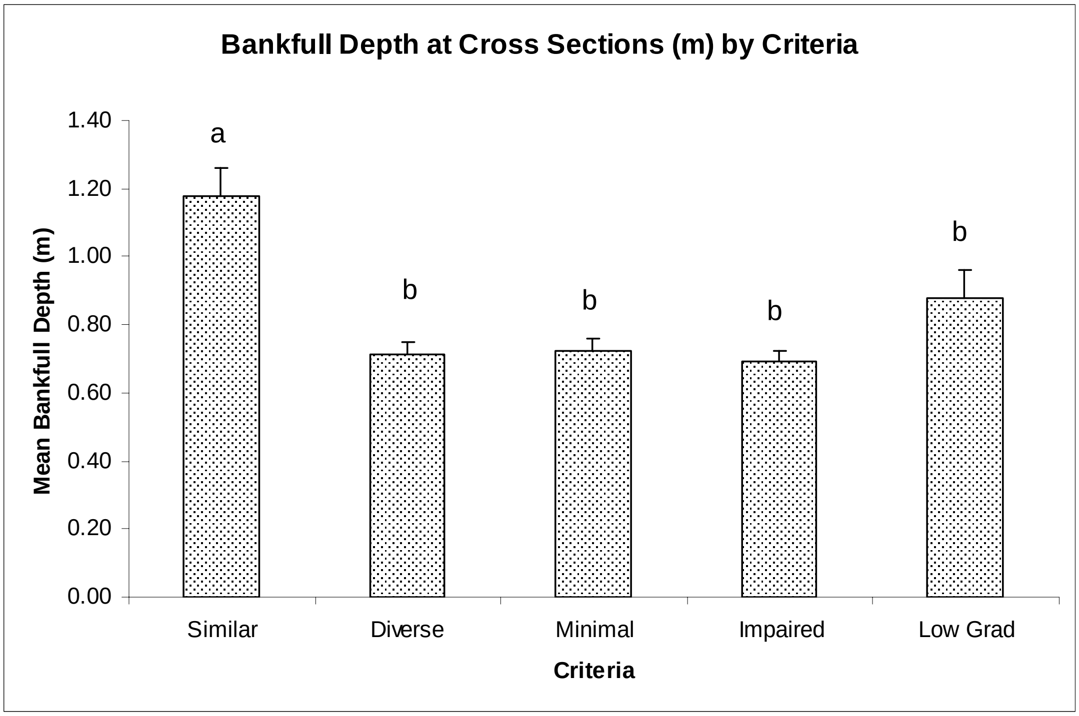

Figure 4.28. Mean Bankfull Depths at Cross Sections by Criteria
(Bars represent one standard error; sites with same letter not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

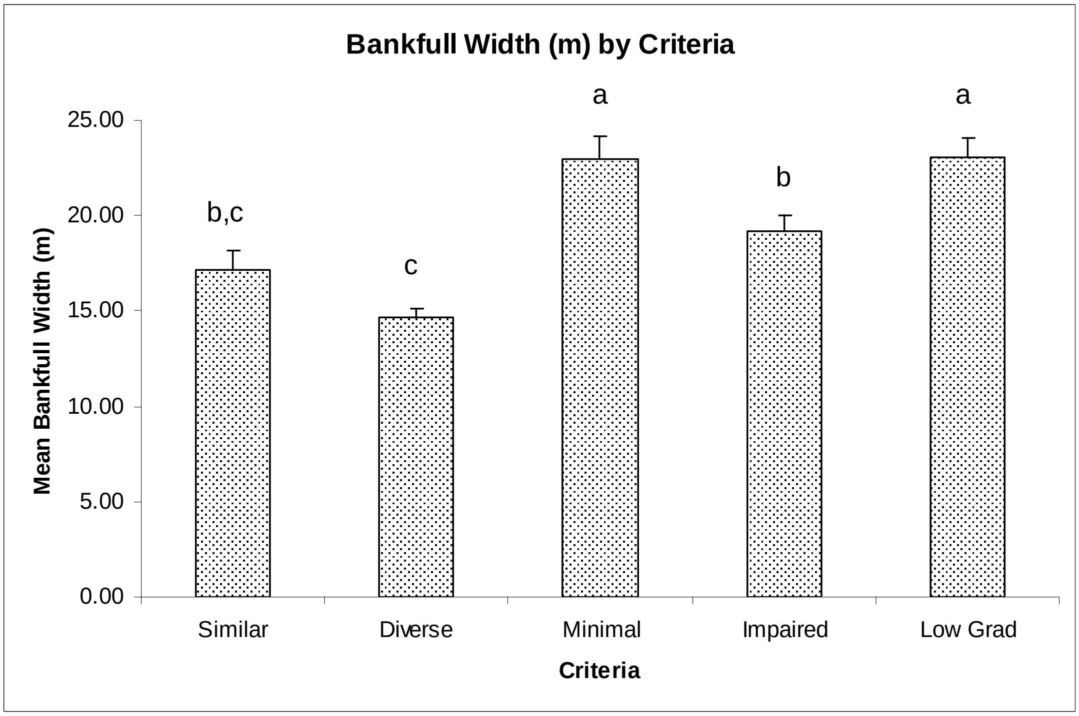

Figure 4.29. Mean Bankfull Widths by Criteria
(Bars represent one standard error; widths measured at pebble count locations; sites with same letter not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

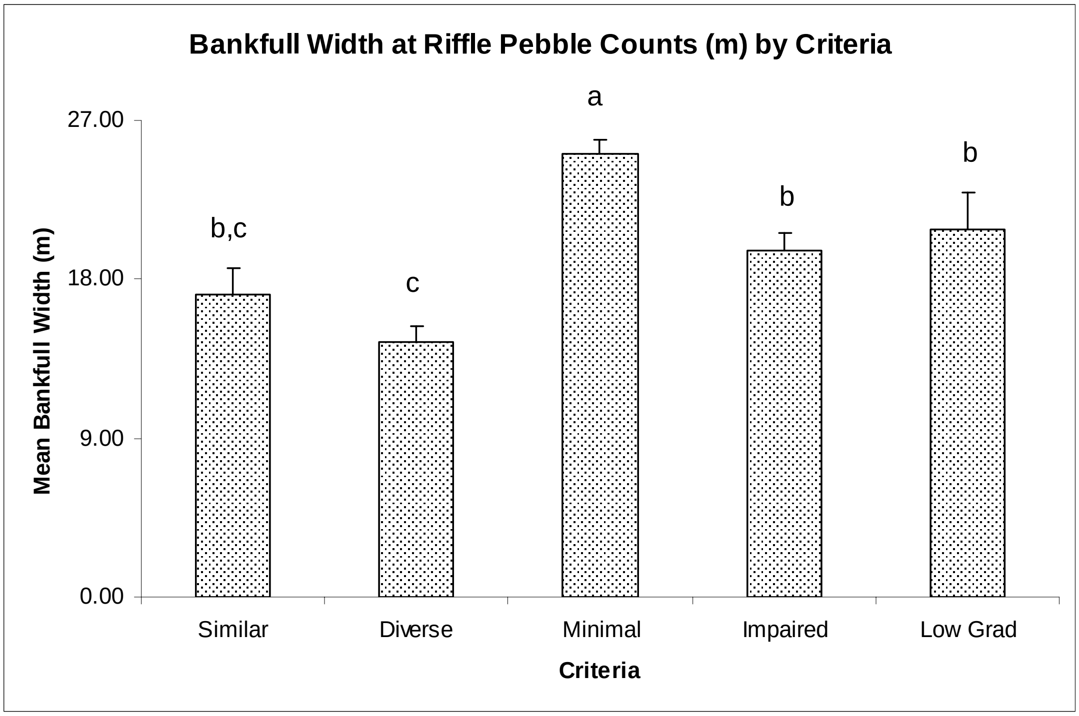

Figure 4.30. Mean Bankfull Widths at Riffle Pebble Count Locations by Criteria
(Bars represent one standard error; widths measured at riffle pebble count locations; sites with same letter not significantly different using Student-Newman-Keuls ($\alpha = 0.05$))

Comparisons also were made between sites and criteria on fish density. As expected, significant differences were noted among sites and criteria, however, no significant difference was found between the Stony River sites and the two sites deemed geomorphically similar (AC & DC) (Figure 4.31). As a consequence, the criteria fish densities were only significantly different between the Diverse sites and the remaining categories, (see Figure 4.32). However, the high densities of fish at the Diverse sites may have skewed the statistical analysis. Statistical analysis was completed only on fish density per area.

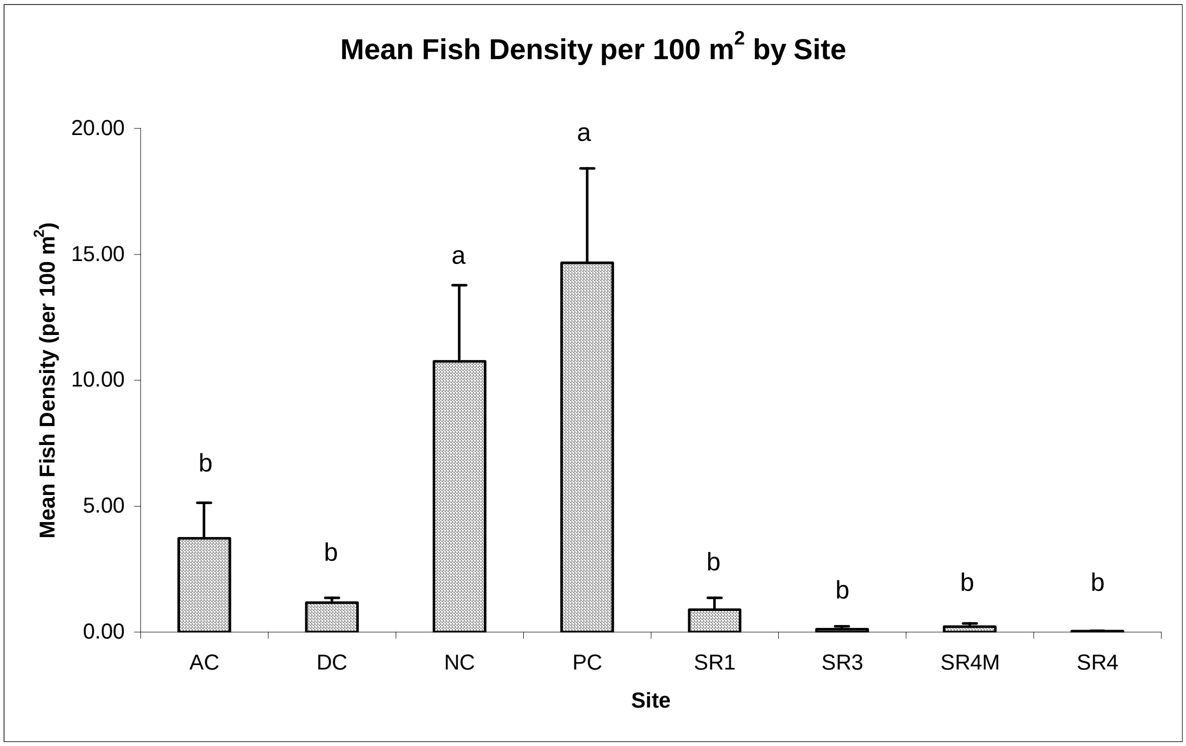

Figure 4.31. Mean Fish Density per 100 m^2 per Site

(Bars represent one standard error; see Table 4.3 for mean values; sites with same letter not significantly different using Student-Newman-Keuls (α = 0.05))

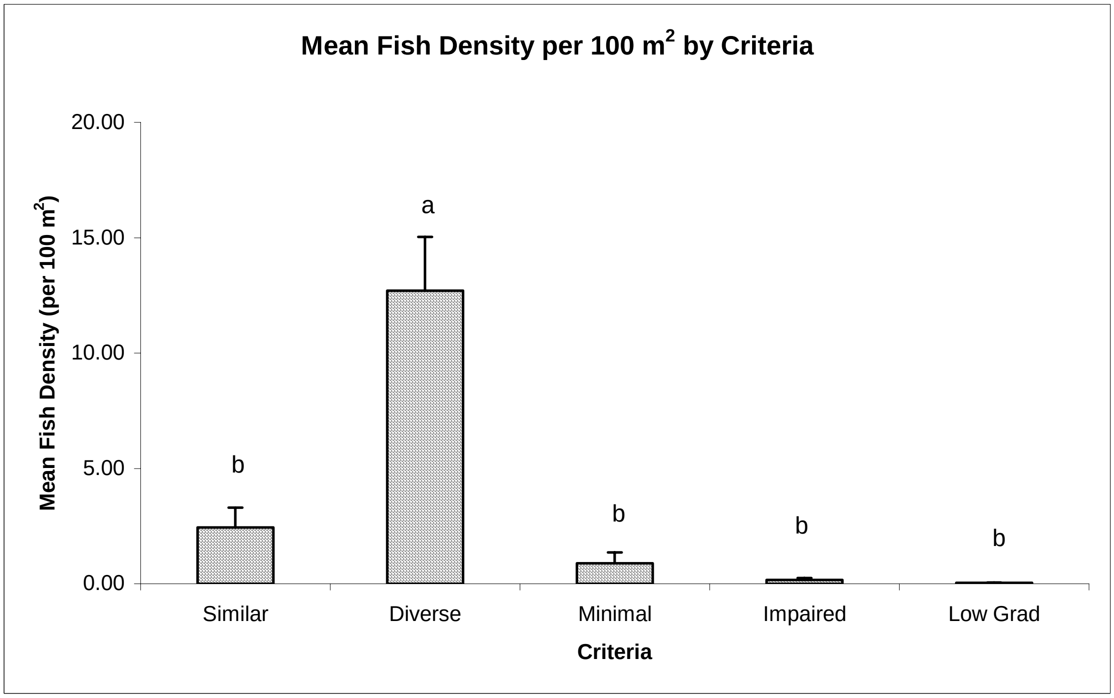

Figure 4.32. Mean Fish Density per 100 m^2 per Criteria

(Bars represent one standard error; criteria with same letter not significantly different using Student-Newman-Keuls (α = 0.05))

In determining the possible effects of geomorphic variables on fish habitat represented by HCUs, multivariate statistics in the form of Principal Components Analysis was chosen. However, prior to analyzing the data with this method, Pearson correlation tests run on the combined variables to ensure no significant correlations would bias the results of the PCA. Unfortunately, almost all of the geomorphic variables were significantly correlated with one another, and the same was found among all of the selected HCU variables. Therefore it was deemed unwise to perform the PCA on the combined data set with such highly significantly correlations. The correlations did reveal some possible effects between particular geomorphologic variables and HCUs. Table 4.16 contains the results of the Pearson correlation test on all of these variables.

Table 4.16. Results of Pearson Correlation Test on Selected Variables

		Later. Scour Pool	Second. Ch. Pool	Backwater Pool	Total Pool	FPAW	W/D Ratio	Cross Sect. Area	Entrenchment	Mean Bfull Width	Mean Bfull Depth	Riffle Density	Rapid Density
Later. Scour Pool	Pearson Correlation	1	.670(**)	.874(**)	.949(**)	0.192	-0.36	-0.107	.534(**)	-.489(*)	0.024	.885(**)	.630(**)
	Sig. (2-tailed)		0	0	0	0.369	0.084	0.619	0.007	0.015	0.913	0	0.001
	N	24	24	24	24	24	24	24	24	24	24	24	24
Second. Ch. Pool	Pearson Correlation	.670(**)	1	.503(*)	.843(**)	0.08	0.003	0.009	0.144	-0.009	-0.043	.697(**)	.662(**)
	Sig. (2-tailed)	0		0.012	0	0.709	0.99	0.965	0.503	0.967	0.844	0	0
	N	24	24	24	24	24	24	24	24	24	24	24	24
Backwater Pool	Pearson Correlation	.874(**)	.503(*)	1	.856(**)	0.082	-0.297	-0.156	.411(*)	-.520(**)	-0.007	.861(**)	.452(*)
	Sig. (2-tailed)	0	0.012		0	0.705	0.159	0.467	0.046	0.009	0.974	0	0.027
	N	24	24	24	24	24	24	24	24	24	24	24	24
Total Pool	Pearson Correlation	.949(**)	.843(**)	.856(**)	1	0.126	-0.218	-0.087	0.379	-0.34	-0.02	.899(**)	.706(**)
	Sig. (2-tailed)	0	0	0		0.558	0.305	0.685	0.068	0.104	0.925	0	0
	N	24	24	24	24	24	24	24	24	24	24	24	24
FPAW	Pearson Correlation	0.192	0.08	0.082	0.126	1	-0.355	.693(**)	.801(**)	0.229	.825(**)	-0.009	-0.172
	Sig. (2-tailed)	0.369	0.709	0.705	0.558		0.089	0	0	0.281	0	0.968	0.422
	N	24	24	24	24	24	24	24	24	24	24	24	24
W/D Ratio	Pearson Correlation	-0.36	0.003	-0.297	-0.218	-0.355	1	-0.239	-.617(**)	.577(**)	-.541(**)	-0.229	-0.018
	Sig. (2-tailed)	0.084	0.99	0.159	0.305	0.089		0.261	0.001	0.003	0.006	0.281	0.934
	N	24	24	24	24	24	24	24	24	24	24	24	24
Cross Sect. Area	Pearson Correlation	-0.107	0.009	-0.156	-0.087	.693(**)	-0.239	1	0.256	.589(**)	.893(**)	-0.294	-0.043
	Sig. (2-tailed)	0.619	0.965	0.467	0.685	0	0.261		0.227	0.002	0	0.163	0.842
	N	24	24	24	24	24	24	24	24	24	24	24	24
Entrenchment	Pearson Correlation	.534(**)	0.144	.411(*)	0.379	.801(**)	-.617(**)	0.256	1	-0.354	.546(**)	0.394	-0.068
	Sig. (2-tailed)	0.007	0.503	0.046	0.068	0	0.001	0.227		0.09	0.006	0.057	0.75
	N	24	24	24	24	24	24	24	24	24	24	24	24
Mean Bfull Width	Pearson Correlation	-.489(*)	-0.009	-.520(**)	-0.34	0.229	.577(**)	.589(**)	-0.354	1	0.281	-.548(**)	-0.122
	Sig. (2-tailed)	0.015	0.967	0.009	0.104	0.281	0.003	0.002	0.09		0.184	0.006	0.571
	N	24	24	24	24	24	24	24	24	24	24	24	24
Mean Bfull Depth	Pearson Correlation	0.024	-0.043	-0.007	-0.02	.825(**)	-.541(**)	.893(**)	.546(**)	0.281	1	-0.189	-0.196
	Sig. (2-tailed)	0.913	0.844	0.974	0.925	0	0.006	0	0.006	0.184		0.375	0.359
	N	24	24	24	24	24	24	24	24	24	24	24	24
Riffle Density	Pearson Correlation	.885(**)	.697(**)	.861(**)	.899(**)	-0.009	-0.229	-0.294	0.394	-.548(**)	-0.189	1	.577(**)

		Later. Scour Pool	**Second. Ch. Pool**	**Backwater Pool**	**Total Pool**	**FPAW**	**W/D Ratio**	**Cross Sect. Area**	**Entrenchment**	**Mean Bfull Width**	**Mean Bfull Depth**	**Riffle Density**	**Rapid Density**
	Sig. (2-tailed)	0	0	0	0	0.968	0.281	0.163	0.057	0.006	0.375		0.003
	N	24	24	24	24	24	24	24	24	24	24	24	24
Rapid Density	Pearson Correlation	.630(**)	.662(**)	.452(*)	.706(**)	-0.172	-0.018	-0.043	-0.068	-0.122	-0.196	.577(**)	1
	Sig. (2-tailed)	0.001	0	0.027	0	0.422	0.934	0.842	0.75	0.571	0.359	0.003	
	N	24	24	24	24	24	24	24	24	24	24	24	24

(*Significant at 0.05 level; **significant at 0.01 level)

As indicated in Table 4.16, entrenchment ratio was significantly and positively correlated with lateral scour pool density and backwater pool density. This would seem to indicate streams with lower entrenchment ratio values (i.e., more entrenched, less floodplain access) also would tend to have less of these types of habitat. Especially in the case of backwater pools, the lack of an accessible floodplain may prevent development of these habitat types relative to streams with a more accessible floodplain. In addition, stream energy may have stronger vertical effects than horizontal in entrenched streams; however, slope also plays a role in stream energy, and slope data could not be included in this analysis. Although not shown, plunge pool density did not have a significant correlative relationship with any of the geomorphologic variables.

Mean bankfull width was significantly and positively correlated with lateral scour pool and backwater pool density, and riffle density. This may be a result of the wider streams having a greater range of channel flow statuses than narrower streams in this study. In addition, no significant relationship existed between entrenchment ratio and mean bankfull width in this study.

Another unexpected result of the correlation test indicated the significant and positive relationship between riffle and rapid densities and all pool type densities. A possible cause of this result could be the influence of slope on stream habitat. Greater slope tends to increase the diversity of instream habitat, and the figures above (4.9 through 4.14) showing significant differences among sites based on HCU density show the sites with the greatest slope (DC and PC) also tended to have the highest densities of all pool types in addition to riffles and rapids (although the latter was not significantly different).

Chapter V. Discussion

As indicated in the Introduction of this report, the main purpose of this study was to compare three reach types in the Stony River:

7. Below dam outfall with minimal mine impairment;
8. Mid-reach mine-impaired;
9. Lower reach with reduced gradient with

- Two structurally similar streams with similar gradient and geology and
- Two streams sustaining diverse fish faunas.

In order to make the preceding comparisons, this study attempted to explore the following:

1. What is the hierarchical setting of these channels, and does this setting pre-dispose these streams for certain habitat types?
2. How do the results of this study compare to other fish studies using similar methods?
3. Is the available physical habitat in these streams conducive to particular fish species traditionally found in the main watershed?
4. Does the hydraulic channel unit classification system used in this study compare favorably with other classification systems?
5. How similar are the reaches used for comparison in this study (in terms of physical habitat)?

Hierarchical Setting of Channels

As indicated in the introduction, the Stony River, Abram Creek and Difficult Creek reaches are set in the Allegheny Highlands physiographic province, while New Creek and Patterson Creek are part of the Ridge and Valley. However, in using Rosgen's (1996) classification of each site, the Stony River sites had geomorphologic characteristics in common with the North Fork of Patterson Creek, while Abram Creek and Difficult Creek were similar to New Creek. This occurred in spite of slope differences among the members of each group ("B" type streams vs. "C" types (Rosgen 1996)). For the streams in this study, physiographic province seemed to have little influence on defining differences between these streams, except for fish density. Although the D_{50} pebble count size seemed to be significantly different between the Ridge and Valley sites and those from the Allegheny Highlands, the mean modified Wentworth pebble count size seemed to be influenced equally by slope and physiographic province, with New Creek and the SR4 site having similar mean pebble sizes. Other geomorphologic variables influenced by basin-wide processes did not seem to differ significantly among the sites, despite obvious differences in valley shapes and patterns (e.g. dendritic vs. trellis). This lack of differences may be attributable to geologic influences in this location acting in the same manner as has been theorized to influence the Shenandoah River (Stauffer et al. 1978). Specifically, the Allegheny Highlands streams may eventually be captured by either the New Creek drainage or they may form a new Ridge and Valley type stream (trellis pattern) in the same manner as the Shenandoah River was formed.

Using the McKenney (1997) classification scheme, all of the present study's streams occurred in straight, narrow valleys (valley sinuosity less than 1.3 = S1 class) except for New Creek, which would be considered to occur in a straight, wide valley (S2 class). Reaches were classified by as either bedrock-influenced (20% or more of channel bottom is bedrock and/or coarse subangular boulders, or one bank of low flow channel is bedrock) or alluvial in her study. Although no single Rosgen reach in the present study could be exclusively classified as bedrock-influenced, all of the reaches had various places where bedrock influenced channel morphology except for New Creek and Stony River-SR4 (See Appendix, Table A2 for pebble count data). In comparing her results with the present study difficulties arise based on differing ecoregion types, where most of the present study's streams reside in a mountain ecoregion (Allegheny Mountains) as opposed to a plateau (Ozark Platueau).

Based on Mosley's comparisons (1987), the streams in this study would be classified from swift to slow trout streams except for the North Fork of Patterson Creek, which would be characterized as a minnow/bass stream. Using Illies and Botosaneanu's classification (1963 in Mosley 1987), all of the streams in the present study would generally be characterized with high dissolved oxygen, fast or turbulent flow, and rubble (cobble) substrate.

Slope seemed to have a greater influence on these channels than other geomorphologic variables. As described in Chapter II, slope has been found to significantly influence other geomorphologic variables, and in turn fish habitat. Streams with the higher slopes tended to have the greater densities of hydraulic channel units (compare Figures 4.9 through 4.13). Despite the similar slopes, one noted difference occurred between the North Fork Patterson Creek and Difficult Creek—Difficult Creek had a larger overall mean pebble count size than North Fork Patterson Creek (Figure 4.4). This could be due to their locations in different physiographic provinces, with Difficult Creek being primarily cobble-controlled as compared to the gravel-controlled North Fork Patterson Creek (D_{50} pebble count size).

One difference (but not found to be significant) was the difference in entrenchment ratios between the streams in the Allegheny Highlands province. AC and DC had similar ratios to the diverse fish streams (PC and NC), and had higher fish densities (although not significant) than the Stony River sites. However, the greater access to flood plain habitats may play a role in supporting fish populations in Abram Creek and Difficult Creek despite impacts due to previous mining (especially Abram Creek).

Fish Study

Although differences in fish densities were observed, a significant pattern based on fish habitat densities as measured by HCUs was not noted in this study. The streams with diverse fish communities (NC and PC) had significantly different amounts of each kind of HCU, but similar numbers of fish. Fish density was not significantly different among all of the Allegheny Highlands sites, and all of these sites had similar densities of HCUs, except for the low gradient SR4 site. This reiterates the influence of slope on the diversity of habitats, but HCU density did not appear to influence fish density in this study.

Although the Stony River sites and Abram Creek have noted impacts due to past mining activities, Difficult Creek did not have a significantly higher fish density than these sites. Some current mining occurs in the Difficult Creek watershed, and past mining has undoubtedly impacted the stream (as all streams in the North Branch Potomac watershed). However, the differences may instead be reflected in fish diversity, which was not recorded for this study.

Although other studies have shown the importance of backwater pools in supporting smaller fish species (and juveniles, fry, and embryos of other species), a significant difference was not found between PC and NC, both the highest fish densities in the study. Secondary channel pools, on the other hand, may be supporting the sparse fish populations in both the Stony River and Difficult Creek. These two sites had the highest density of this habitat type, mainly due to large, mid-channel bars (islands).

Available Physical Habitat

Both mesohabitat and microhabitat in the study streams seem to have enough diversity to support any number of fish species traditionally found in the streams. Based on the lack of significant differences between HSI variables between streams, structurally all of the streams in this study may support some species common in the North Branch Potomac watershed. Based on a review of the HSI variables, it appeared blacknose dace, common shiner, brook trout, creek chub, rainbow trout, and smallmouth bass could all be structurally supported by the study streams. Other species such as rosyside dace, which was found in one study to prefer lateral scour pools adjacent to high currents (Freeman and Grossman 1993), may be particularly suited to those streams with high densities of this habitat type (DC, PC AC and SR3). The habitat type described in their study is equivalent to a lateral scour pool associated with boulders in the current study (HCU 5 in Table 3.6).

Although no data was taken for riparian species on any channel, a not insignificant amount of the riparian vegetation on the Stony River is comprised of eastern hemlock (*Tsuga canadensis*). Bryant et al. (1992) showed conifer tree species were not suitable in forming large woody debris habitat types, which can be important habitats for many fish species.

Hydraulic Unit Classification

After a review of other studies using an HCU-type system, it is apparent the current study did not have enough data for each unit to make more rigorous comparisons among sites. However, the results of this study seem to reiterate the role of slope in producing diverse fish habitats. Whether a large number of different habitats enhance fish diversity is unclear, as most of the streams in the study had low fish densities despite the apparent diversity of fish habitat.

One aspect of the methods used to record HCU was surface area of each habitat type. Other studies, however, have shown surface area does not have a significant influence on fish density, as discussed in Chapter II. The Stony River site with the highest fish densities (SR1) also had two large pools within the study reach which contained the clear majority of the fish in the reach. SR1 had the highest pool to riffle ratio (mesohabitat) of all of the sites besides the low gradient SR4 site (Table 4.5). The low gradient Stony River site (SR4) had very small numbers of fish, despite having a large amount of glide/pool mesohabitat. Confounding variables, such as water quality appear to be controlling fish populations in the study streams.

The method of HCU classification used in the study might have had greater usefulness if other parameters of each unit were included, such as depth, dominant substrate type per unit, velocity, etc. Use of data from Total Stations may facilitate these measurements, and this equipment can be used for the point transect method suggested by some workers (Stanfield and Jones 1998). Objective measurements improve the accuracy of HCU classification, and also provide insights into the possibility of use by fish.

Another promising method of habitat unit classification might be the use of remotely sensed data. The Lower Yakima River has similar characteristics to the Stony River in this study in that the study portion occurred below an existing dam, the channel is relatively confined with little area for the river to meander, and alluvial islands are dispersed throughout the 70-km reach, and Whitted et al. (2002) were able to successfully classify habitats using aerial photography. However, sites such as PC, DC and NC, with high amounts of stream cover, may somewhat preclude its use in some streams. Also, some units such as backwater pools and secondary channel pools may not be classified correctly or even observed on streams with even a minimal amount of riparian cover. This method of classification may still be worth exploring. However, it is quite costly.

Conclusion

In terms of physical fish habitat structure, the streams with similar slopes also tended to have similar HCUs, both in type and in density. A confounding variable which may be skewing the results of the fish density to HCU density results is the level of impact experienced by the Allegheny Highlands streams. Water quality appears to be the controlling variable precluding fish recruitment in these streams. As was described earliear, other studies have shown pool availability can be one of the most important aspects of fish habitat. However, despite having the lowest amount of pool habitat, New Creek also supported the second highest fish densities in the study.

The results of Sullivan's (1987) study emphasize the importance of the backwater pools found in this study as resting places for fish. Therefore although the large boulder bars in the Stony River reaches may prevent upstream migration, they also serve to diversify microhabitats within the stream, especially backwater and secondary channel pools. Secondary channels seemed to be a recurring theme in some of the study sites, particularly Difficult Creek, Abram Creek, SR3, SR4M, and areas on the Upper Stony River reach. The transition between bars and "islands" is unclear, but Sullivan (1987) indicated the convexity of the top of these longitudinal bars often cause water to flow symmetrically on each side of the bar's long axis even during low flows, causing secondary channels, as was observed in this study, particularly on Difficult Creek, SR3, and the lower portion of the Upper Stony River reach. In McKenney's study (1997), she found habitat stability and disturbances can be substantial when compared to the total habitat available in her study reaches. She did recognize the importance of backwaters for young of the year minnows, bass, and sunfishes as well as juvenile darters and madtoms (Peterson 1996 in McKenney 1997).

In terms of available physical fish habitat structure, most of the Stony River sites appear to have the diversity of types and amount of pools to support a diverse fish fauna. Most of the Stony River sites also had “optimal” physical habitat based on the RBP method (Barbour et al. 1999), perhaps indicating the riparian zones also are stable enough to support fish populations. The “best” habitat may be in the areas considered “impaired” by acid mine drainage and other water quality effects. Based on the results of this study, physical habitat does not appear to be a limiting factor for fish populations in these streams.

Bibliography

Angermeier, PL. Spatiotemporal variation in habitat selection by fishes in small Illinois streams. In Community and Evolutionary Ecology of North American Stream Fishes. Eds. WJ Matthews, DC Heins. Norman, OK: University of Oklahoma Press; 1987: 52-60.

Barbour MT et al. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish, second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.: 1999. 229 p.

Bart, Jr, HL. Fish habitat association in an Ozark stream. Environmental Biology of Fishes 1989; 24: 173-186.

Beschta, RL, Platts, WS. Morphological features of small streams: significance and function. Water Resources Bulletin 1986; 22: 369-379.

Bisson PA et al. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. Portland, OR: Acquisition and Utilization of Aquatic Habitat Inventory Information Symposium Proceedings, Oct. 28-30, 1981; 1982: 62-73.

Bisson, PA, Sullivan, K, Nielsen, JL. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 1988; 117: 262-273.

Bowlby, JN, Imhof, JG. Alternative approaches in predicting trout populations from habitat in streams. In Alternatives in regulated river management. Eds. JA Gore, GE Petts. Boca Raton, FL: CRC Press, Inc; 1989. 317-330.

Bryant MD, Wright BE, Davies BJ. Application of a hierarchical habitat unit classification system: stream habitat and salmonid distribution in Ward Creek, southeast Alaska PNW-RN-508. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 1992. 18 p.

Buffagni, A et al. Using macroinvertebrate species assemblages to identify river channel habitat units: an application of the functional habitats concept to a large, unpolluted Italian river (River Ticino, northern Italy). Hydrobiologia 2000; 435: 213-225.

Cardwell, D.H., Erwin, R.B., and Woodward, H.P., 1968, Geologic Map of West Virginia. 1:250,000 scale.

Curry, KD, Spacie, A. Differential use of stream habitat by spawning catostomids. American Midland Naturalist 1984; 111: 267-279.

De Jalon, DG, Mayo, M, Molles, MC. Characterization of Spanish Pyrenean stream habitat: relationships between fish communities and their habitat. Regulated Rivers: Research and Management 1996; 12: 305-316.

Doloff CA, Hankin DG, Reeves GH. Basinwide estimation of habitat and fish populations in streams GTR-SE-83. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experimental Station: 1993. 25 p.

Dunning, JB, Danielson, BF, Pulliam, HR. Ecological processes that affect populations in complex landscapes. Oikos 1992; 65: 169-175.

Edwards, EA, Gebhart, G, Maughan, OE. Habitat suitability information: smallmouth bass. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.36. 1983. 47 p.

Edwards, EA, Li, H, Schreck, CB. Habitat suitability index models: longnose dace. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.33. 1983. 13 p.

Emery, JC et al. Classifying the hydraulic performance of riffle-pool bedforms for habitat assessment and river rehabilitation design. River Research and Applications 2003; 19: 533-549.

Etnier, DA, Starnes, WC. The fishes of Tennessee. Knoxville, TN: The University of Tennessee Press; 1993. 689 p.

Felley, JD, Hill, LG. Multivariate assessment of environmental preferences of cyprinid fishes of the Illinois River, Oklahoma. American Midland Naturalist 1983; 109: 209-221.

Freeman, MC, Grossman, GD. Effects of habitat availability on dispersion of a stream cyprinid. Environmental Biology of Fishes 1993; 37: 121-130.

Frissell, CA, et al. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 1986; 10: 199-214.

Gorman, OT. Habitat segregation in an assemblage of minnows in an Ozark stream. In Community and Evolutionary Ecology of North American Stream Fishes. Eds. WJ Matthews, DC Heins. Norman, OK: University of Oklahoma Press; 1987: 33-41.

Gorman, OT, Karr, JR. Habitat structure and stream fish communities. Ecology 1978; 59: 507-515.

Graham, PJ, Shepard, BB, Fraley, JJ. Use of stream habitat classifications to identify bull trout spawning areas in streams. Portland, OR: Acquisition and Utilization of Aquatic Habitat Inventory Information Symposium Proceedings, Oct. 28-30, 1981; 1982: 186-190.

Grossman, GD, Ratajczak, Jr, RE. Long-term patterns of microhabitat use by fish in a southern Appalachian stream from 1983 to 1992: effects of hydrologic period, season and fish length. Ecology of Freshwater Fish 1998; 7: 108-131.

Hawkins, CP et al. A hierarchical approach to classifying stream habitat features. Fisheries 1993; 18: 3-12.

Hawkins, CP, Murphy, ML, Anderson, NH. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. Ecology 1982; 63: 1840-1856.

Hicks, BJ, Hall, JD. Rock type and channel gradient structure salmonid populations in the Oregon Coast Range. Transactions of the American Fisheries Society 2003; 132: 468-482.

Inoue, M, Nakano, S. Habitat structure along channel-unit sequences for juvenile salmon: a subunit-based analysis of in-stream landscapes. Freshwater Biology 1999; 42: 597-608.

Inoue, M, Nunokawa, M. Effects of longitudinal variations in stream habitat structure on fish abundance: an analysis based on subunit-scale habitat classification. Freshwater Biology 2002; 47: 1594-1607.

Jenkins, RE, Burkhead, NM. Freshwater fishes of Virginia. Bethesda, MD: American Fisheries Society; 1994. 1079 p.

Kershner, JL et al. Distribution and sequencing of mesohabitats: are there differences at the reach scale? Rivers 1992; 3: 179-190.

Kershner, JL, Snider, WM. Importance of a habitat-level classification system to design instream flow studies. In River conservation and management. Ed. PJ Boon, P Calow, GE Pettis. Chichester, England: John Wiley and Sons; 1992. 470 p.

Knapp, RA, Vredenburg, VT, Matthews, KR. Effects of stream channel morphology on golden trout spawning habitat and recruitment. Ecological Applications 1998; 8: 1104-1117.

Kondolf, GM. Geomorphological stream channel classification in aquatic habitat restoration: uses and limitations. Aquatic Conservation: Marine and Freshwater Ecosystems 1995; 5: 127-141.

Legleiter, CJ. Spectrally driven classification of high spatial resolution, hyperspectral imagery: a tool for mapping in-stream habitat. Environmental Management 2003; 32: 399-411.

McCormick, FH, Peck, DV, Larsen, DP. Comparison of geographic classification schemes for Mid-Atlantic stream fish assemblages. Journal of the North American Benthological Society 2000; 19: 385-404.

McGarrell, CA. Stream reach morphology and macroinvertebrate community structure in high-quality, cold water streams. Harrisburg, PA: Susquehanna River Basin Commission; 1997. 92 p.

McKenney, R. “Formation and maintenance of hydraulic habitat units in streams of the Ozark plateaus, Missouri and Arkansas.” Dissertation Pennsylvania State University. 1997.

McMahon, TE. Habitat suitability index models: creek chub. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.4. 1982. 23 p.

McMahon, TE, Terrell, JW. Habitat suitability index models: channel catfish. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.2. 1982. 29 p.

McNab, WH, Avers, PE. Ecological subregions of the United States. United States Forest Service, ECOMAP Team. WO-WSA-5. 1994.

Meffe, GK, Sheldon, AL. The influence of habitat structure on fish assemblage composition in southeastern blackwater streams. American Midland Naturalist 1988; 120: 225-240.

Meffe, GK, Sheldon, AL. Post-defaunation recovery of fish assemblages in southeastern blackwater streams. Ecology 1990; 71: 657-667.

Modde, T, Ford, RC, Parsons, MG. Use of a habitat-based stream classification system for categorizing trout biomass. North American Journal of Fisheries Management 1991; 11: 305-311.

Mosley, M.P. The classification and characterization of rivers. In River channels: environment and process. Ed. Keith Richards. New York: Basil Blackwell, Inc.; 1987. 391 p.

Natural Resources Conservation Service (NRCS) Aquatic Assessment Workgroup. Stream visual assessment protocol. National Water and Climate Center Technical Note 99–1. United States Department of Agriculture, NRCS. 1998. 42 p.

Nelson, RL et al. Trout distribution and habitat in relation to geology and geomorphology in the North Fork Humboldt River drainage, northeastern Nevada. Transactions of the American Fisheries Society 1992; 121: 405-426.

Newson, MD, Newson, CL. Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. Progress in Physical Geography 2000; 24: 195-217.

Osborne, LL et al. Stream habitat assessment programs in states of the AFS North Central Division. Fisheries 1991; 16: 28-35.

Parsons, MG, Maxwell, JR, Heller, D. A predictive fish habitat index model using geomorphic parameters. Portland, OR: Acquisition and Utilization of Aquatic Habitat Inventory Information Symposium Proceedings, Oct. 28-30, 1981; 85-91.

Peterson, JT, Rabeni, CF. Evaluating the physical characteristics of channel units in an Ozark stream. Transactions of the American Fisheries Society 2001a; 130: 898-910.

Peterson, JT, Rabeni, CF. The relation of fish assemblages to channel units in an Ozark stream. Transactions of the American Fisheries Society 2001b; 130: 911-926.

Pflieger, WL, Schene, Jr, MA, Haverland, PS. Techniques for the classification of stream habitats, with examples of their application in defining the stream habitats of Missouri. Portland, OR: Acquisition and Utilization of Aquatic Habitat Inventory Information Symposium Proceedings, Oct. 28-30, 1981; 362-368.

Poole, GC, Frissell, CA, Ralph, SC. In-stream habitat unit classification: inadequacies for monitoring and some consequences for management. Journal of the American Water Resources Association 1997; 33: 879-896.

Porter, MS, Rosefeld, J, Parkinson, EA. Predictive models of fish species distribution in the Blackwater drainage, British Columbia. North American Journal of Fisheries Management 2000; 20: 349-359.

Prichard, D., H. Barrett, J. Cagney, R. Clark, J. Fogg, K. Gebhart, P.L. Hansen, B. Mitchell, and D. Tippy. 1993. Riparian Area Management: Process for Assessing Proper Functioning Condition. TR 1737-9 (Revised 1998). Bureau of Land Management,BLM/SC/ST-93/003+1737+REV95+REV98, Service Center, CO. 51 pp.

Pusey, BJ, Arthington, AH, Read, MG. Spatial and temporal variation in fish assemblage structure in the Mary River, southeastern Queensland: the influence of habitat structure. Environmental Biology of Fishes 1993; 37: 355-380.

Pusey, BJ, Kennard, MJ, Arthington, AH. Discharge variability and the development of predictive models relating stream fish assemblage structure to habitat in northeastern Australia. Ecology of Freshwater Fish 2000; 9: 30-50.

Rabeni, CF, Doisy, KE, Galat, DL. Testing the biological basis of a stream habitat classification using benthic invertebrates. Ecological Applications 2002; 12: 782-796.

Raleigh, RF. Habitat suitability index models: brook trout. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.24. 1982. 24 p.

Raleigh, RF et al. Habitat suitability information: rainbow trout. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.60. 1984. 64 p.

Rosgen, D. Applied river morphology. Pagosa Springs, CO: Wildland Hydrology; 1996.

Ross, ST, Baker, JA, Clark, KE. Microhabitat partitioning of southeastern stream fishes: temporal and spatial predictability. In Community and Evolutionary Ecology of North American Stream Fishes. Eds. WJ Matthews, DC Heins. Norman, OK: University of Oklahoma Press; 1987: 42-51.

Schlosser, IJ. Critical landscape attributes that influence fish population dynamics in headwater streams. Hydrobiologia 1995; 303: 71-81.

Schlosser, IJ, Toth, LA. Niche relationships and population ecology of rainbow (*Etheostoma caeruleum*) and fantail (*E. flabellare*) darters in a temporally variable environment. Oikos 1984; 42: 229-238.

Sedell, JR et al. Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. Environmental Management 1990; 14: 711-724.

Sheldon, AL. Perlid stoneflies (Plecoptera) in an Appalachian drainage: a multivariate approach to mapping stream communities. American Midland Naturalist 1985; 113: 334-342.

Stanfield, LW, Jones, ML. A comparison of full-station visual and transect-based methods of conducting habitat surveys in support of habitat suitability index models for southern Ontario. North American Journal of Fisheries Management 1998; 18: 657-675.

Statzner, B, Gore, JA, Resh, VH. Hydraulic stream ecology: observed patterns and potential applications. Journal of the North American Benthological Society 1988; 7: 307-360.

Stauffer, Jr, JR, Boltz, JM, White, LR. The fishes of West Virginia. Philadelphia: Academy of Natural Sciences of Philadelphia; 1995. 389 p.

Stauffer, JR, Hocutt, CH, and Pistolas, S. Preliminary comparison of the ichthyofauna of the north and south tributaries of the upper Potomac River. Proceedings of the second annual meeting, Potomac Chapter of the American Fisheries Society : May 11-12, 1978, Cacapon State Park, West Virginia 1978; 24-38.

Stuber, RJ, Gebhart, G, Maughan, OE. Habitat suitability index models: bluegill. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.8. 1982a. 26 p.

Stuber, RJ, Gebhart, G, Maughan, OE. Habitat suitability index models: green sunfish. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.15. 1982b. 28 p.

Stuber, JG, Gebhart, G, Maughan, OE. Habitat suitability index models: largemouth bass. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.16. 1982c. 32 p.

Sullivan, K. Hydraulics and fish habitat in relation to channel morphology. Dissertation Johns Hopkins University. Ann Arbor, MI: University Microfilms International; 1987. 409 p.

Thomson, JR et al. A geomorphological framework for river characterization and habitat assessment. Aquatic Conservation: Marine and Freshwater Ecosystems 2001; 11: 373-389.

Thomson, JR, Taylor, MP, Brierley, GJ. Are River Styles ecologically meaningful? A test of the ecological significance of a geomorphic river characterization scheme. Aquatic Conservation: Marine and Freshwater Ecosystems 2004; 14: 25-48.

Trial, JG et al. Habitat suitability information: blacknose dace. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.41. 1983a. 28 p.

Trial, JG et al. Habitat suitability information: common shiner. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.40. 1983b. 22 p.

Trial, JG et al. Habitat suitability information: fallfish. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.48. 1983c. 15 p.

Tsao, EH et al. A stream classification system for identifying reintroduction sites of Formosan landlocked salmon. Acta Zoologica Taiwanica 1996; 7: 39-59.

Twomey, KA, Williamson, KL, Nelson, PC. Habitat suitability index models and instream flow suitability curves: white sucker. US Department of Interior, Fish and Wildlife Services. FWS/OBS-82/10.64. 1984. 56 p.

Ward, TA et al. A comparison of three visual assessments for riparian and stream health. Journal of Soil and Water Conservation 2003; 58: 83-88.

Watson, G, Hillman, TW. Factors affecting the distribution and abundance of bull trout: an investigation at hierarchical scales. North American Journal of Fisheries Management 1997; 17: 237-252.

Whited, D, Stanford, JA, Kimball, JS. Application of airborne multispectral digital imagery to quantify riverine habitats at different base flows. River Research and Applications 2002; 18: 583-594.

WV DEP. An ecological assessment of the North Branch of the Potomac River watershed 1997. Report number - 02070002 – 1997. Charleston, WV: West Virginia Department of Environmental Protection, Office of Water Resources, Watershed Assessment Program; 1997. 147 p.

WV DEP. 2004 Section 303(d) list draft. Charleston, WV: West Virginia Department of Environmental Protection, Division of Water and Waste Management; 2004. 137 p.

Young, WJ. Field techniques for the classification of near-bed flow regimes. Freshwater Biology 1993; 29: 377-383.

APPENDIX

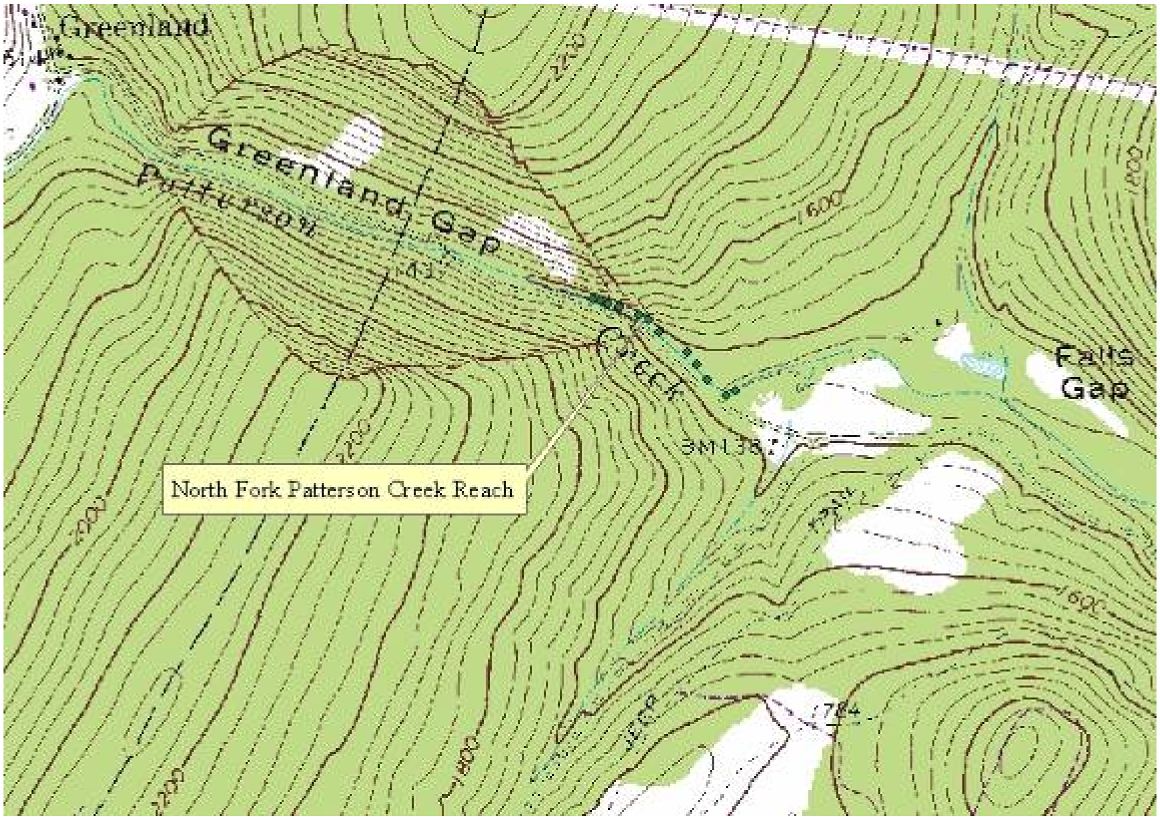

Figure A1. PC reach location

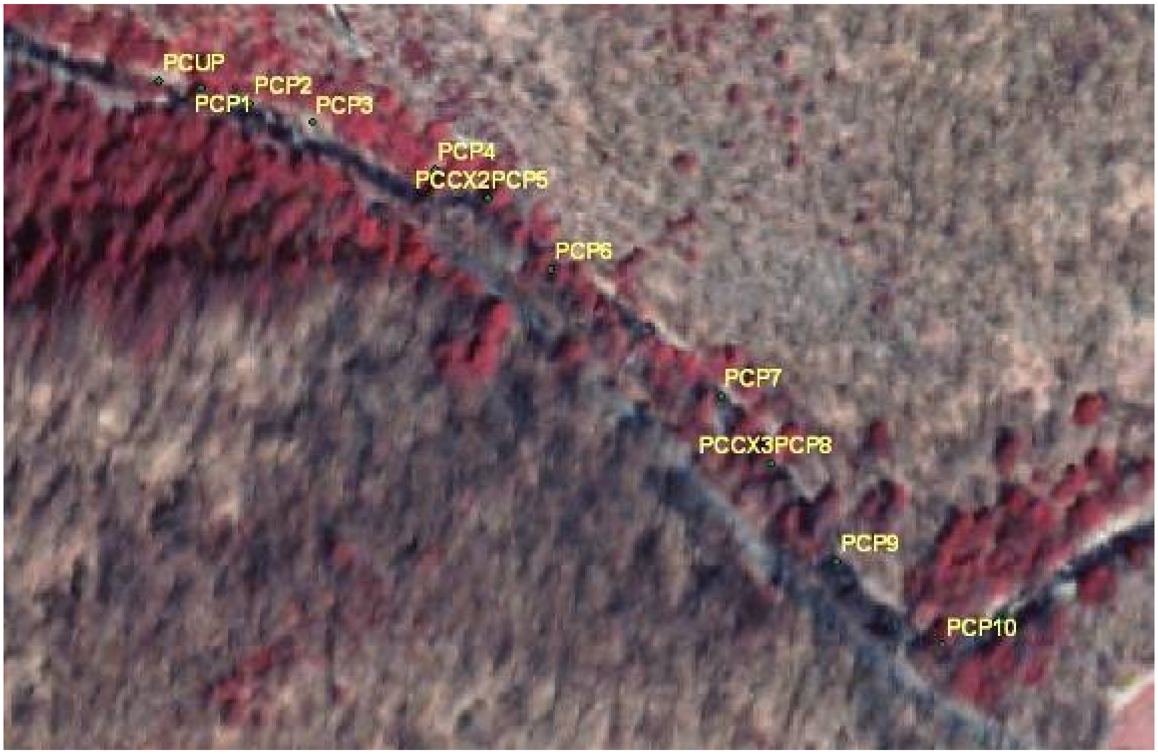

Figure A2. PC pebble count and cross-section locations

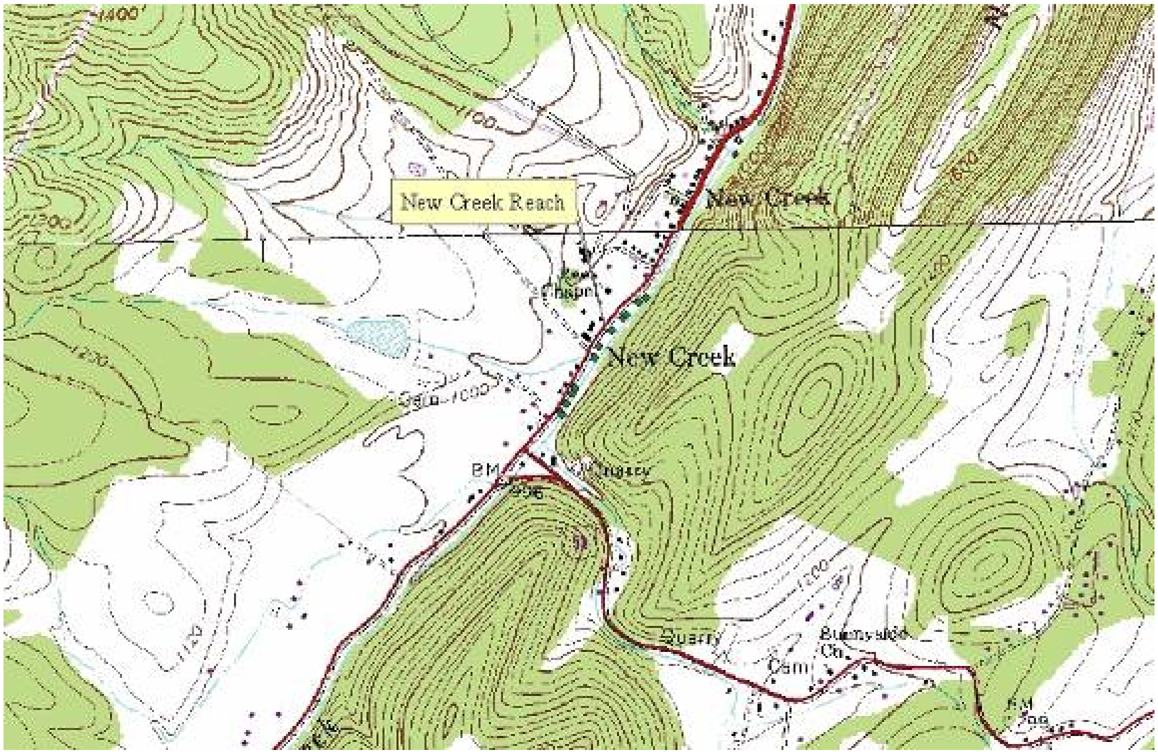

Figure A3. NC reach location

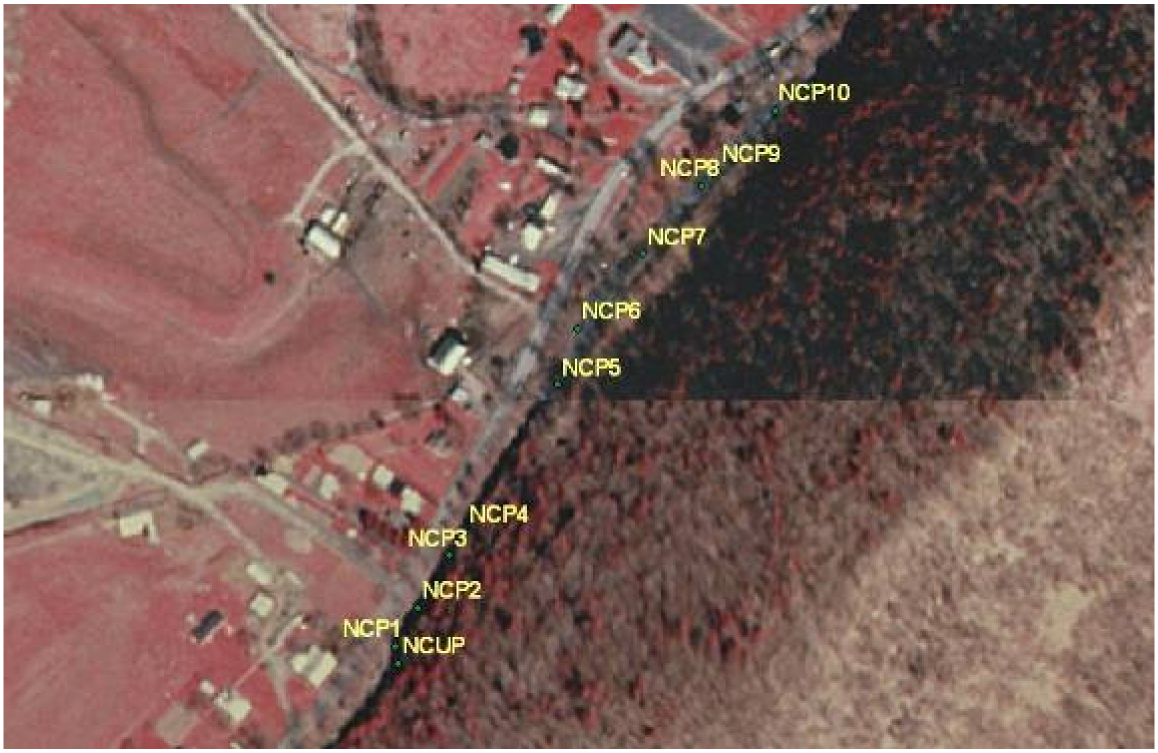

Figure A4. NC pebble count and cross section locations

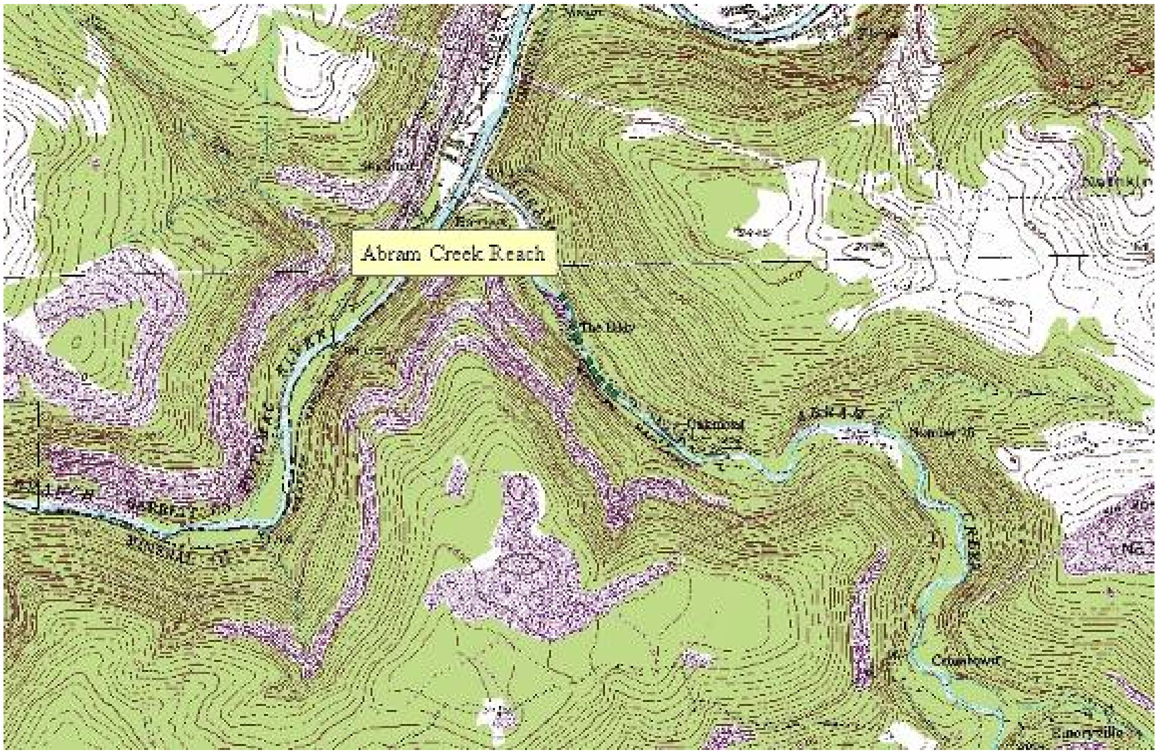

Figure A5. AC reach location

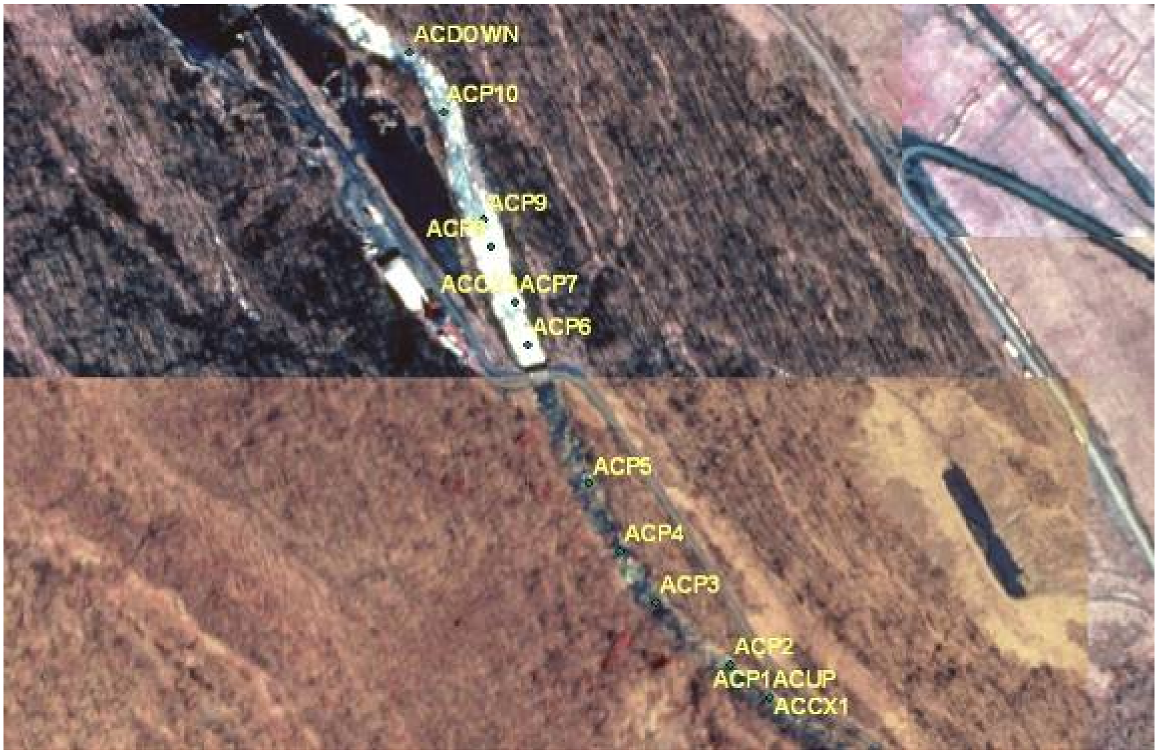

Figure A6. AC pebble count and cross section locations

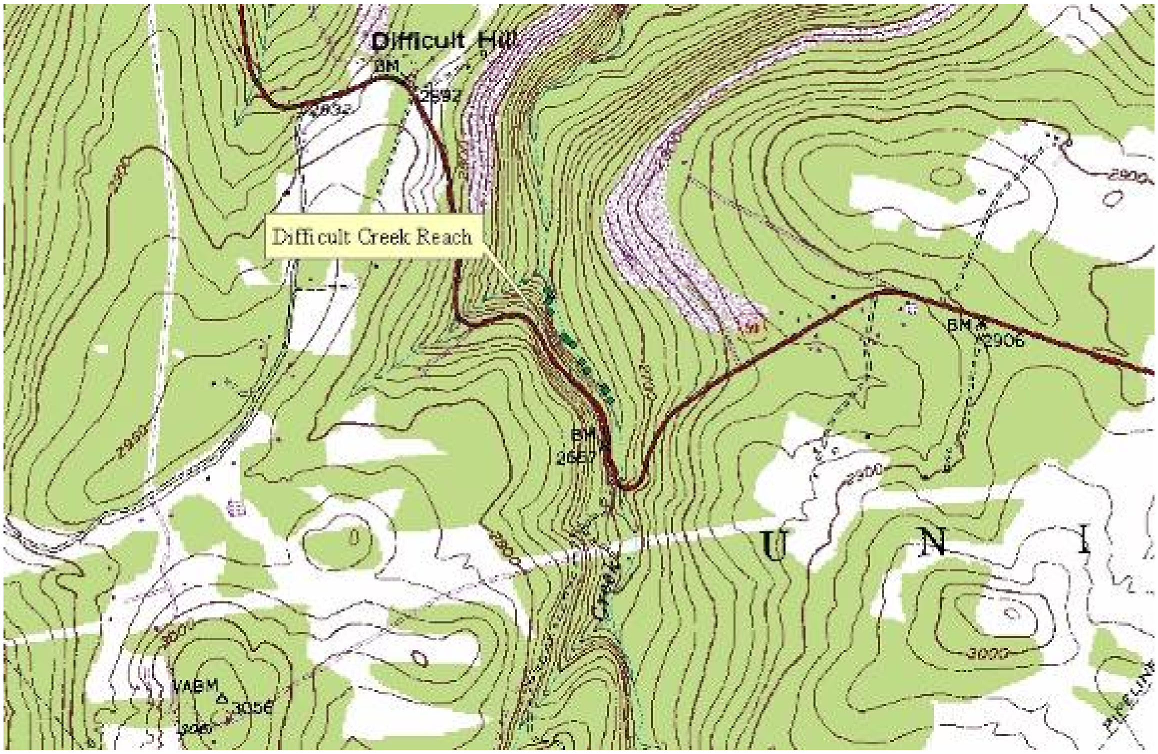

Figure A7. DC reach location

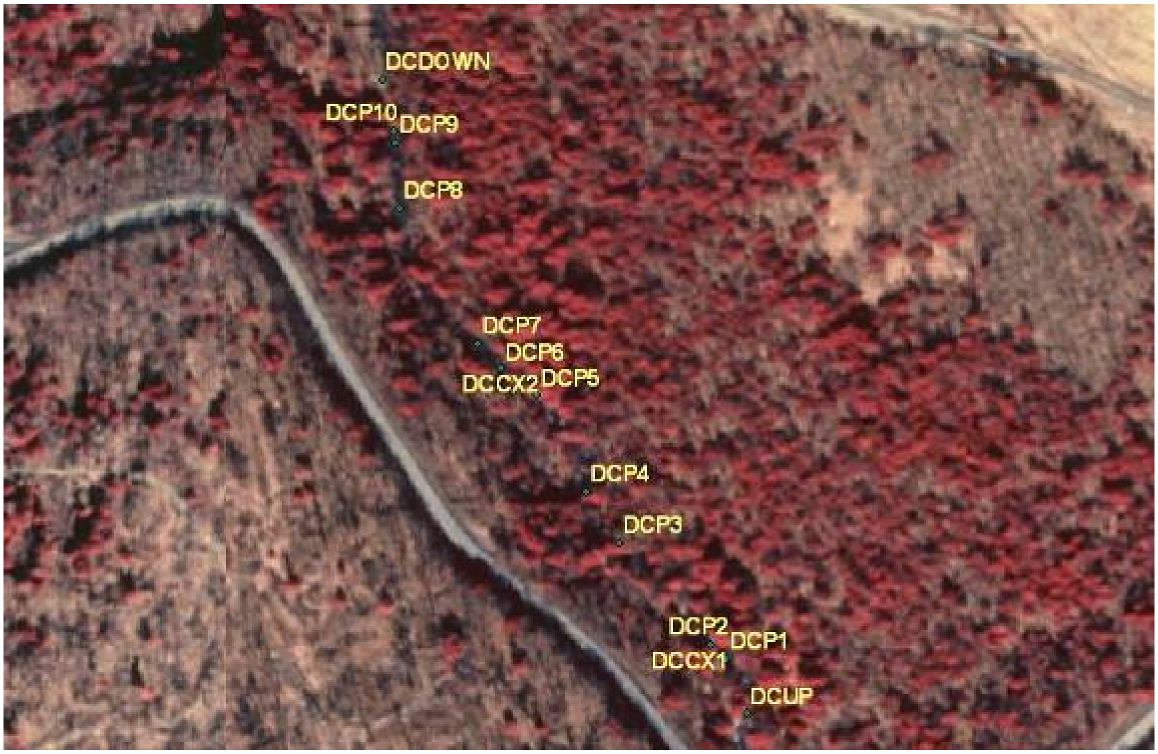

Figure A8. DC pebble count and cross section locations

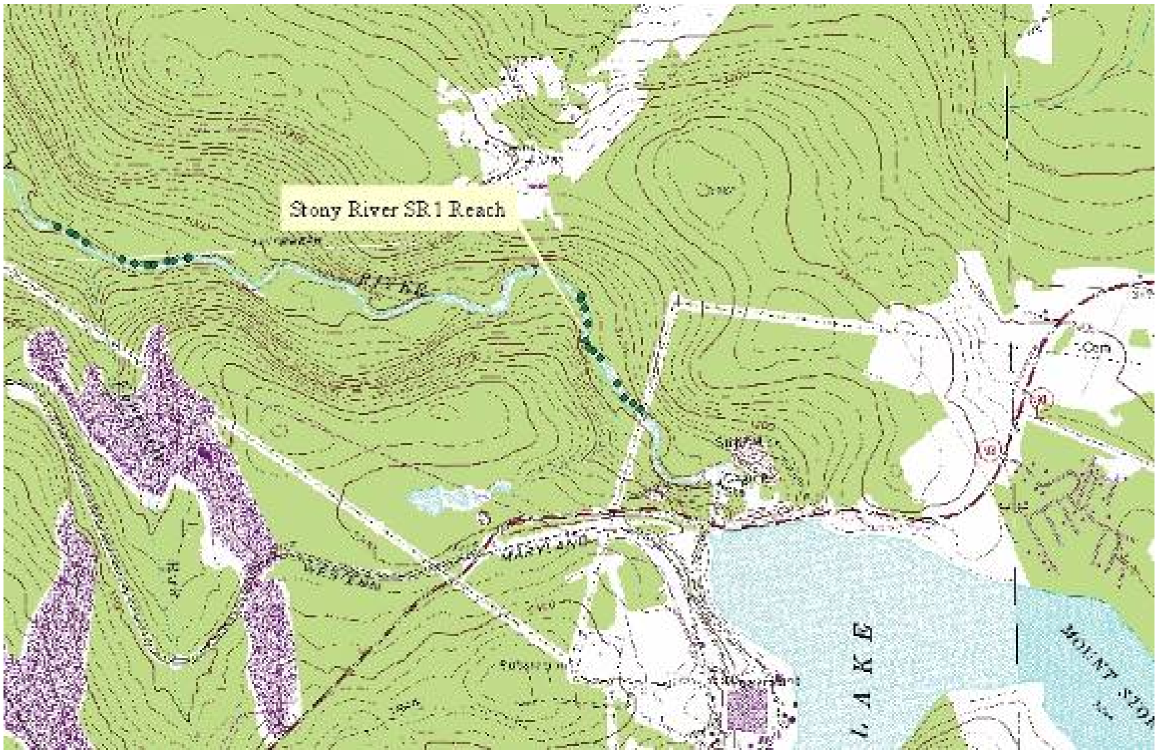

Figure A9. SR1 reach location

Figure A10. SR1 pebble count and cross section locations

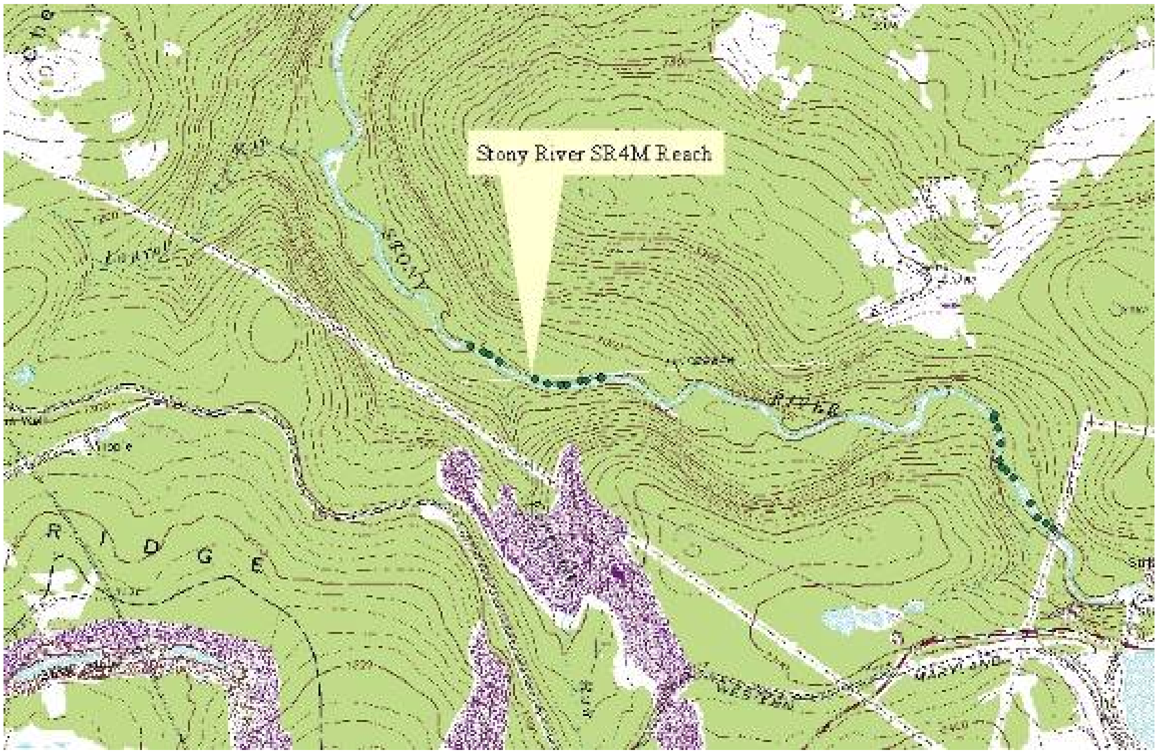

Figure A11. SR4M reach location

Figure A12. SR4M pebble count and cross section locations

Figure A13. SR3 reach location

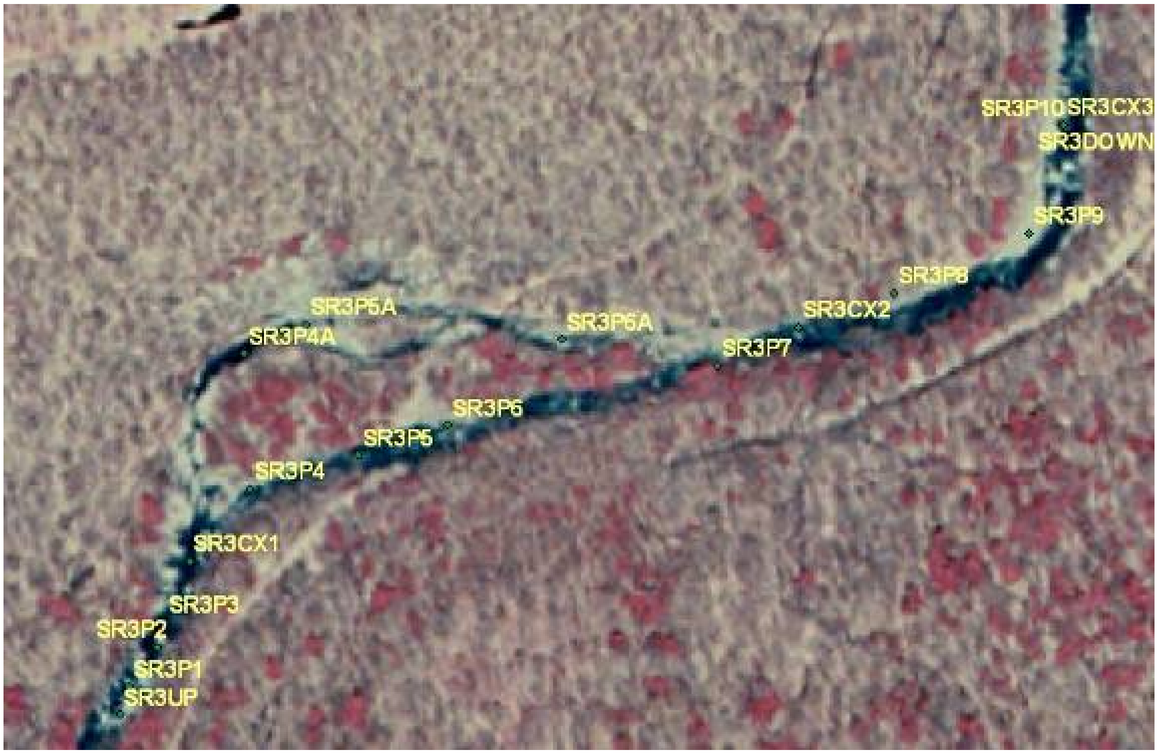

Figure A14. SR3 pebble count and cross section locations

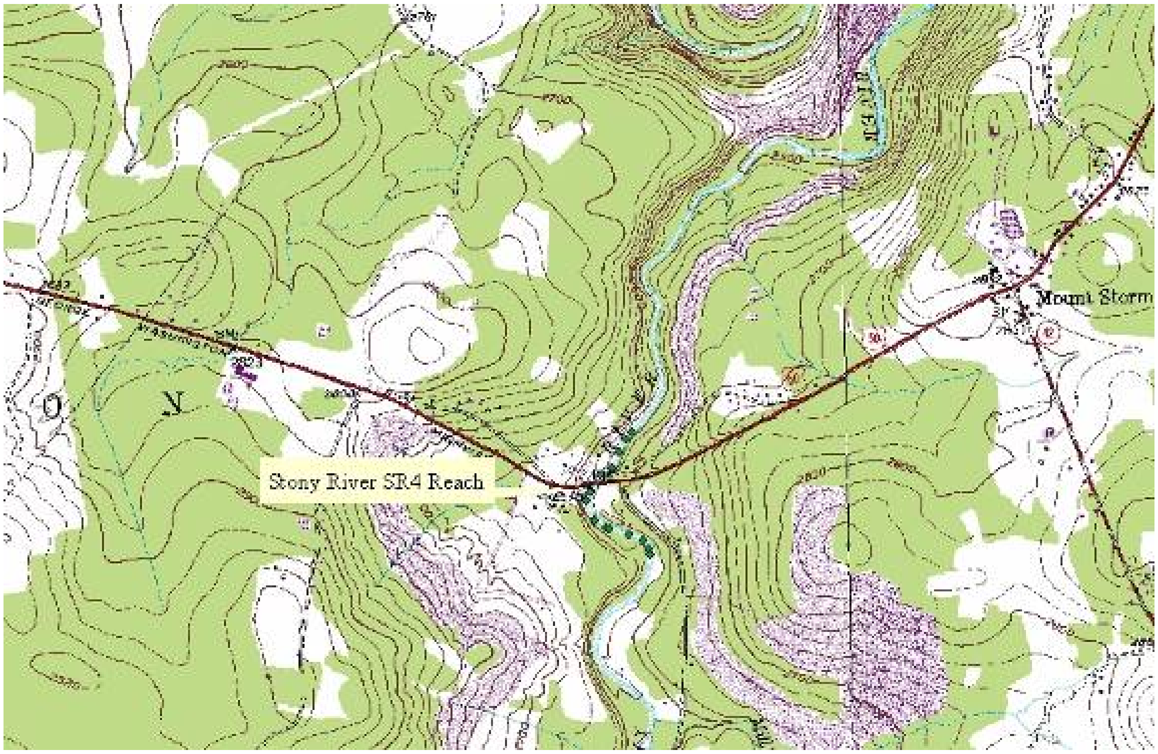

Figure A15. SR4 reach location

Figure A16. SR4 pebble count and cross section locations

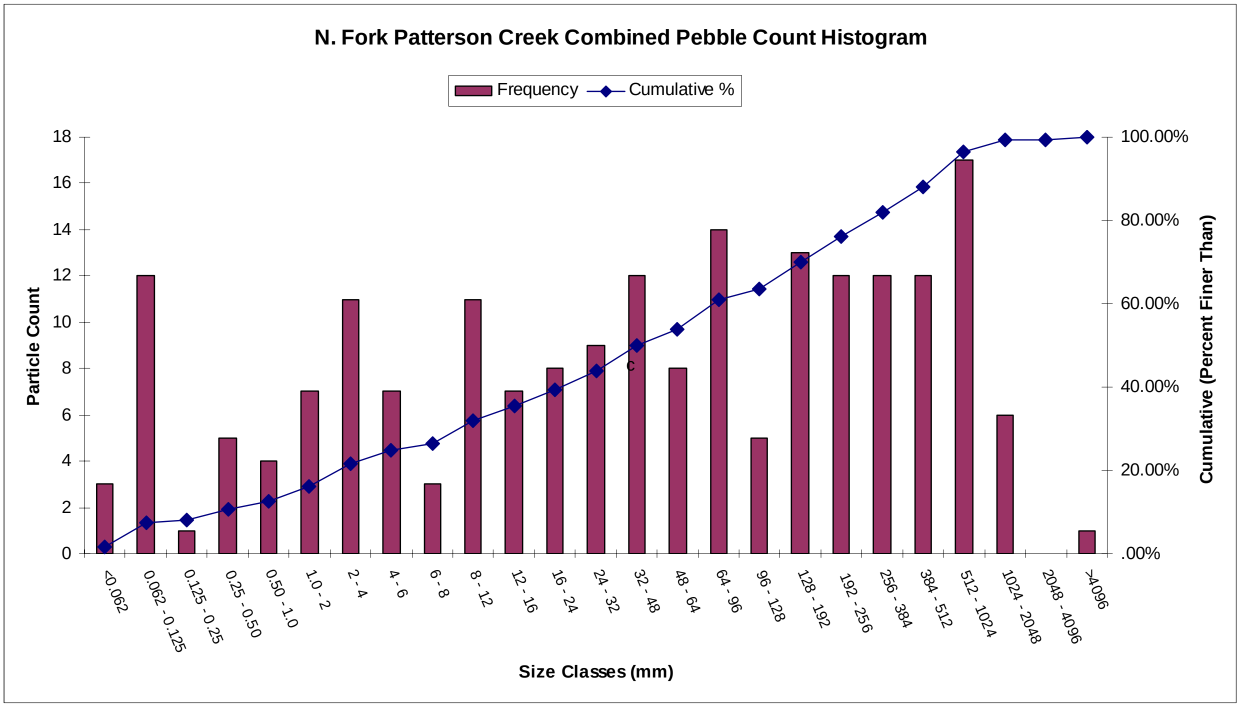

Figure A17. PC Overall Pebble Count

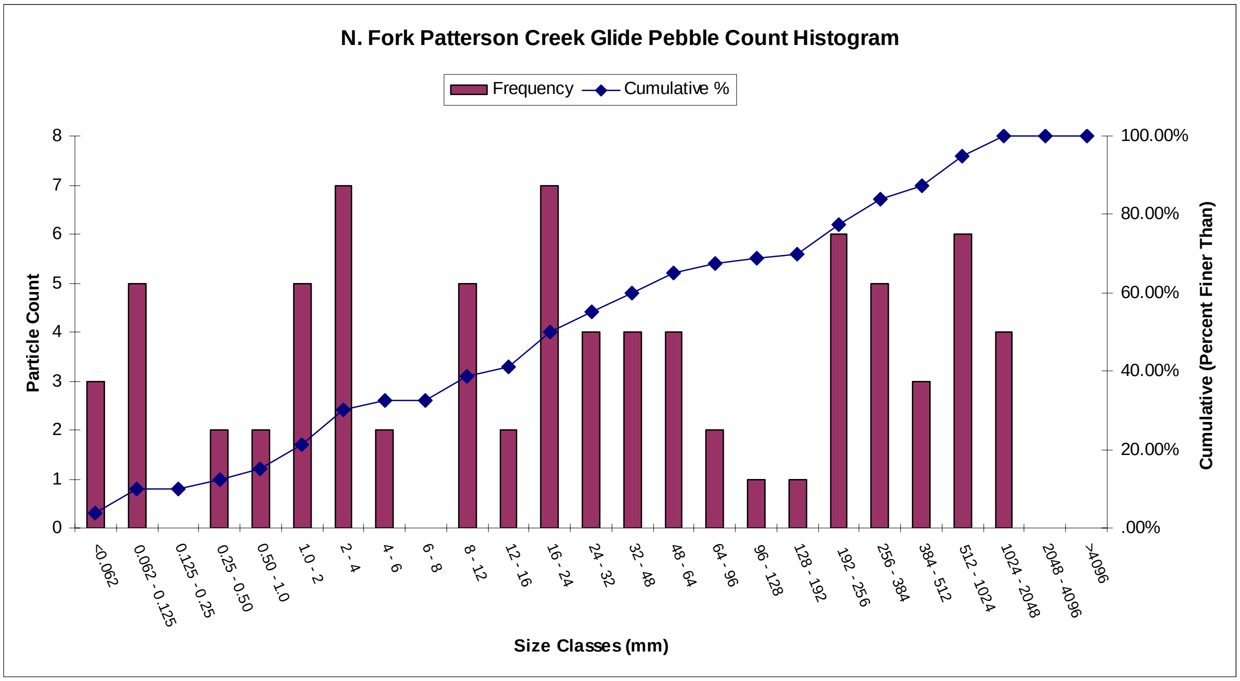

Figure A18. PC Glide Pebble Count

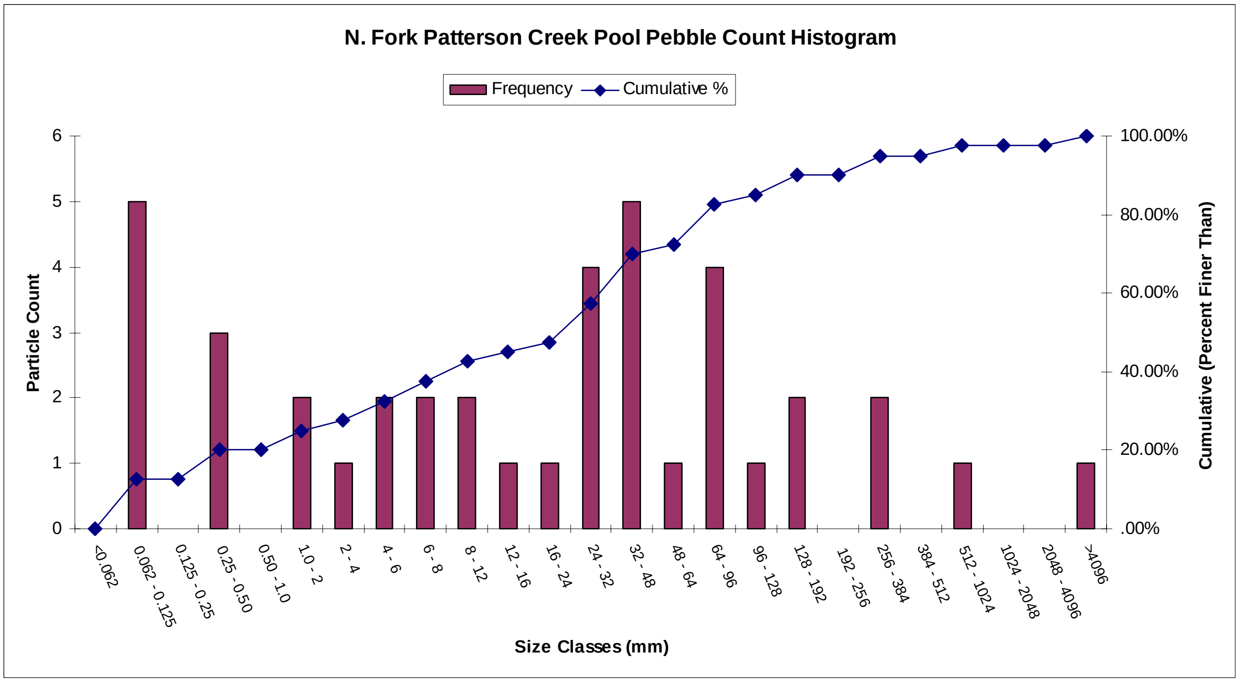

Figure A19. PC Pool Pebble Count

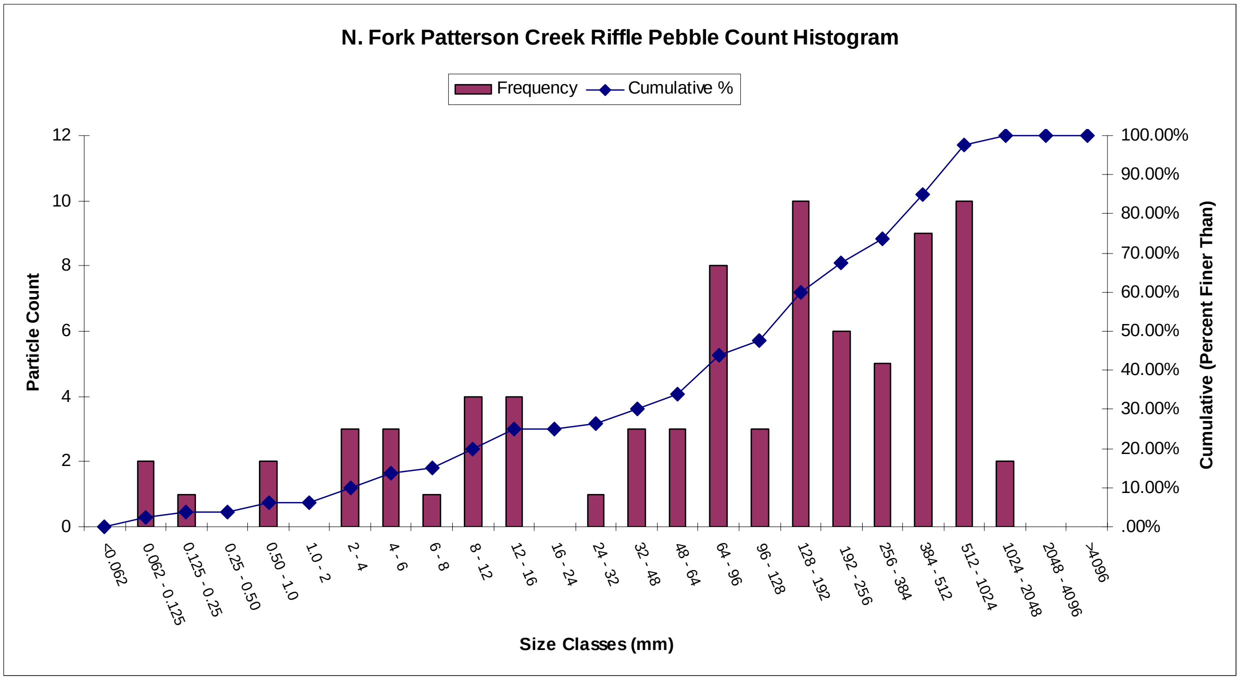

Figure A20. PC Riffle Pebble Count

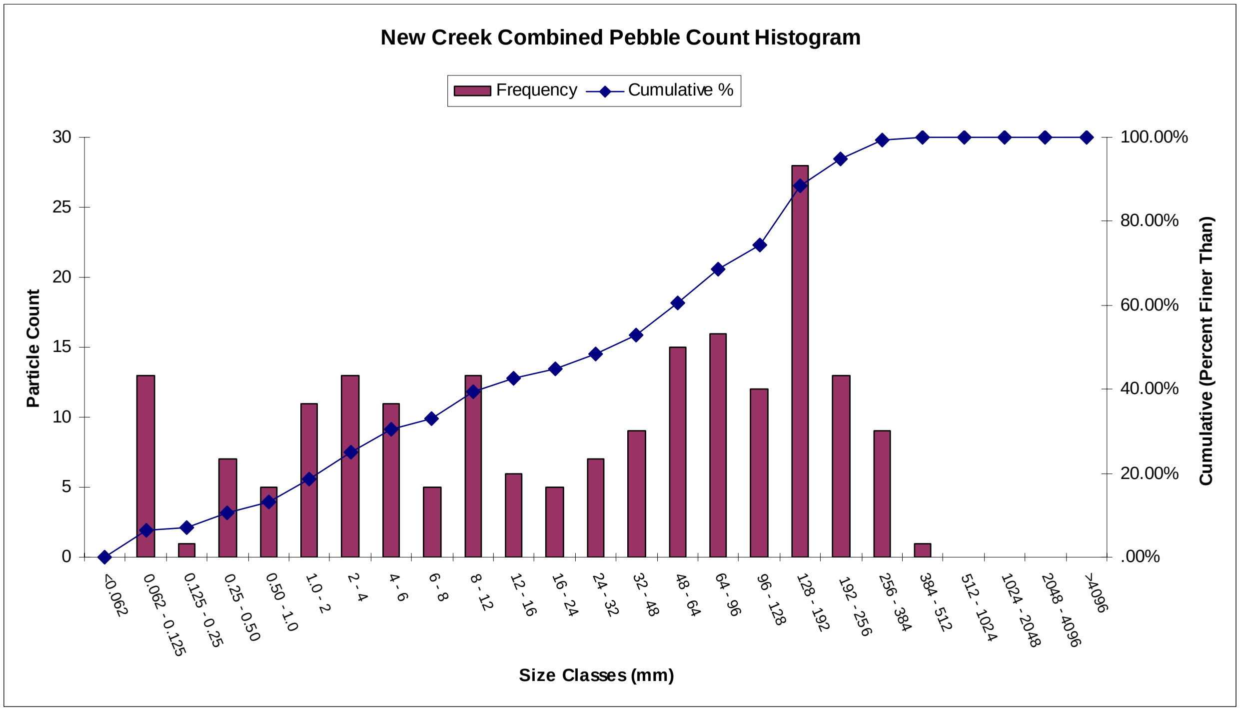

Figure A21. NC Overall Pebble Count

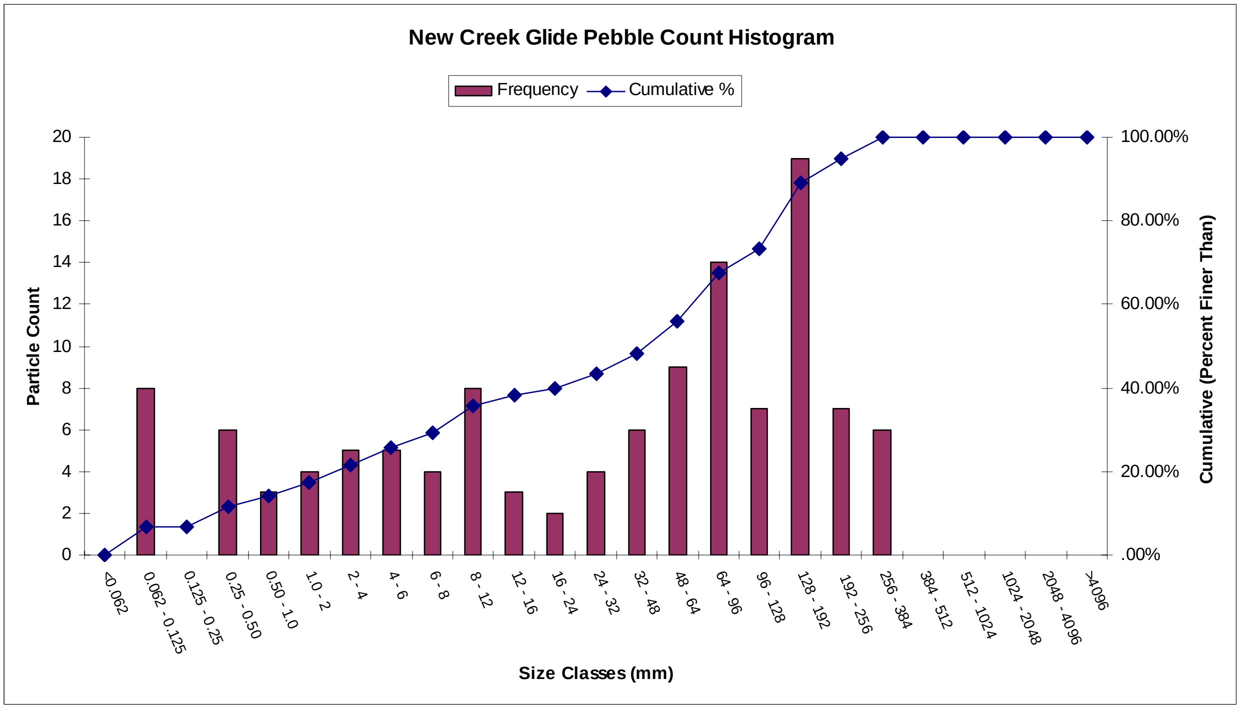

Figure A22. NC Glide Pebble Count

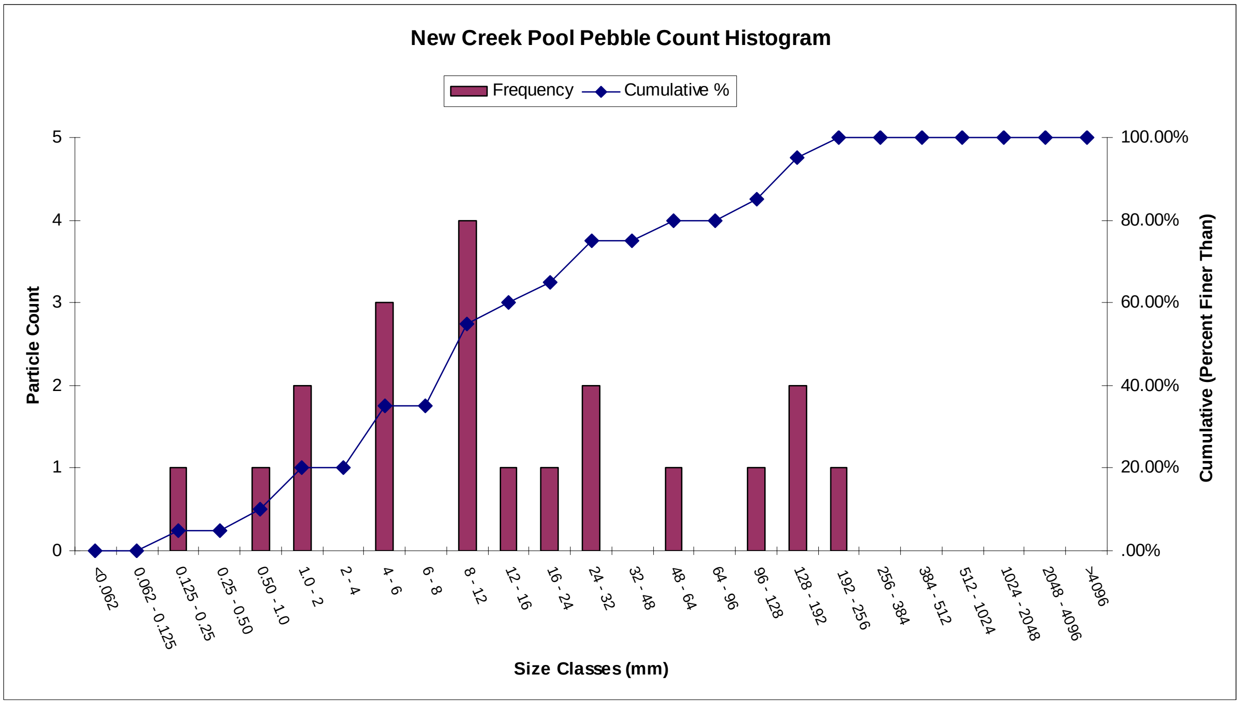

Figure A23. NC Pool Pebble Count

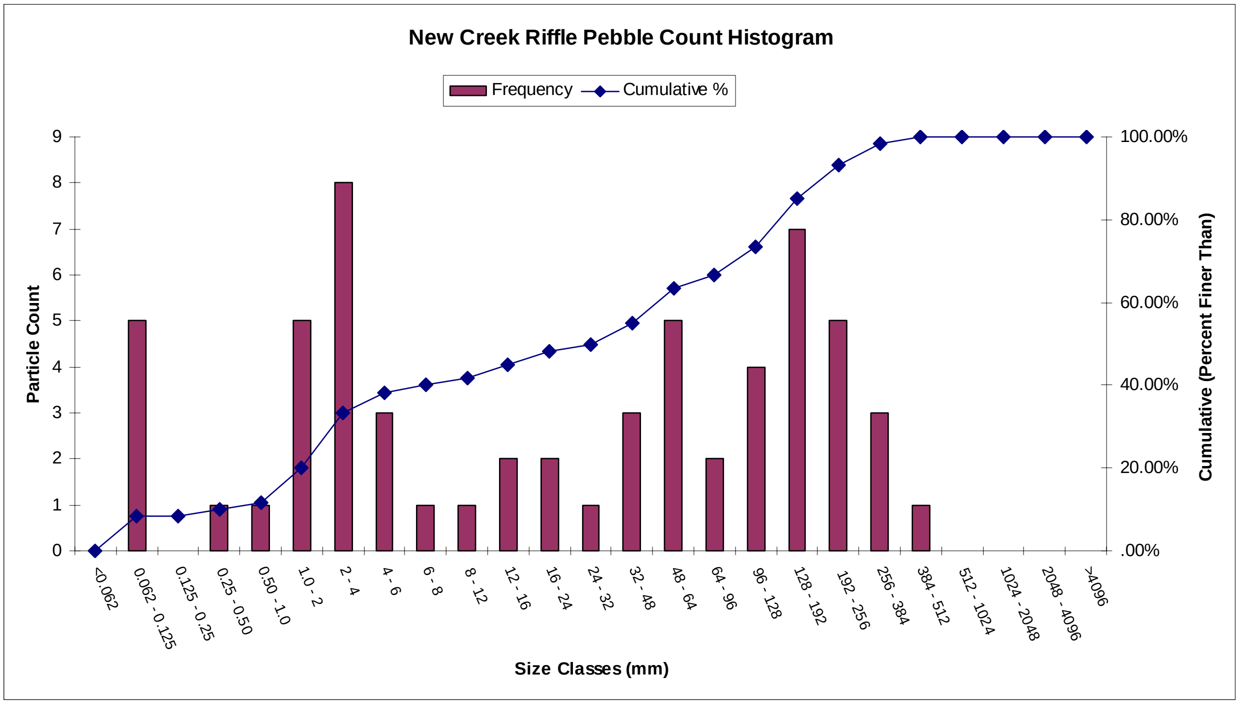

Figure A24. NC Riffle Pebble Count

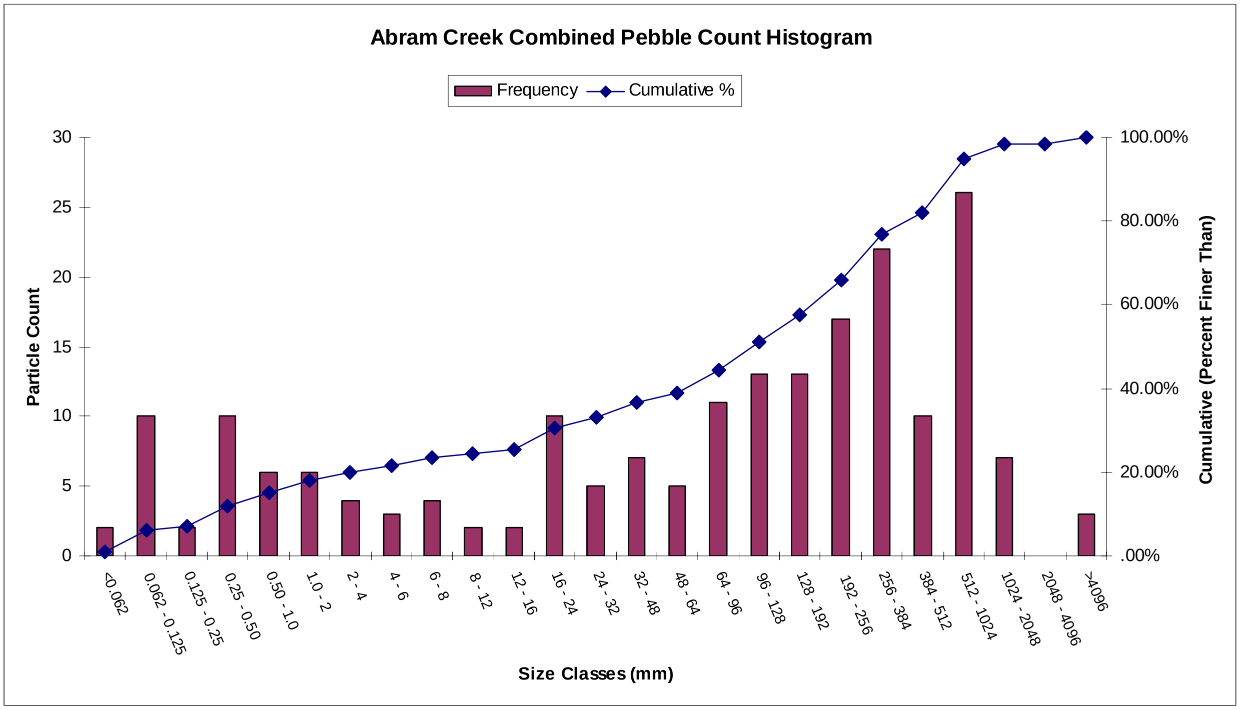

Figure A25. AC Overall Pebble Count

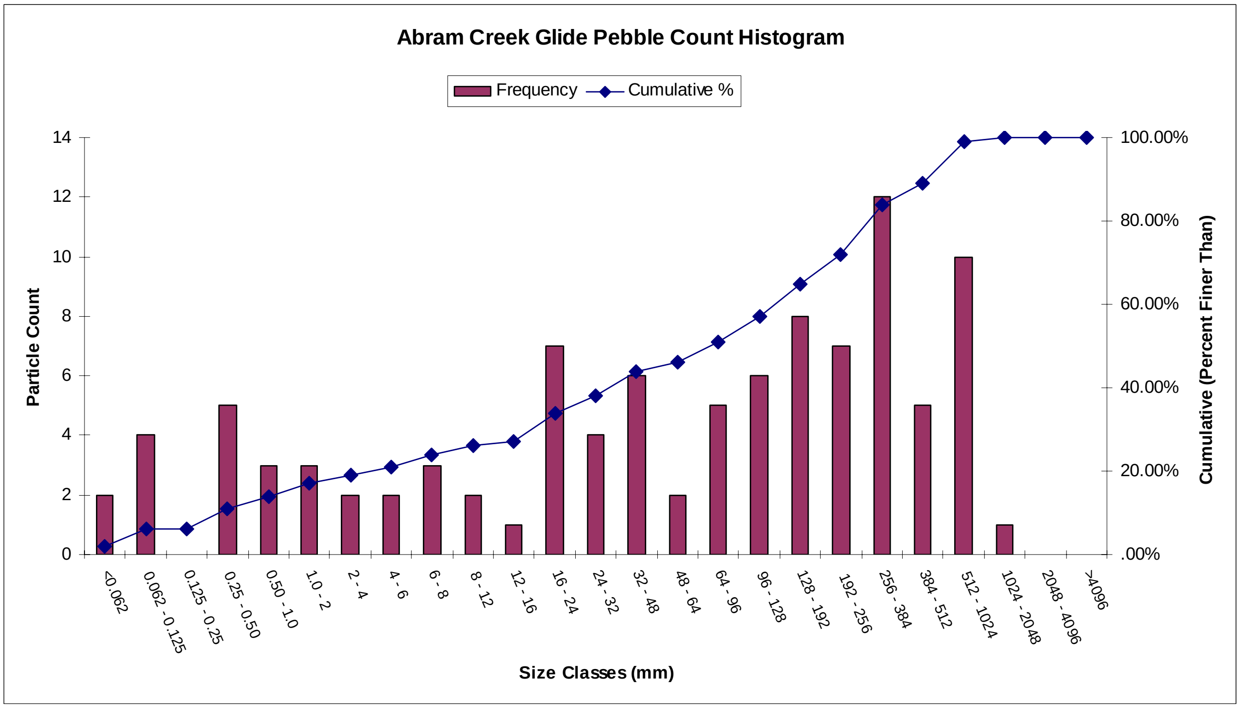

Figure A26. AC Glide Pebble Count

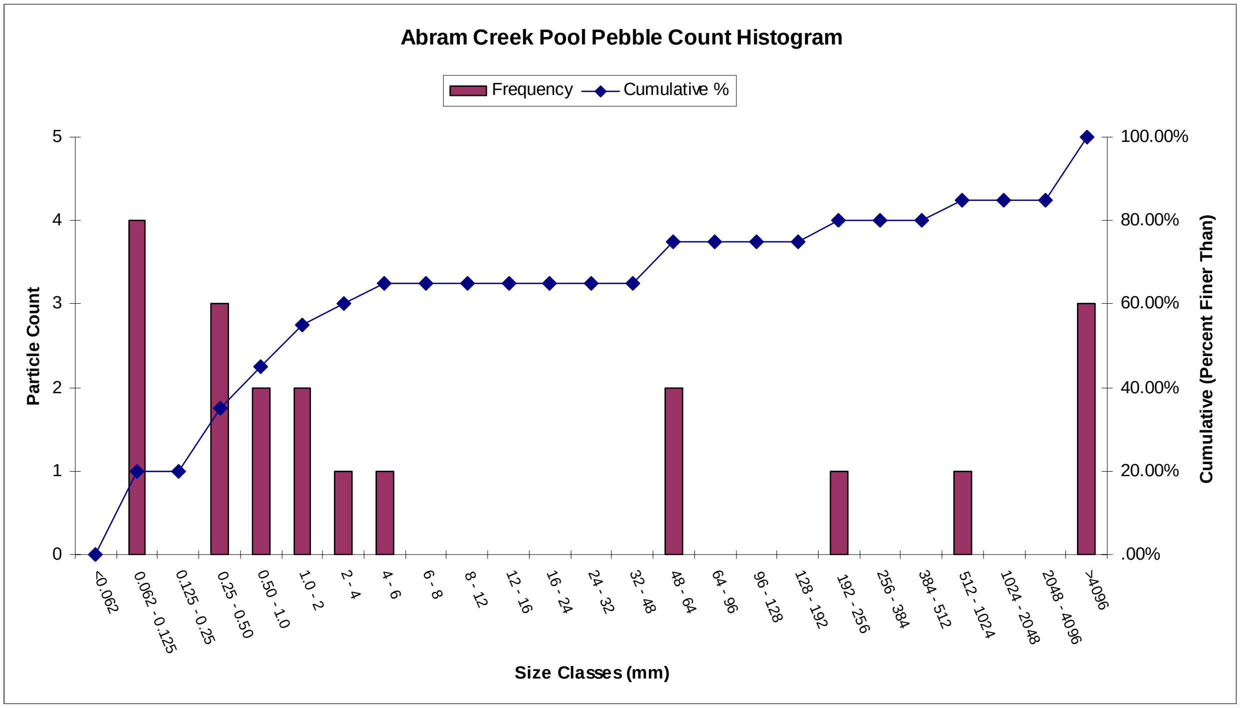

Figure A27. AC Pool Pebble Count

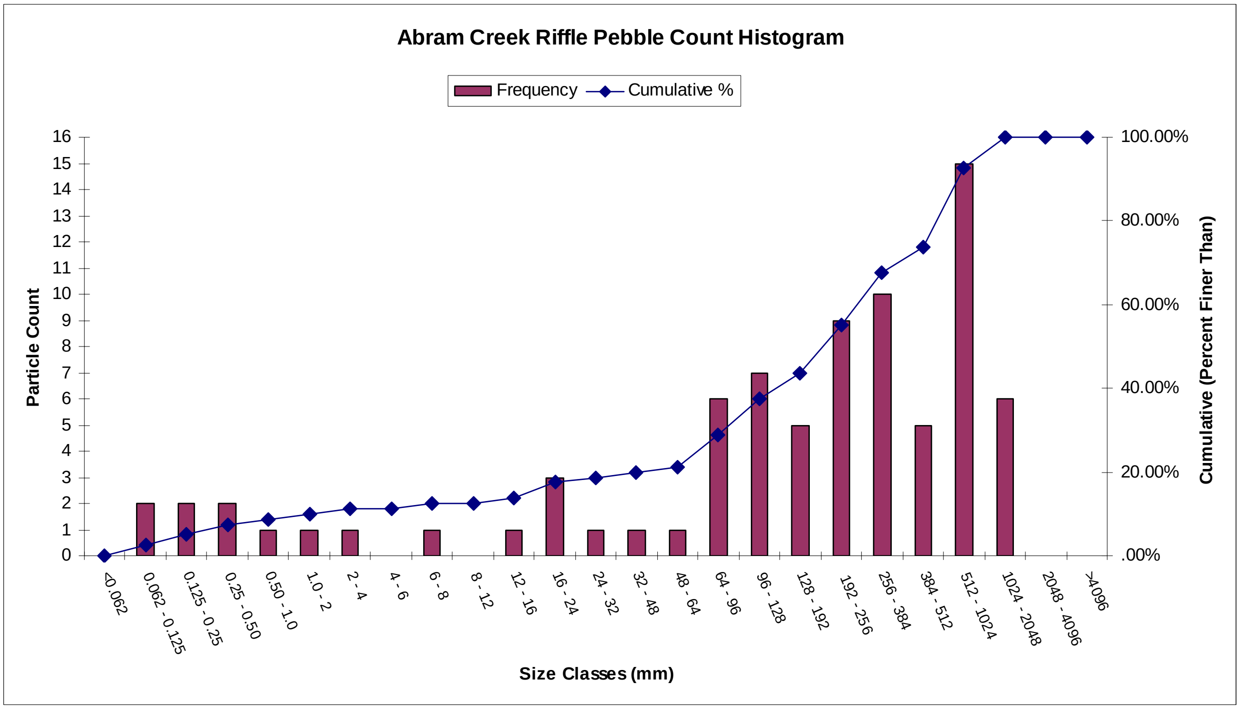

Figure A28. AC Riffle Pebble Count

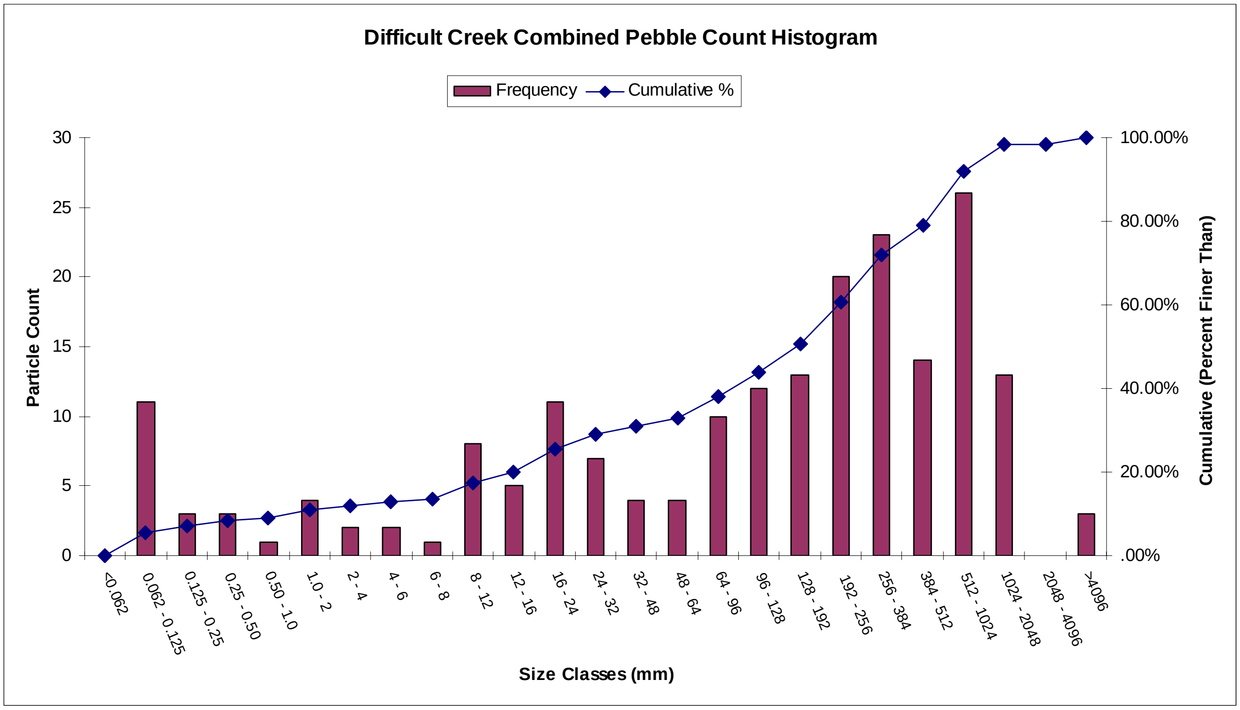

Figure A29. DC Overall Pebble Count

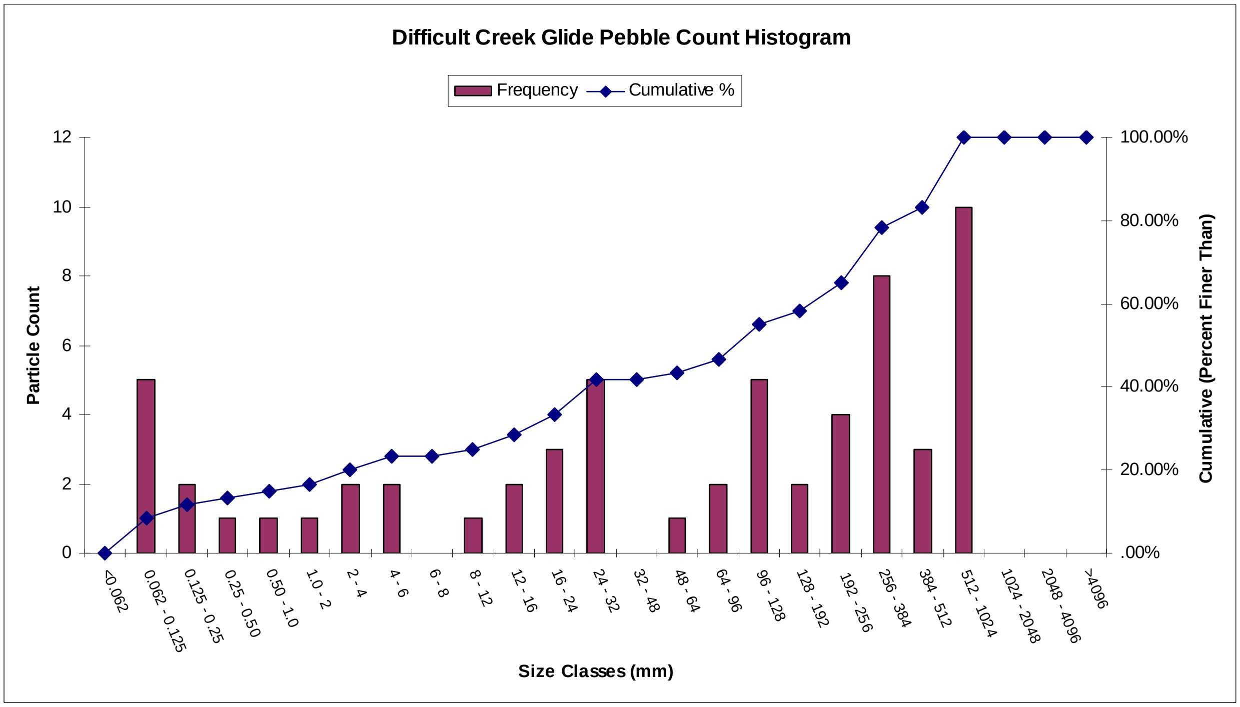

Figure A30. DC Glide Pebble Count

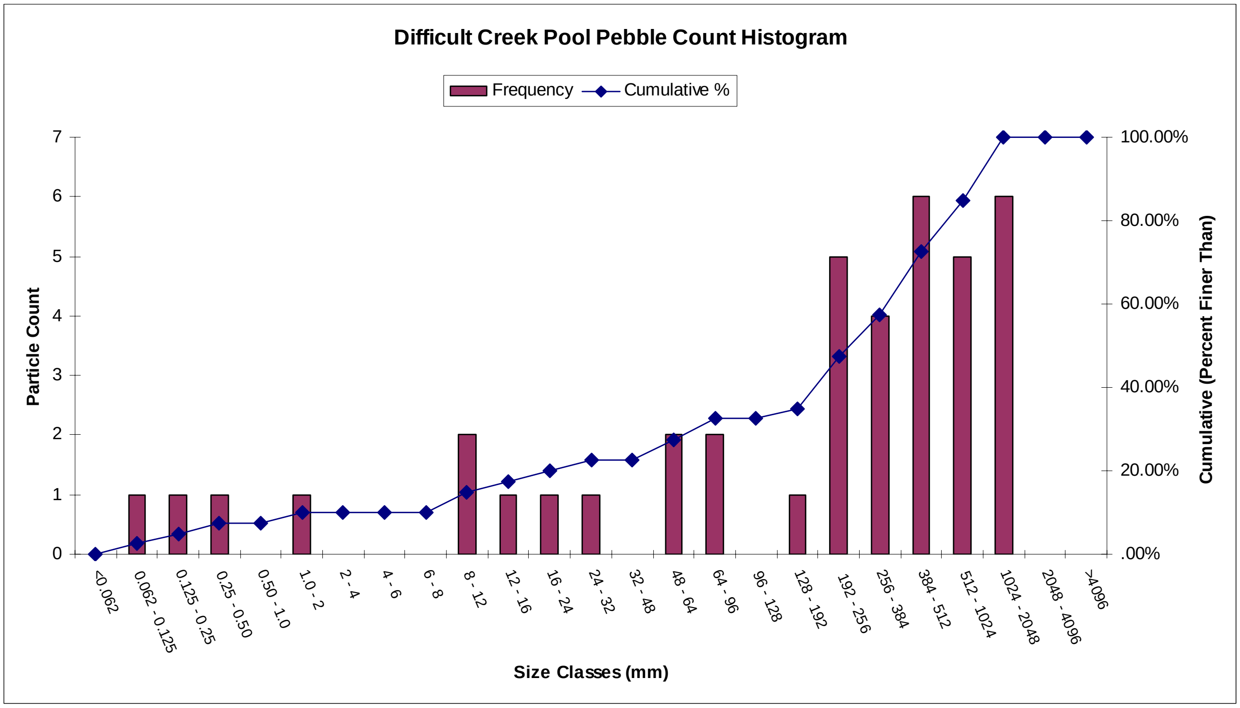

Figure A31. DC Pool Pebble Count

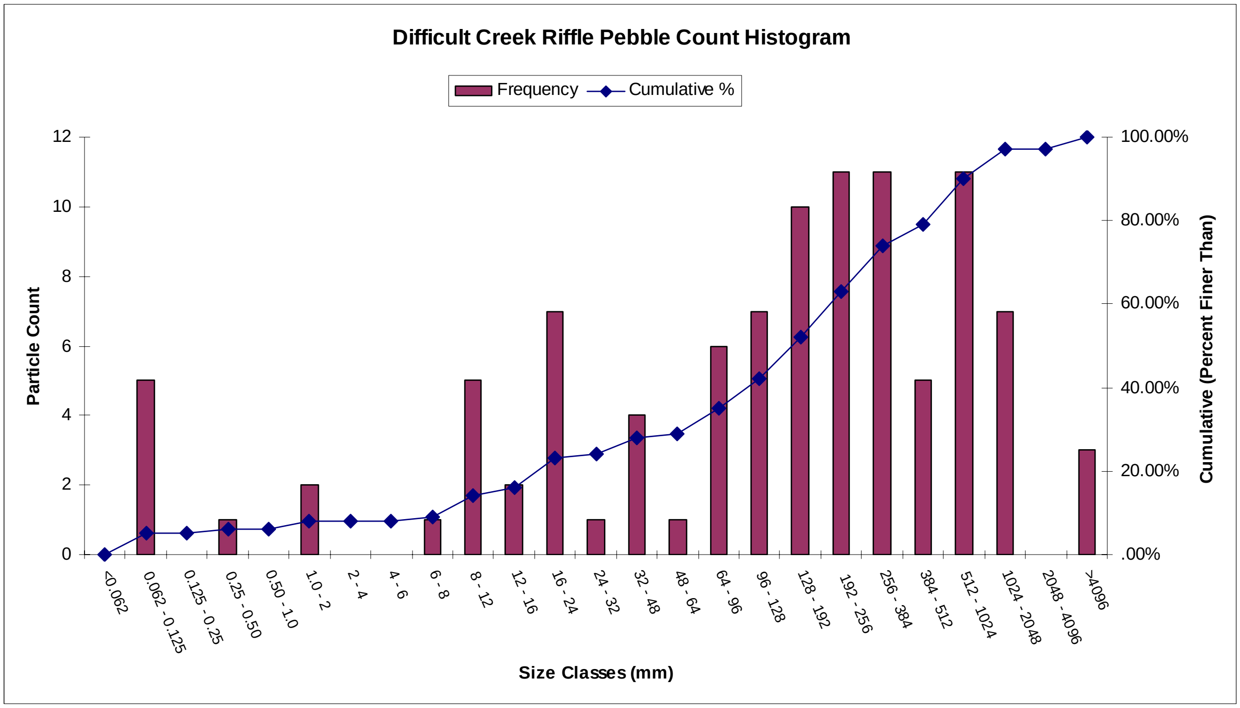

Figure A32. DC Riffle Pebble Count

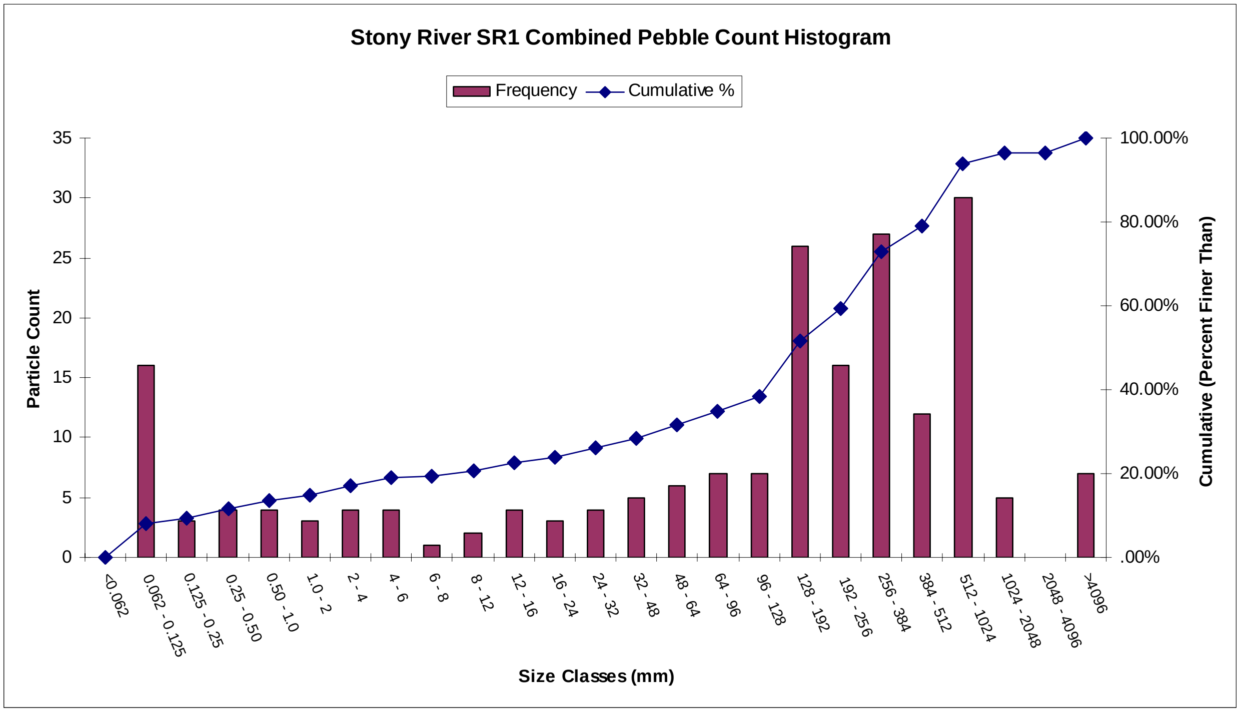

Figure A33. SR1 Overall Pebble Count

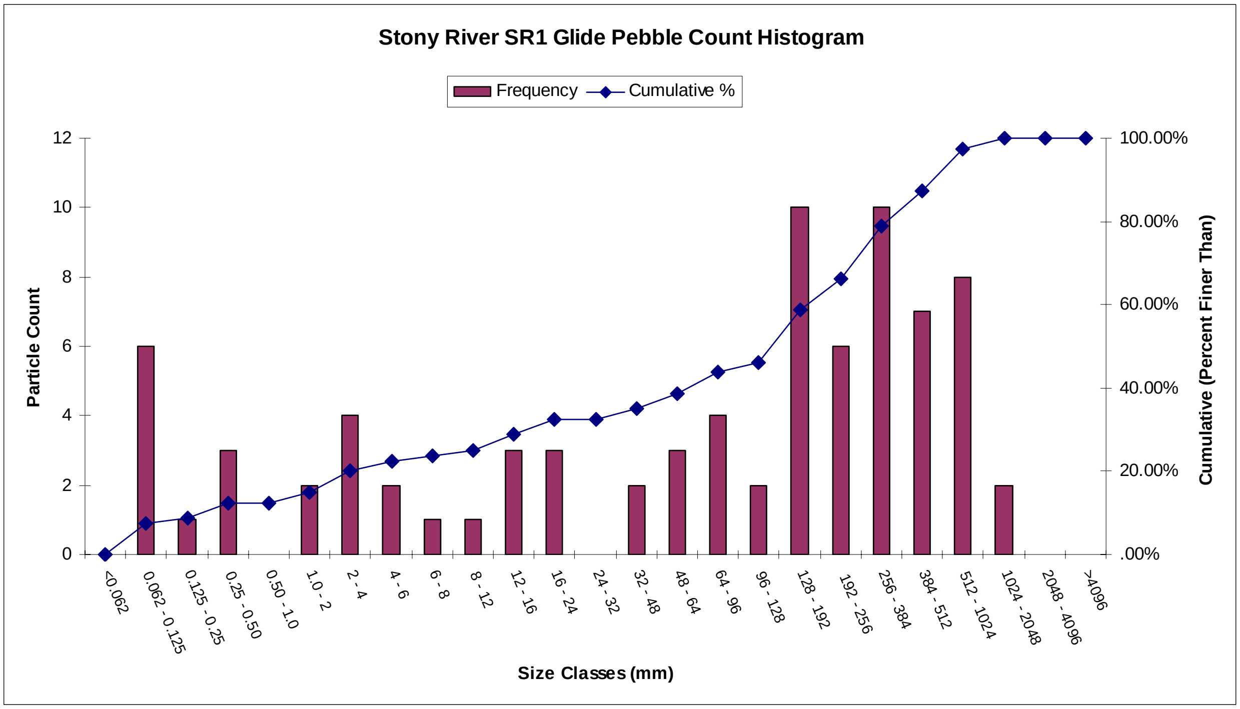

Figure A34. SR1 Glide Pebble Count

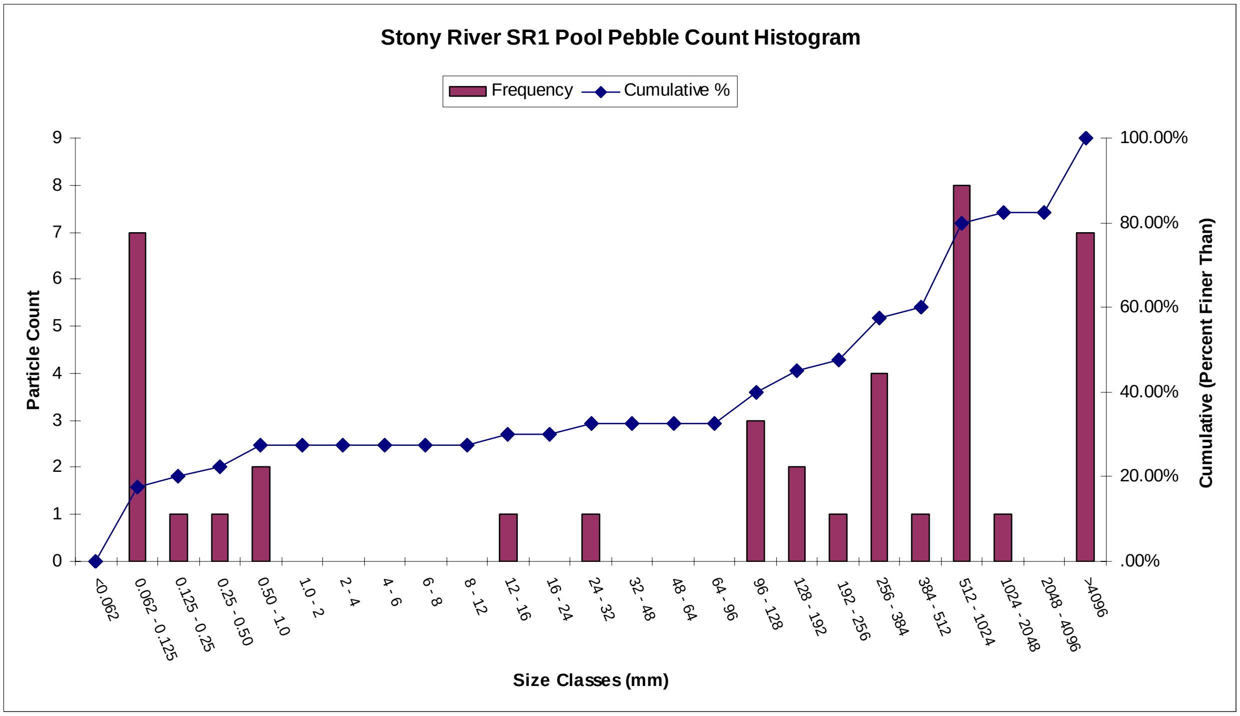

Figure A35. SR1 Pool Pebble Count

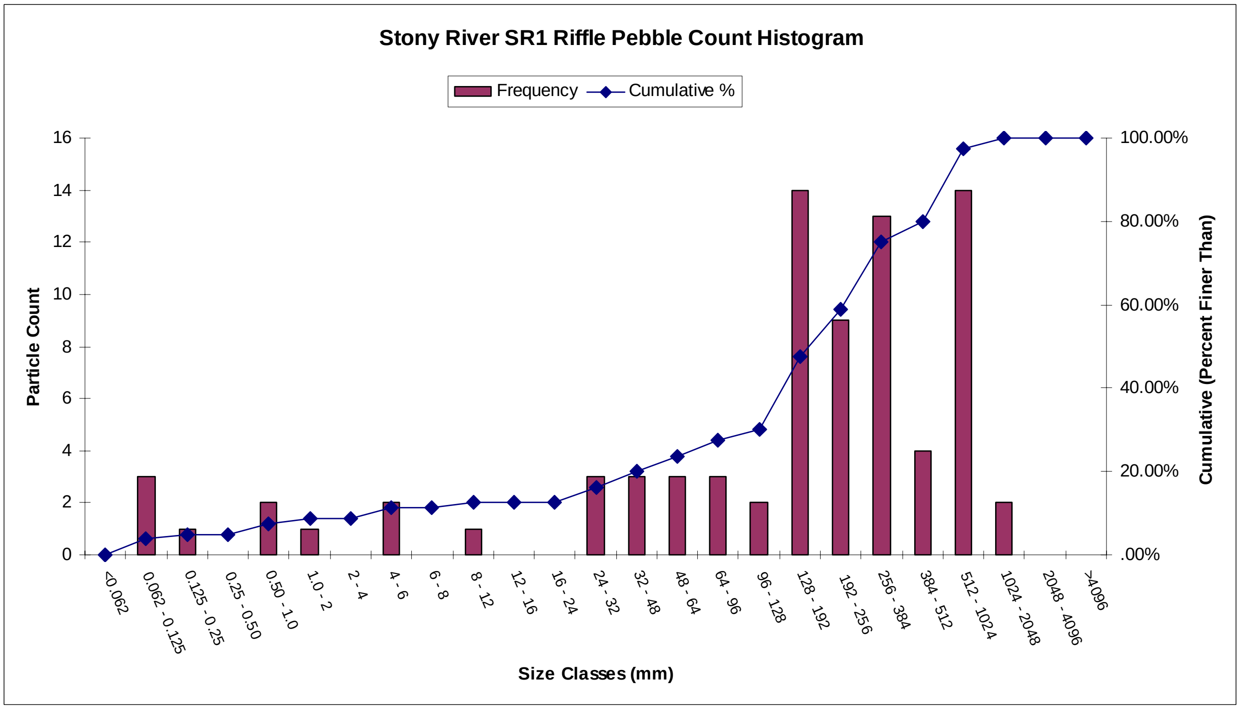

Figure A36. SR1 Riffle Pebble Count

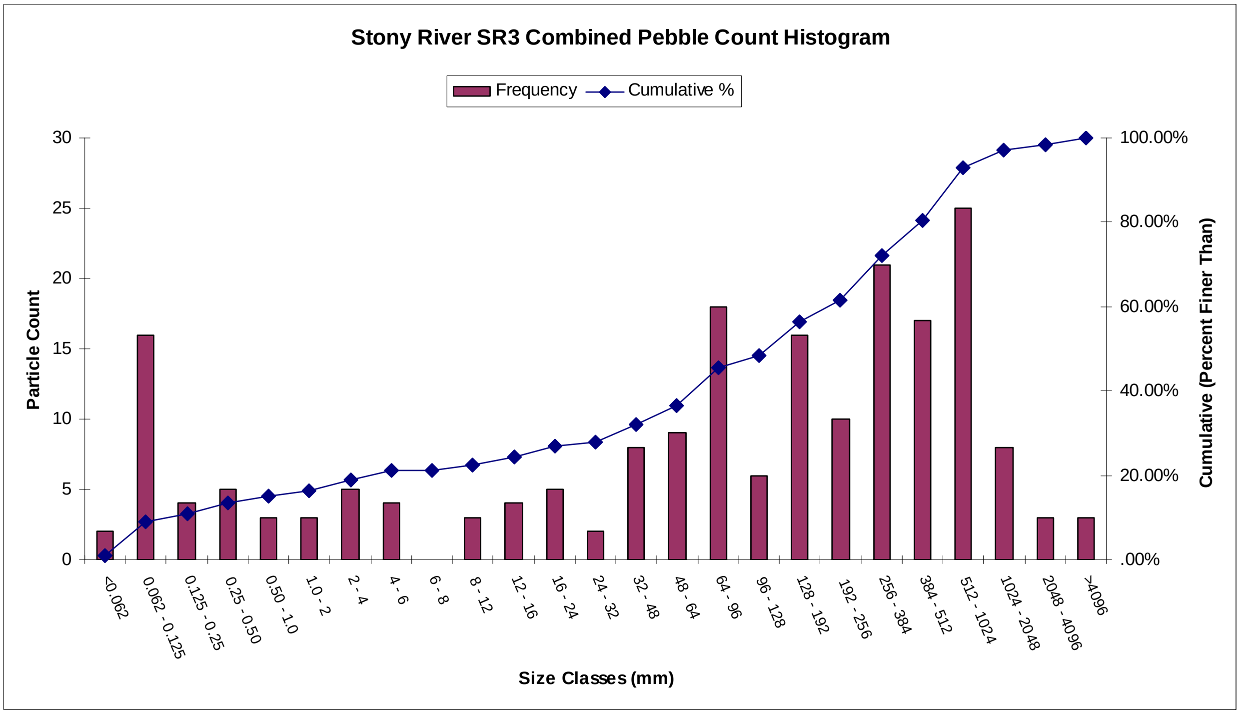

Figure A37. SR3 Overall Pebble Count

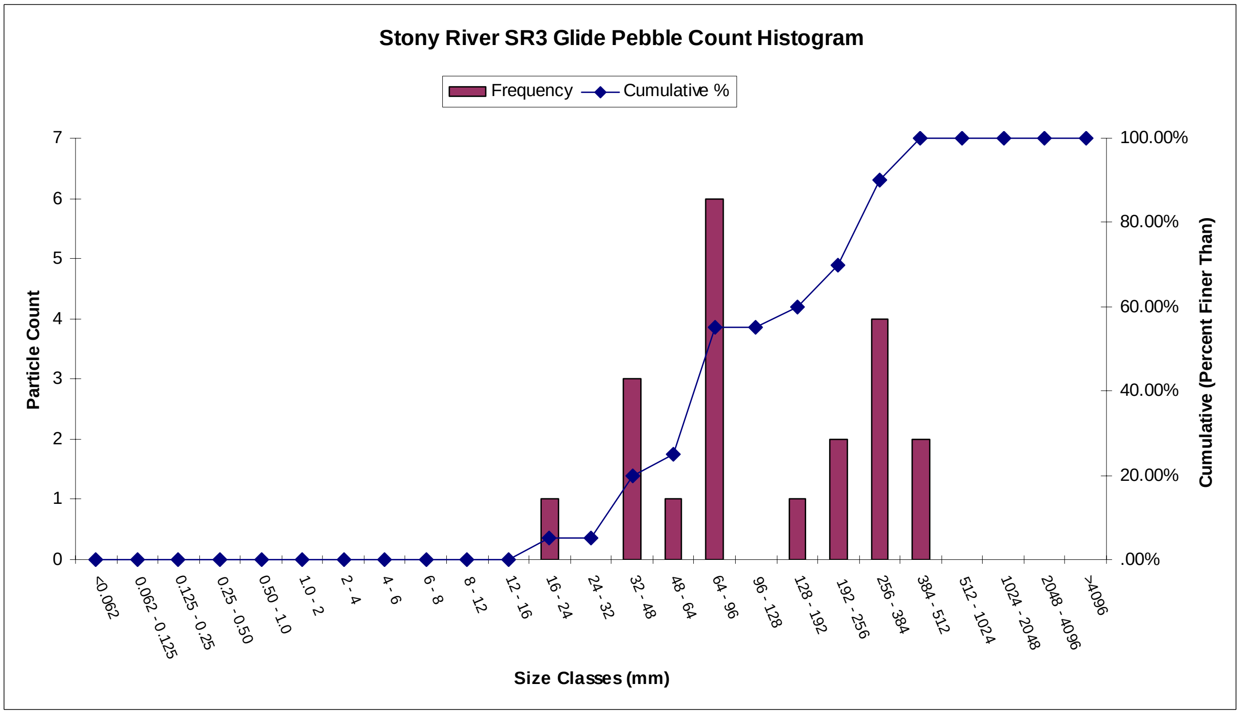

Figure A38. SR3 Glide Pebble Count

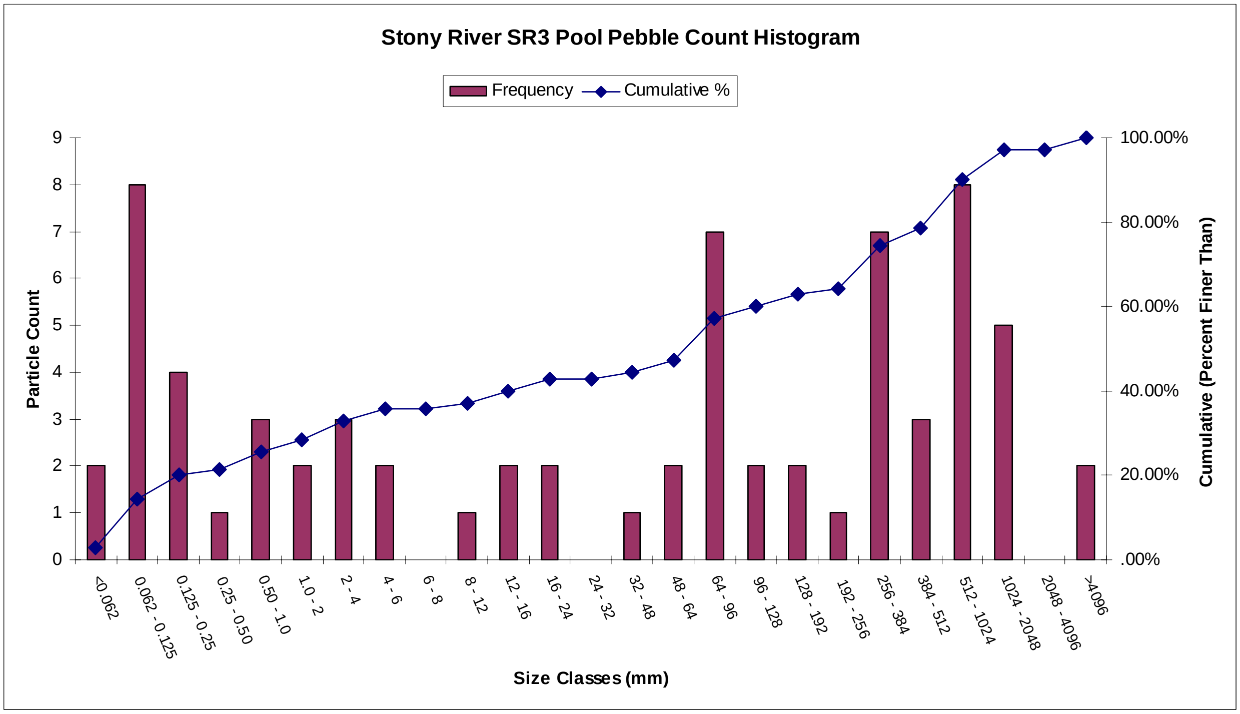

Figure A39. SR3 Pool Pebble Count

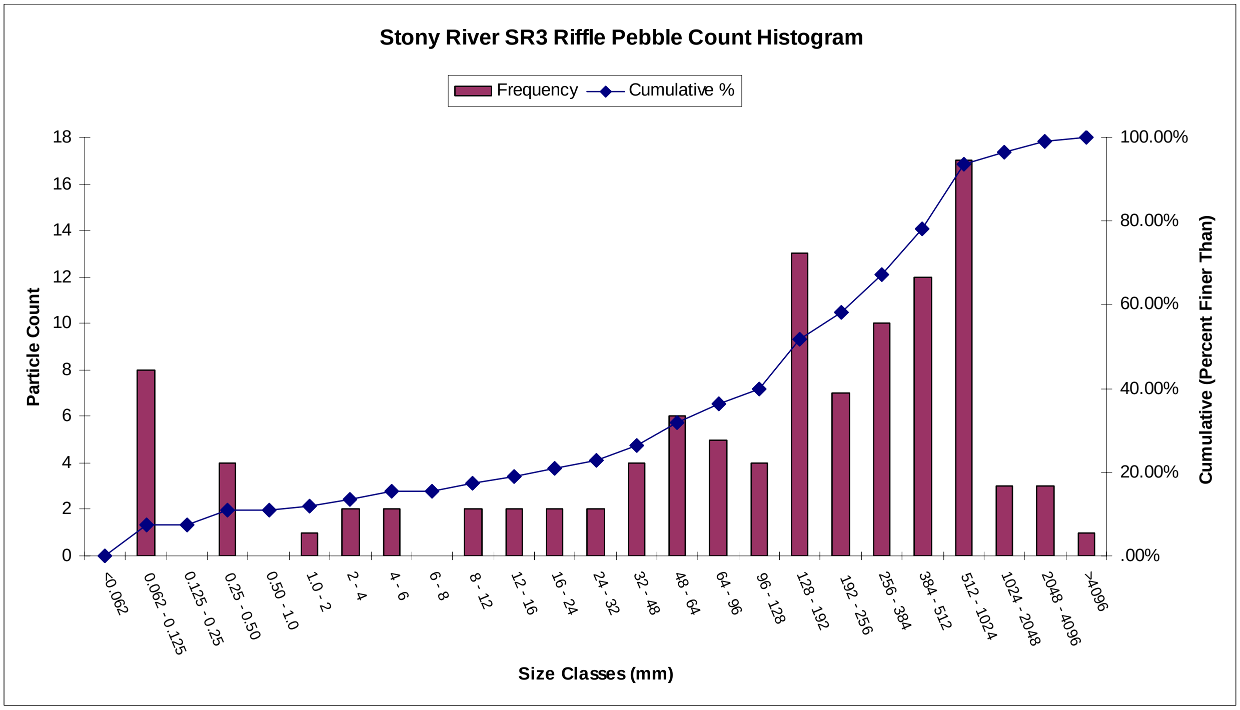

Figure A40. SR3 Riffle Pebble Count

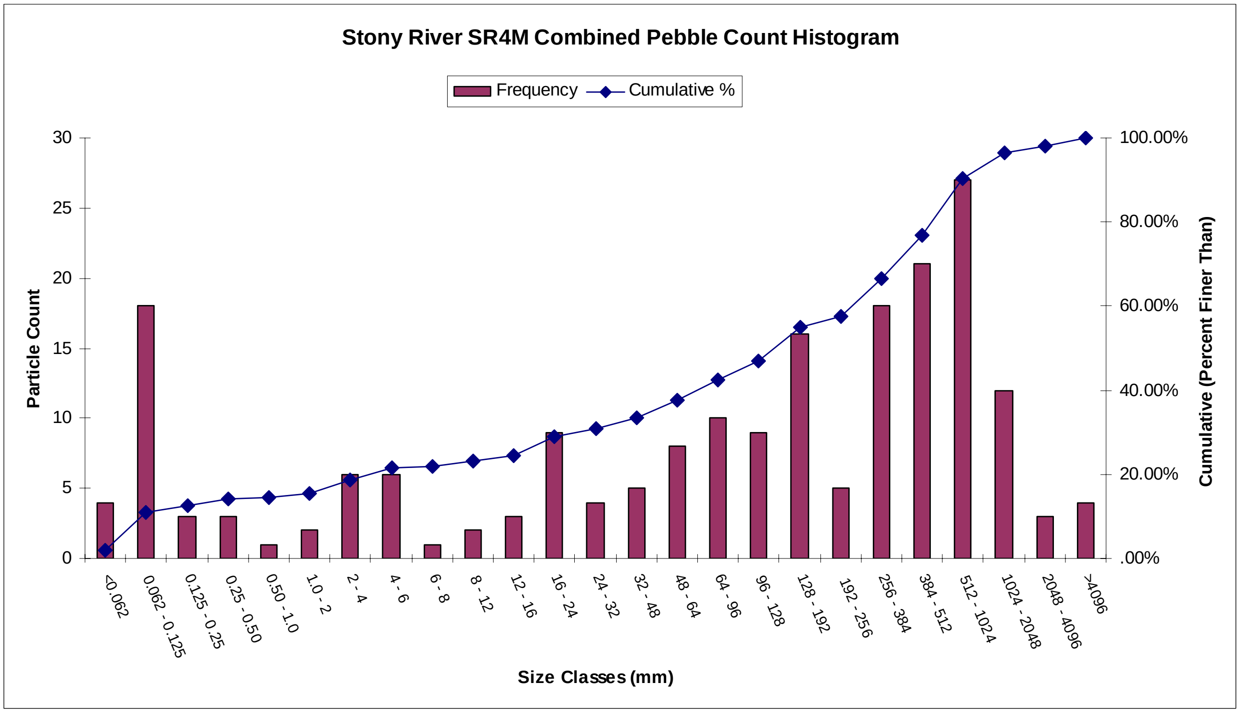

Figure A41. SR4M Overall Pebble Count

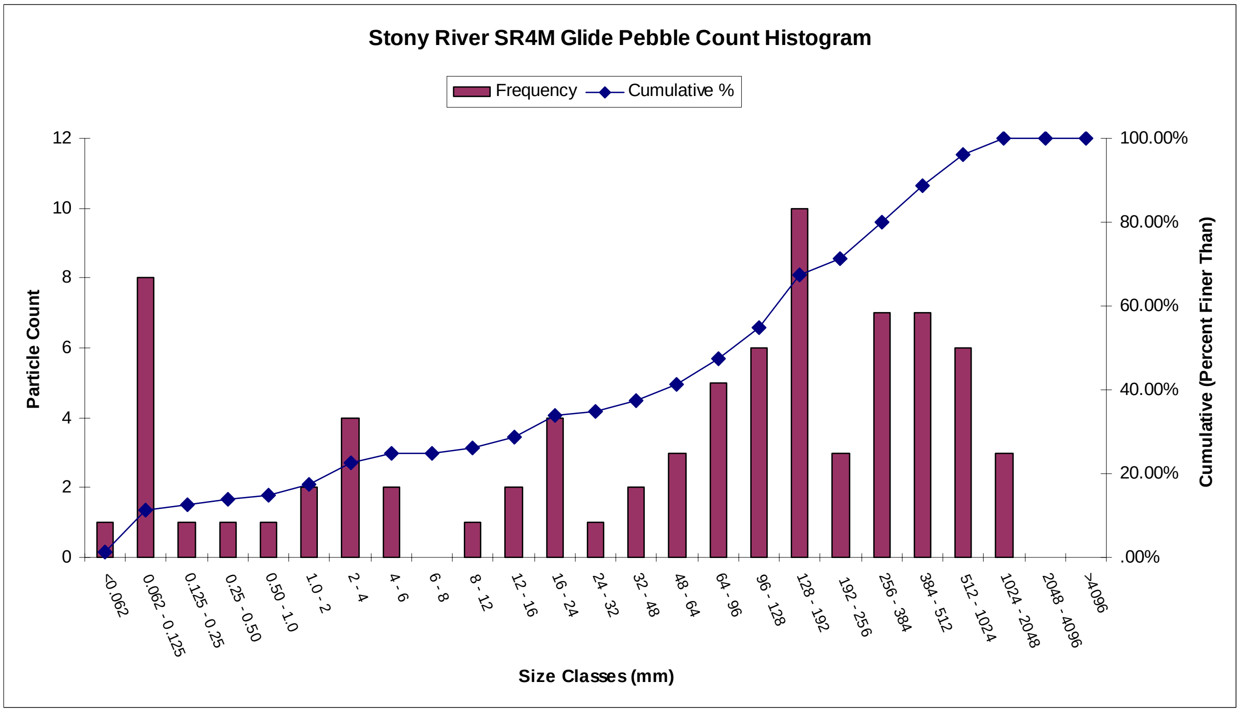

Figure A42. SR4M Glide Pebble Count

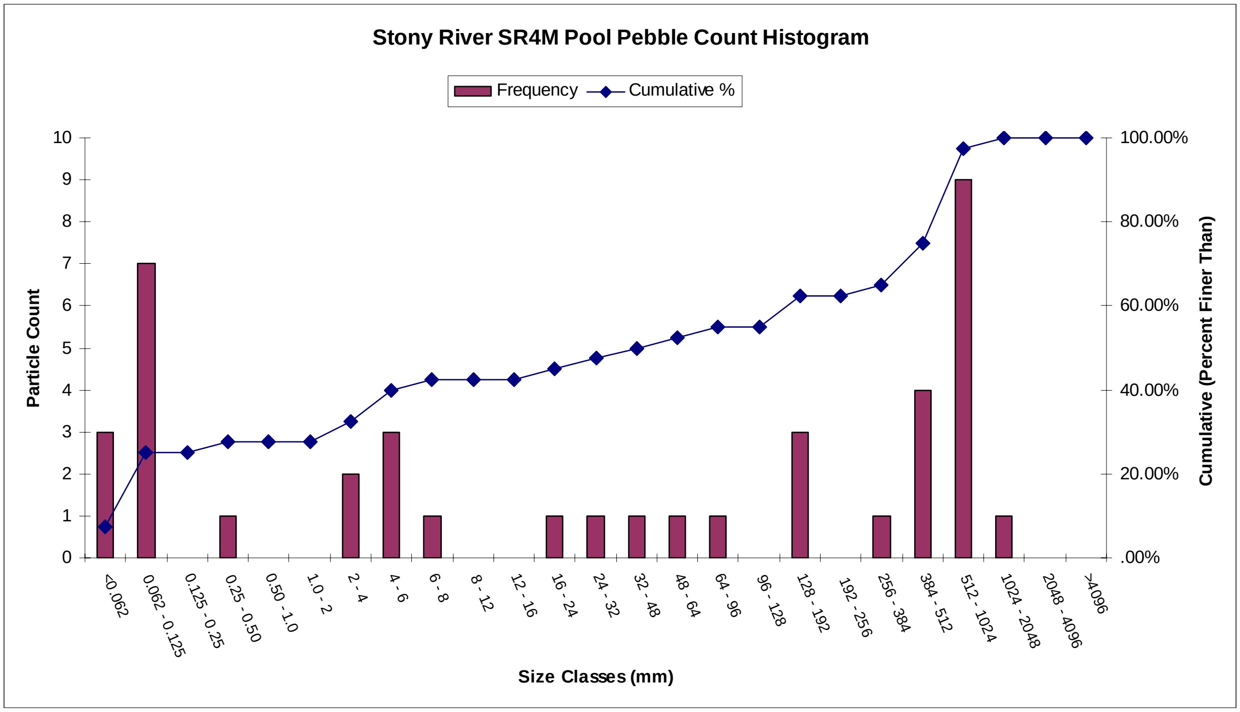

Figure A43. SR4M Pool Pebble Count

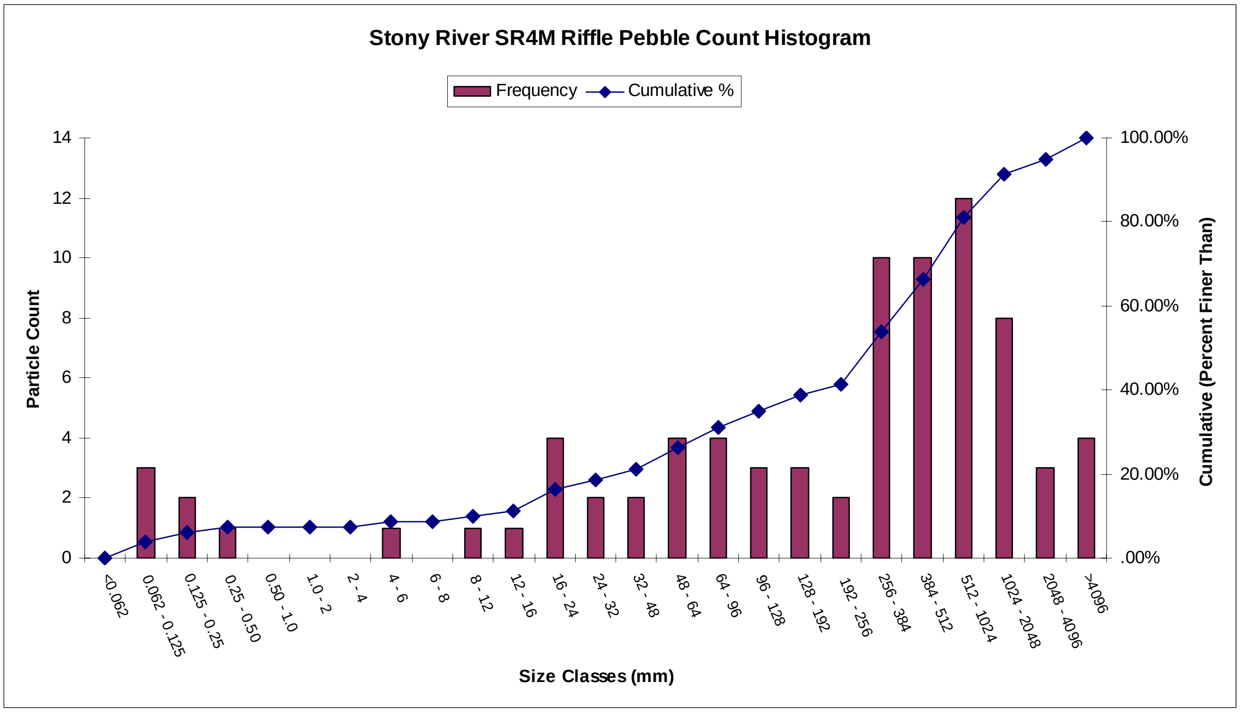

Figure A44. SR4M Riffle Pebble Count

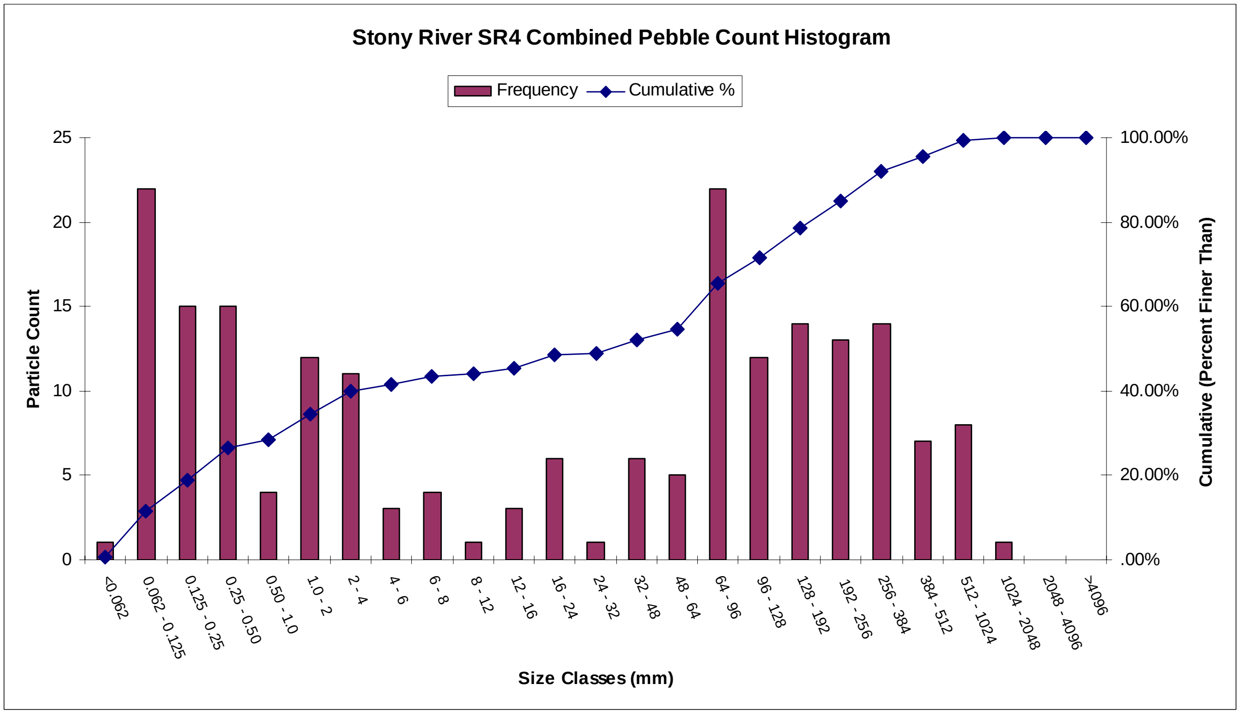

Figure A45. SR4 Overall Pebble Count

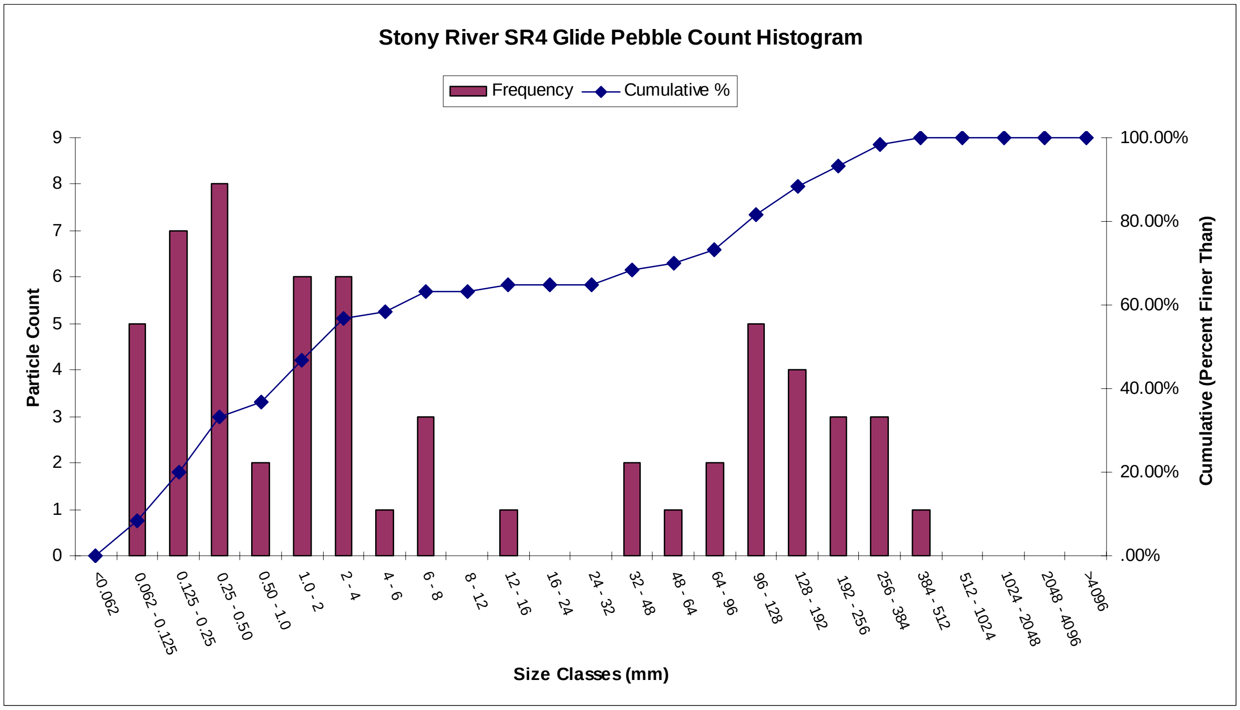

Figure A46. SR4 Glide Pebble Count

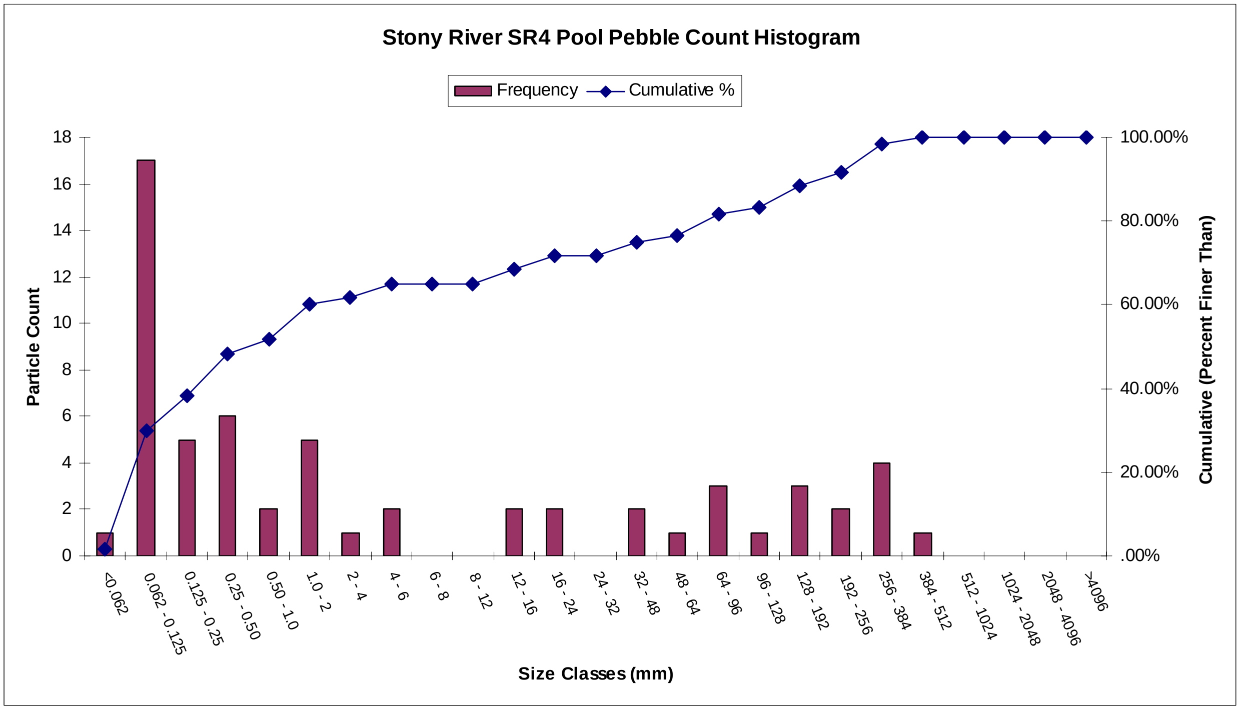

Figure A47. SR4 Pool Pebble Count

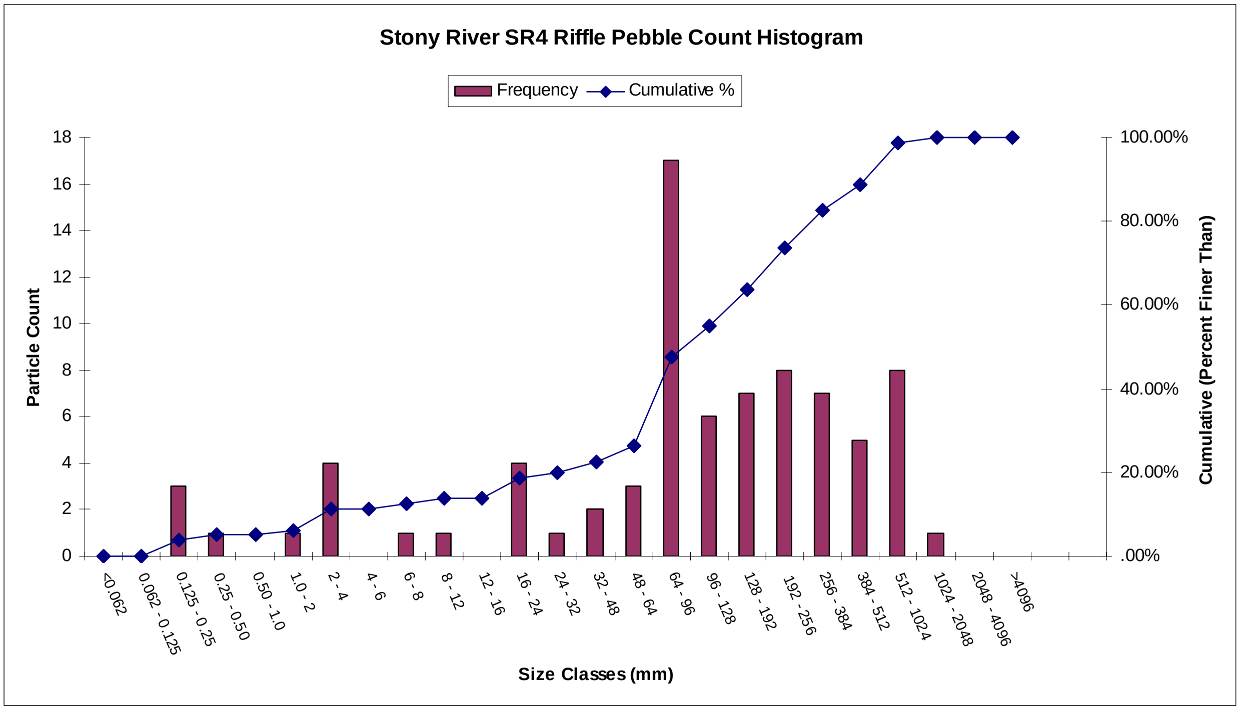

Figure A48. SR4 Riffle Pebble Count

Table A1. GPS Locations of Pebble Counts and Cross Sections (All Points in UTM Zone 17 North)

Site	Northing	Easting	Site	Northing	Easting
ACCX1 (ACP1; ACUP)	4359307.26	655576.67	SR1P4	4342016.85	649326.53
ACCX2 (ACP2)	4359332.06	655546.31	SR1P5	4342042.36	649297.36
ACCX3 (ACP7)	4359603.89	655384.51	SR1P7	4342087.61	649265.73
ACDOWN	4359791.48	655305.96	SR1P8	4342164.7	649269.9
ACP4	4359416.5	655463.95	SR1P10	4342269.53	649243.19
ACP5	4359467.53	655440.24	SR3CX1	4344822.93	647341.94
ACP6	4359571.99	655394.42	SR3CX2	4344929.59	647619.88
ACP8	4359645.9	655366.63	SR3CX3 (SR3DOWN)	4345021.84	647740.81
ACP9	4359665.56	655361.03	SR3P1	4344766.18	647314.26
ACP10	4359746.23	655331.14	SR3P2	4344784.06	647327.19
DCCX1 (DCP2)	4348977.86	645456.25	SR3P3	4344795.01	647330.56
DCCX2 (DCP6)	4349137.03	645335.47	SR3P4	4344856.23	647369.5
DCCX3 (DCP10)	4349270.93	645271.11	SR3P4A	4344917.41	647366.83
DCDOWN	4349302.8	645266.83	SR3P5	4344871.38	647418.52
DCP3	4349035.86	645403.14	SR3P5A	4344930.95	647395.02
DCP4	4349065.48	645384.45	SR3P6	4344884.94	647459.63
DCP5	4349121.7	645355.79	SR3P6A	4344923.9	647511.9
DCP7	4349150.91	645322.5	SR3P7	4344912.18	647582.53
DCP8	4349226.35	645274.75	SR3P8	4344945.14	647662.88
DCP9	4349265.02	645272.02	SR3P9	4344972.62	647725.23
DCUP	4348937.82	645477.11	SR3P10	4345021.05	647739.82
NCCX1 (NCP2)	4359754.79	669584.85	SR3UP	4344753.1	647310.17
NCCX2 (NCP5)	4359886.38	669667.34	SR4MCX1 (SR4MP2)	4342436.38	647478.5
NCCX3 (NCP10)	4360048.39	669795.92	SR4MCX2 (SR4MP7)	4342442.44	647256.36
NCP1	4359731.83	669571.08	SR4MCX3 (SR4MP8)	4342514.25	647103.39
NCP3	4359785.37	669603.12	SR4MDOWN	4342583.27	646982.42
NCP4	4359799.14	669612.15	SR4MP1	4342444.75	647539.13
NCP6	4359919.49	669679.36	SR4MP3	4342434.93	647458.36
NCP7	4359963.91	669718.07	SR4MP4	4342414.25	647396.54
NCP8	4360004.11	669752.48	SR4MP5	4342412.45	647370.33
NCP9	4360012.75	669761.42	SR4MP6	4342419.92	647312.21
PCCX1 (PCP1)	4339193.72	660709.06	SR4MP9	4342541.68	647059.2
PCCX2 (PCP5)	4339152.58	660816.46	SR4MP10	4342558.67	647037.61
PCCX3 (PCP8)	4339052.83	660923.08	SR4CX1	4347901.02	650104.22
PCDOWN	4338993.08	661010.42	SR4CX2	4347953.3	649957.36
PCP2	4339187.82	660727.19	SR4CX3 (SR4P7)	4348184.4	649922.13
PCP3	4339180.5	660750.69	SR4MUP	4342447.62	647547.81
PCP4	4339163.04	660796.52	SR4DOWN	4348372.32	650056.11
PCP6	4339125.75	660840.33	SR4P1	4347865.74	650131.38
PCP7	4339078.08	660904.25	SR4P2	4347924.07	650041.48
PCP9	4339016.08	660948.03	SR4P3	4347959.19	649943.28
PCP10	4338984.64	660987.49	SR4P4	4347990.75	649896.66
PCUP	4339196.43	660692.96	SR4P5	4348076.18	649860.53
SR1CX1 (SR1P2)	4341840.94	649430.53	SR4P6	4348113.18	649874.26
SR1CX2 (SR1P6)	4342057.96	649280.83	SR4P8	4348214.08	649967.85
SR1CX3 (SR1P9)	4342228.72	649260.53	SR4P9	4348283.68	650002.29
SR1P1	4341815.62	649469.54	SR4P10	4348340.84	650027.36
SR1P3	4341901.389	649400.821	SR4UP	4347843.67	650134.45

Table A2. Individual Pebble Counts Using Modified Wentworth Scale (see Table 3.4)

Pebble Count	Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
ACP1	Glide	4	5	5	5	3	5	4	5	5	4	5	4	5	4	4	4	3	2	4	5
ACP2	Riffle	2	4	3	4	5	4	4	5	5	4	5	5	5	4	5	4	5	4	5	3
ACP3	Glide	5	5	2	4	2	2	3	5	4	4	5	2	4	3	5	2	3	3	2	3
ACP4	Pool	4	2	3	2	2	2	2	2	2	6	6	6	2	2	5	2	2	3	3	3
ACP5	Riffle	5	2	5	4	4	3	4	5	5	4	4	5	4	4	4	2	3	4	5	5
ACP6	Glide	5	1	3	3	5	2	5	5	4	3	3	5	4	3	3	3	4	5	2	4
ACP7	Glide	4	3	5	3	5	3	2	3	5	5	4	4	5	3	3	2	3	4	4	4
ACP8	Glide	3	2	3	2	4	3	3	2	3	5	4	3	4	4	3	3	5	5	1	2
ACP9	Riffle	4	5	3	5	5	4	4	4	5	4	4	3	4	3	3	3	2	5	5	2
ACP10	Riffle	2	2	5	5	5	3	5	5	5	5	4	5	5	5	4	5	5	5	4	5
DCP1	Pool	5	5	3	5	5	4	3	4	5	3	2	3	3	4	5	4	4	5	5	5
DCP2	Glide	3	2	3	4	5	5	4	5	3	5	5	4	4	3	3	5	3	2	2	5
DCP3	Riffle	5	5	4	5	4	5	5	3	4	4	3	3	4	3	4	4	4	4	3	3
DCP4	Riffle	4	3	4	3	4	5	4	5	4	5	5	4	3	4	2	3	5	4	3	2
DCP5	Pool	2	5	5	5	5	5	5	5	4	4	4	3	2	5	5	2	3	5	5	5

Pebble Count	**Type**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
DCP6	Glide	2	4	3	5	5	5	4	4	3	4	3	3	5	2	5	4	2	3	3	2
DCP7	Riffle	4	5	4	4	2	4	4	2	5	5	3	4	5	4	5	4	4	3	5	2
DCP8	Riffle	4	2	3	3	4	3	5	4	4	3	5	2	4	5	5	6	6	6	4	3
DCP9	Riffle	4	5	5	5	3	5	5	5	3	5	5	4	5	5	2	5	4	5	5	5
DCP10	Glide	5	5	4	3	5	2	5	4	2	2	3	4	5	3	5	3	5	5	4	5
NCP1	Pool	3	3	2	3	4	3	3	3	4	2	4	3	4	3	2	3	3	3	2	3
NCP2	Glide	2	2	2	4	3	4	4	3	3	3	3	3	2	4	4	3	2	4	3	4
NCP3	Glide	3	3	4	4	4	5	3	3	3	4	3	3	4	4	5	4	3	5	2	4
NCP4	Riffle	4	3	3	4	2	3	2	3	2	4	3	4	2	3	3	4	4	2	3	2
NCP5	Glide	2	2	2	3	3	3	2	3	2	3	3	3	4	4	3	4	3	4	4	4
NCP6	Riffle	3	4	5	4	3	4	5	3	3	3	2	3	3	5	4	4	2	3	2	3
NCP7	Glide	4	2	5	4	4	3	4	3	4	4	3	3	4	3	4	3	4	2	3	2
NCP8	Riffle	5	3	2	4	3	4	2	3	4	3	3	3	3	3	2	4	4	3	4	4
NCP9	Glide	3	3	3	4	2	4	2	4	4	3	4	3	3	3	3	4	4	4	4	4
NCP10	Glide	3	4	4	3	2	5	4	3	3	4	2	3	2	2	2	4	4	4	4	3
PCP1	Glide	5	2	3	3	4	2	5	5	5	3	3	3	2	3	2	2	5	5	5	5
PCP2	Riffle	5	5	3	3	3	3	4	5	3	4	3	3	3	4	5	5	4	4	5	5
PCP3	Pool	3	3	4	3	2	3	2	2	3	4	5	3	4	4	4	5	4	5	3	4
PCP4	Riffle	2	4	4	5	5	4	5	5	3	5	3	5	4	3	4	4	5	4	2	3
PCP5	Glide	3	5	3	3	4	3	3	3	3	3	2	4	3	4	5	3	5	5	4	4
PCP6	Pool	2	2	3	3	3	3	2	3	3	3	3	3	3	3	2	2	3	2	2	6
PCP7	Riffle	3	4	5	4	4	5	4	4	5	4	5	3	4	5	3	3	4	5	4	5
PCP8	Glide	2	2	5	2	2	3	3	2	5	2	4	5	3	2	3	1	4	3	4	5
PCP9	Riffle	5	2	3	3	5	3	3	4	3	4	2	4	3	5	5	4	4	2	5	4
PCP10	Glide	2	3	3	3	3	3	3	3	3	4	3	3	3	3	1	3	1	5	4	3
SR1P1	Riffle	5	4	4	2	5	2	3	3	5	4	4	4	5	4	5	4	3	3	2	4
SR1P2	Glide	4	3	3	3	3	5	4	4	5	3	3	3	2	4	4	4	2	4	2	4
SR1P3	Glide	5	5	2	4	3	2	3	2	5	4	4	4	5	3	2	5	3	2	5	3
SR1P4	Pool	3	2	2	2	5	4	2	4	2	5	5	5	5	2	2	2	2	5	2	4
SR1P5	Riffle	3	4	5	3	4	4	4	5	5	5	5	5	5	4	5	5	4	5	4	2
SR1P6	Glide	5	4	5	5	4	3	3	3	3	5	4	4	5	3	5	5	4	5	4	4
SR1P7	Riffle	4	4	5	5	4	5	2	2	5	5	4	4	4	4	4	3	3	5	3	4
SR1P8	Pool	5	5	5	5	5	5	4	4	4	5	2	5	3	6	6	6	6	6	6	6
SR1P9	Glide	5	5	4	5	2	2	3	4	5	5	5	4	5	5	5	2	2	3	5	5
SR1P10	Riffle	5	4	3	3	4	2	4	5	5	5	5	5	5	3	5	5	5	5	4	5
SR3P1	Riffle	5	3	3	5	5	5	3	5	5	5	5	4	5	5	5	5	5	5	4	4
SR3P2	Pool	2	2	5	2	3	4	4	5	5	5	3	3	3	2	4	4	3	3	3	3
SR3P3	Pool	2	3	2	2	5	4	3	5	3	2	2	5	4	5	3	5	2	2	5	5
SR3P4*	Riffle	3	3	5	5	4	5	5	2	2	2										
SR3P4A*	Pool	2	2	1	1	2	6	6	2	2	2										
SR3P5*	Riffle	5	5	2	5	5	4	4	5	2	3										
SR3P5A*	Riffle	4	4	4	4	4	4	2	3	3	4										
SR3P6*	Riffle	4	5	5	5	3	5	4	5	4	5										
SR3P6A*	Riffle	2	4	2	6	5	5	5	5	2	5										
SR3P7	Riffle	5	4	2	3	3	3	5	3	5	5	4	5	4	4	5	5	5	4	2	5
SR3P8	Glide	4	4	5	4	5	4	3	5	3	4	5	3	3	4	4	5	4	5	3	4
SR3P9	Riffle	3	4	4	4	3	5	2	2	4	3	3	4	3	4	3	4	5	3	3	3
SR3P10	Pool	5	5	5	5	5	2	5	4	4	5	5	4	5	5	5	5	4	4	3	4
SR4MP1	Riffle	5	3	5	4	3	5	5	5	5	5	4	5	5	5	4	5	5	5	5	5
SR4MP2	Glide	5	4	3	5	3	4	4	3	4	4	3	4	5	4	5	5	3	3	5	4
SR4MP3	Pool	5	4	5	2	3	3	3	5	5	5	3	3	5	2	5	5	5	2	5	2
SR4MP4	Glide	5	2	2	3	4	3	5	5	5	3	5	2	4	3	4	2	5	4	2	5
SR4MP5	Pool	2	1	5	1	1	4	3	2	3	4	3	2	3	5	5	5	5	2	3	4
SR4MP6	Riffle	6	3	3	6	6	6	4	5	5	5	5	5	5	5	5	5	5	5	5	2
SR4MP7	Glide	5	5	5	2	2	5	3	5	4	4	4	3	2	4	3	5	4	4	4	3
SR4MP8	Glide	5	5	2	4	2	3	3	5	5	4	3	4	2	1	3	2	4	2	4	4
SR4MP9	Riffle	2	2	2	3	3	3	4	5	5	5	3	5	5	4	5	4	4	5	3	5
SR4MP10	Riffle	5	3	3	3	5	3	5	3	5	2	5	5	3	5	5	4	4	2	4	4
SR4P1	Pool	3	2	2	3	2	2	2	5	2	4	4	4	2	2	2	4	2	2	1	2
SR4P2	Riffle	4	4	4	3	3	3	4	4	4	3	4	4	4	5	4	5	4	5	4	4
SR4P3	Glide	2	3	2	3	4	3	3	3	2	2	2	3	3	2	3	4	2	2	2	2
SR4P4	Pool	2	2	3	2	3	3	2	2	4	3	2	2	2	2	2	2	2	2	4	2
SR4P5	Glide	2	2	2	2	2	2	3	3	4	4	3	4	4	5	4	4	5	5	3	4
SR4P6	Riffle	5	3	4	2	5	4	4	4	4	4	3	4	4	5	4	5	5	4	2	5
SR4P7	Pool	2	2	4	4	4	3	4	5	2	3	2	2	3	5	5	5	2	2	2	2
SR4P8	Riffle	2	2	3	5	3	4	5	4	4	5	4	3	3	5	5	5	3	5	5	2
SR4P9	Riffle	4	4	3	4	4	4	3	5	4	5	4	3	4	3	5	4	5	3	4	4
SR4P10	Glide	2	2	3	4	4	3	2	4	2	5	2	2	2	2	2	4	2	2	4	2

*These pebble counts were split between sides of the large island in reach SR3

Table A3. Results of Fish Surveys

Site	Date	Total Fish	Density per 100 m	Density per 100 m^2
AC	27-Aug-04	601	105	4.98
AC	4-Sep-04	638	111	5.29
AC	24-Sep-04	108	19	0.89
DC*	28-Aug-04	86	20	1.47
DC	5-Sep-04	88	16	1.23
DC	25-Sep-04	52	11	0.79
NC	27-Aug-04	1113	260	16.21
NC	4-Sep-04	705	165	10.27
NC	24-Sep-04	397	93	5.78
PC	27-Aug-04	1122	280	20.55
PC	4-Sep-04	860	214	15.75
PC	24-Sep-04	420	105	7.69
SR1	28-Aug-04	251	42	1.82
SR1	5-Sep-04	66	11	0.48
SR1	25-Sep-04	51	8	0.37
SR3*	29-Aug-04	1	0.2	0.01
SR3	5-Sep-04	0	0.0	0.00
SR3	26-Sep-04	72	6.4	0.33
SR4M	29-Aug-04	62	10	0.48
SR4M	5-Sep-04	14	2	0.11
SR4M	26-Sep-04	9	1	0.07
SR4	28-Aug-04	9	1.2	0.05
SR4	4-Sep-04	10	1.3	0.06
SR4	25-Sep-04	3	0.4	0.02
Upper Stony	15-Oct-04	91	5.0	n/a

*Did not include side channels on other sides of large, mid-reach islands

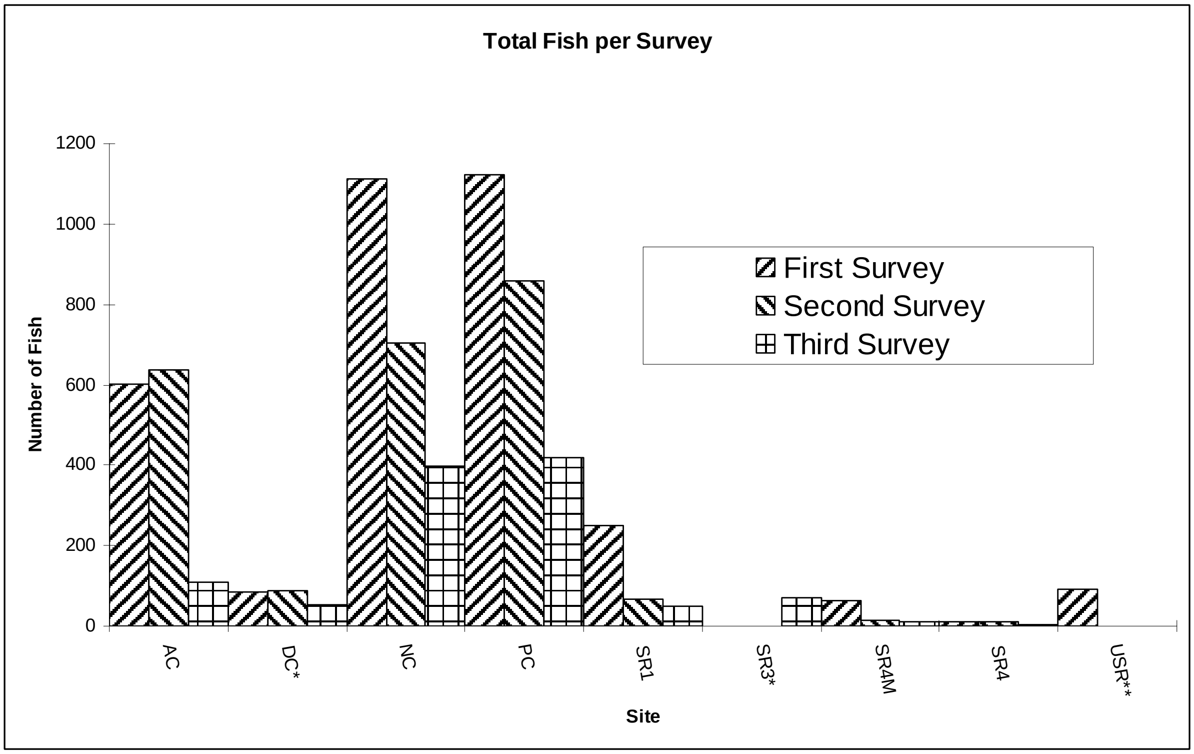

Figure A49. Total Fish per Survey Histogram

(*side channels not surveyed in first survey; **USR=Upper Stony River, only one survey; see Table A3 for dates)

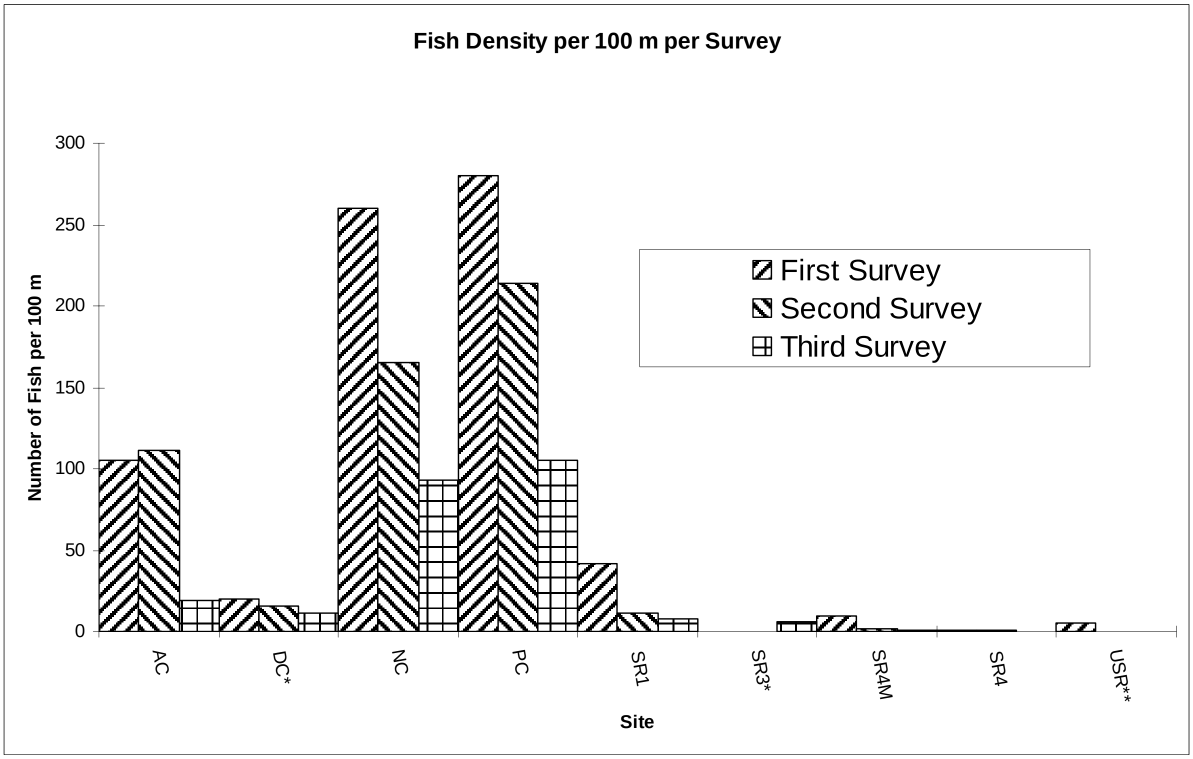

Figure A50. Fish Density per 100 m per Survey Histogram

(*side channels not surveyed in first survey; **USR=Upper Stony River, only one survey; see Table A3 for dates)

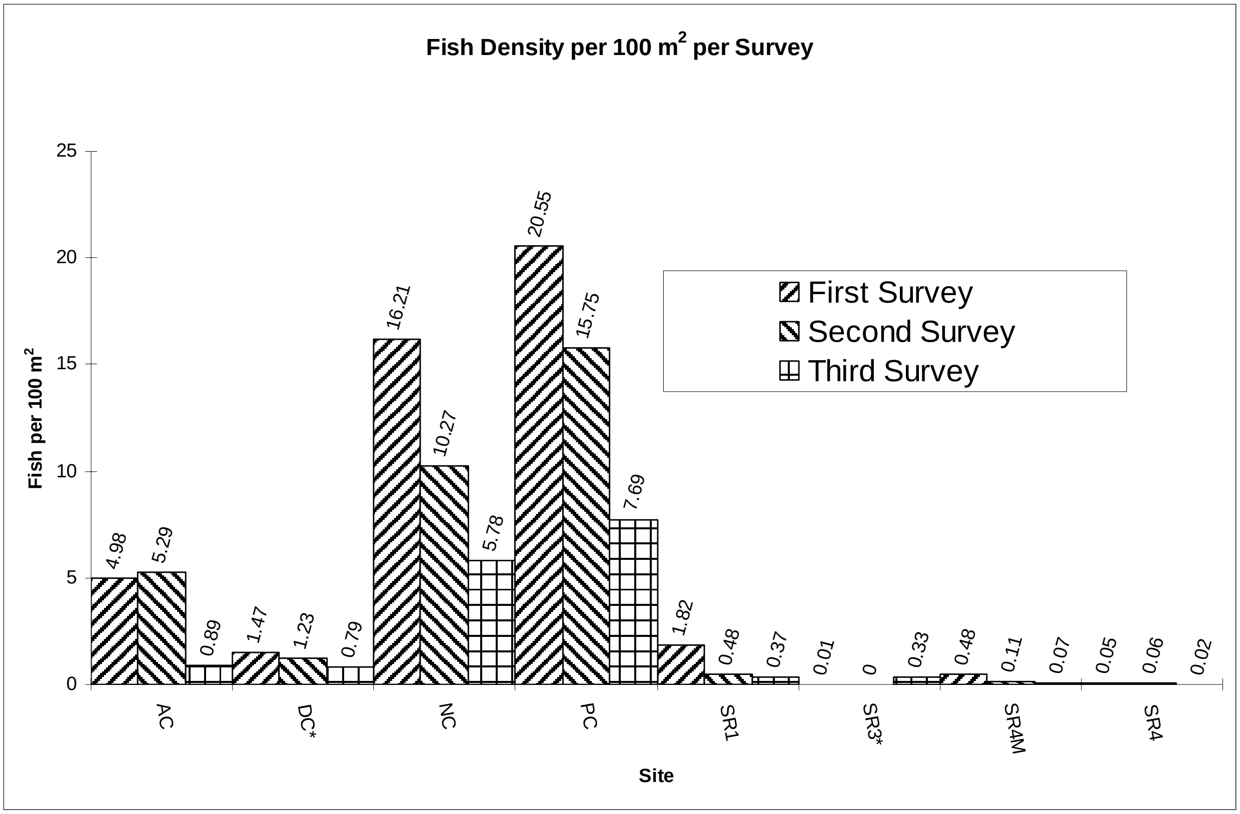

Figure A51. Fish Density per 100 m^2 per Survey Histogram

(*side channels not surveyed in first survey; see Table A3 for dates)

Table A4. RBP (Barbour et al 1999) Values per Location and Site (Partial)

Parameter	**Stream**	PC	PC	PC	PC	AC	AC	AC	AC	AC	DC	DC	DC	DC	SR4M	SR4M
	Location	PCP5 Midpt.	PCP2 Midpt.	PCP9 Midpt.	PCP6 - PCP7	Below Bridge	Below ACP7	Above Bridge	Below ACP8	ACCX2 Midpt.	100m Above DCDOWN	DCP7 Midpt.	DCP3 Midpt.	100m Below DCUP	100m Below SR4MUP	SR4MCX3 Midpt.
	Date	16-Oct-04	16-Oct-04	16-Oct-04	16-Oct-04	16-Oct-04	16-Oct-04	16-Oct-04	5-Nov-04	5-Nov-04	17-Oct-04	17-Oct-04	17-Oct-04	17-Oct-04	12-Nov-04	12-Nov-04
Epifaunal Substrate/Available Cover		14	16	14	18	17	18	18	12	12	19	19	20	20	15	14
Embeddedness		19	14	13	17	19	19	18	19	18	15	16	18	19	18	14
Velocity/Depth Regime		7	17	17	15	13	7	15	19	16	15	19	15	18	19	18
Sediment Deposition		19	18	10	16	18	18	18	16	19	16	17	15	16	18	15
Channel Flow Status		9	16	10	13	16	9	17	18	18	16	18	17	18	17	19
Channel Alteration		19	19	10	15	18	15	16	17	19	19	15	17	17	18	15
Frequency of Riffles (or Bends)		19	17	10	19	18	19	17	19	16	20	18	19	19	18	20
Bank Stability--LDB		10	10	9	9	9	9	10	6	6	9	10	6	10	10	9
Bank Stability--RDB		8	10	9	9	9	9	7	9	7	10	8	8	8	10	10
Vegetative Protection--LDB		9	8	8	10	7	4	10	7	8	10	9	7	9	10	10
Vegetative Protection--RDB		7	8	7	6	5	8	10	6	7	10	8	9	8	10	10
Riparian Vegetative Zone Width--LDB		10	10	9	10	9	5	7	4	10	10	10	9	10	10	8
Riparian Vegetative Zone Width--RDB		6	6	5	7	5	10	7	10	8	10	10	10	10	10	10
Total Score		156	169	131	164	163	150	170	162	164	179	177	170	182	183	172

Table A5. RBP (Barbour et al. 1999) Values per Location and Site (Partial)

Parameter	**Stream**	SR4M	SR4M	SR3	SR3	SR3	SR3	SR1	SR1	SR1	SR1	NC	NC	NC	NC
	Location	SR4MCX2 Midpt.	100m Above SR4MDOWN	100m Below SR3UP	SR3P7 Midpt.	SR3P5 Midpt.	100m Above SR3DOWN	100m Above SR1DOWN	100m Below SR1BM	100m Below SR1CX2	100m Below SR1UP	NCP8 Midpt.	NCP4 Midpt.	NCUP - NCP3	NCP5 Midpt.
	Date	12-Nov-04	12-Nov-04	12-Nov-04	12-Nov-04	12-Nov-04	14-Nov-04	13-Nov-04	13-Nov-04	13-Nov-04	13-Nov-04	16-Oct-04	16-Oct-04	16-Oct-04	16-Oct-04
Epifaunal Substrate/Available Cover		13	12	13	15	16	20	16	16	18	18	13	16	13	13
Embeddedness		18	12	15	17	16	19	18	17	17	16	18	15	16	17
Velocity/Depth Regime		20	19	16	18	15	19	19	19	15	19	20	13	5	8
Sediment Deposition		18	13	15	17	14	16	19	17	18	18	18	18	12	14
Channel Flow Status		15	12	19	16	19	16	18	14	18	18	15	18	10	13
Channel Alteration		20	19	18	19	15	17	19	16	19	19	20	20	13	11
Frequency of Riffles (or Bends)		17	19	15	19	17	16	18	16	19	19	17	7	3	4
Bank Stability--LDB		10	9	10	10	9	10	10	10	10	10	10	5	3	6
Bank Stability--RDB		10	10	10	10	9	8	9	10	10	10	10	10	9	10
Vegetative Protection--LDB		10	10	10	10	10	10	10	10	10	10	10	5	2	2
Vegetative Protection--RDB		10	10	10	10	9	10	10	10	10	10	10	8	8	10
Riparian Vegetative Zone Width--LDB		10	10	9	10	10	10	10	10	10	10	10	5	2	1
Riparian Vegetative Zone Width--RDB		10	10	9	10	9	10	10	10	10	10	10	10	9	10
Total Score		181	165	169	181	168	181	186	175	184	187	181	150	105	119

Table A6. RBP (Barbour et al. 1999) Values per Location and Site (Partial)

Parameter	**Stream**	SR4	SR4	SR4	SR4
	Location	Above Bridge	Below Bridge	100m Below SR4UP	100m Above SR4DOWN
	Date	16-Oct-04	16-Oct-04	11-Nov-04	11-Nov-04
Epifaunal Substrate/Available Cover		14	12	8	10
Embeddedness		14	10	5	3
Velocity/Depth Regime		17	12	6	7
Sediment Deposition		14	10	5	6
Channel Flow Status		12	15	15	19
Channel Alteration		18	15	19	15
Frequency of Riffles (or Bends)		15	17	8	7
Bank Stability--LDB		6	9	6	9
Bank Stability--RDB		6	9	4	9
Vegetative Protection--LDB		6	9	10	9
Vegetative Protection--RDB		6	9	9	9
Riparian Vegetative Zone Width--LDB		7	10	10	9
Riparian Vegetative Zone Width--RDB		7	7	10	10
Total Score		142	144	115	122

Table A7. Stream Shading Values by Site

Site		AC			DC			NC			PC			SR1			SR3			SR4M			SR4	
Location	RDB	MID	LDB	RDB	MID	LDB	RDB	MID	LDB	RDB	MID	LDB	RDB	MID	LDB	RDB	MID	LDB	RDB	MID	LDB	RDB	MID	LDB
	70	35	99	88	40	0	100	40	10	85	40	95	0	0	65	50	0	95	50	0	75	30	0	100
	20	85	90	97	35	95	75	25	60	85	75	100	20	0	90	40	0	85	95	0	95	100	0	0
	90	0	0	60	40	99	95	70	80	15	50	90	95	0	100	85	0	0	80	0	85	0	0	0
	95	50	70	90	45	95	100	0	90	99	0	40	95	10	90	0	0	99	100	0	95	95	99	0
	55	0	80	40	10	15	90	20	95	95	40	65	75	0	10	80	10	10	85	0	40	0	20	95
	0	0	0	90	25	85	100	5	0	85	0	100	80	5	25	85	25	95	100	0	10	0	0	80
	100	0	45	90	80	95	90	40	65	0	0	99	95	0	0	90	0	0	99	0	95	70	0	40
	40	0	70	40	60	85	95	80	95	95	20	80	80	0	85	80	40	99	30	0	80	15	0	90
	0	0	75	99	20	70	90	50	45	80	99	55	0	0	100	100	80	90	0	0	100	80	0	15
	0	0	25	85	95	99	55	90	90	99	100	100	0	0	75	100	0	100	100	0	70	98	5	95
	60	0	90	40	30	75	100	90	90	0	75	95	0	0	100	100	10	100	100	0	0	15	0	5
	0	0	100	99	30	10	95	65	90	85	50	90				15	0	0	100	5	0	0	0	85
																0	0	0						

RDB = right-descending bank; MID = mid-channel; LDB = left-descending bank

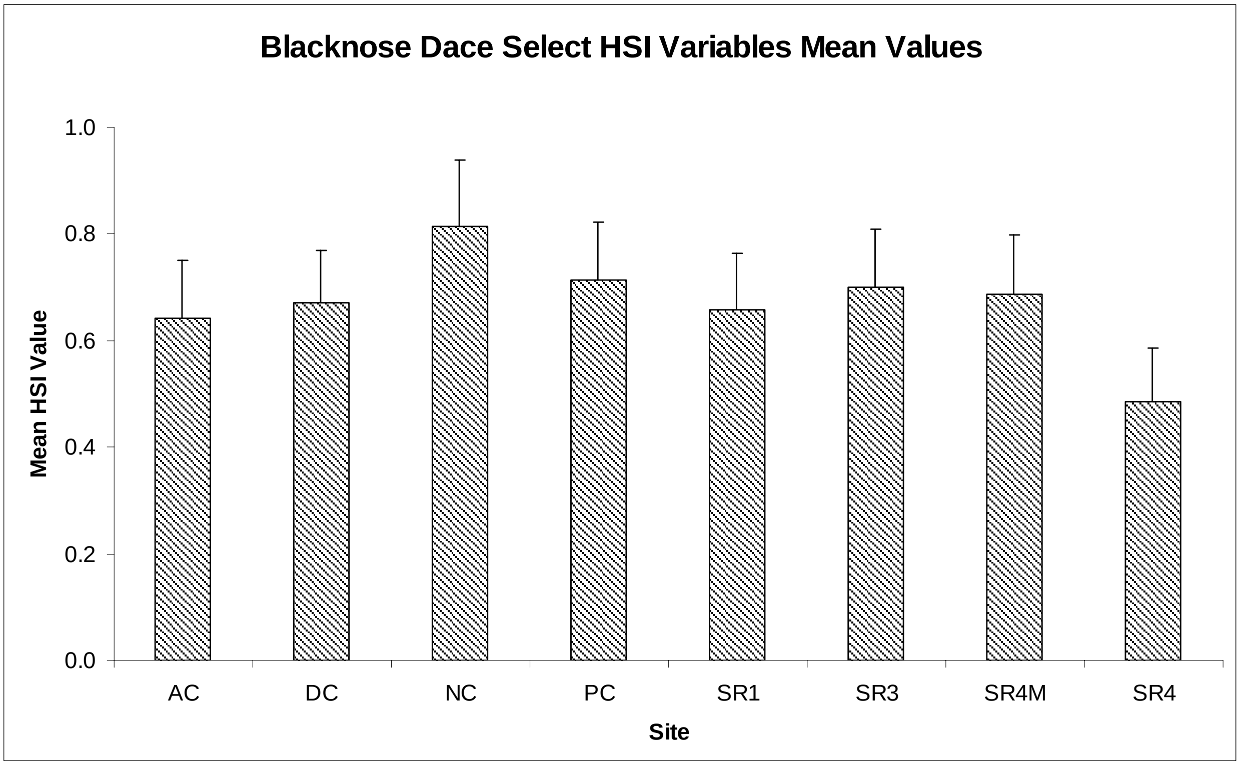

Figure A52. Bar Chart of Mean of Select HSI Variables for Blacknose Dace

(Bars represent one standard error)

Table A8. Descriptions and Means of Select Blacknose Dace HSI Values*

HSI Variable	V_1	V_2	V_3	V_4	V_7	V_{11}	V_{13}	Mean+	SEM
Description	% stream area shaded	% pools	stream gradient	stream width	predom riffle substrate	predom pool substrate	predom riffle substrate (juv)		
AC	0.6	0.6	1.0	0.2	0.6	1.0	0.5	0.643	0.107
DC	1.0	0.6	0.7	0.3	0.6	1.0	0.5	0.671	0.097
NC	1.0	0.5	1.0	0.2	1.0	1.0	1.0	0.814	0.124
PC	1.0	0.6	1.0	0.3	0.6	1.0	0.5	0.714	0.108
SR1	0.6	0.7	1.0	0.2	0.6	1.0	0.5	0.657	0.107
SR3	0.8	0.8	1.0	0.2	0.6	1.0	0.5	0.700	0.109
SR4M	0.9	0.6	1.0	0.2	0.6	1.0	0.5	0.686	0.112
SR4	0.5	0.6	0.1	0.2	0.6	0.9	0.5	0.486	0.101

*See Trial et al. (1983a); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

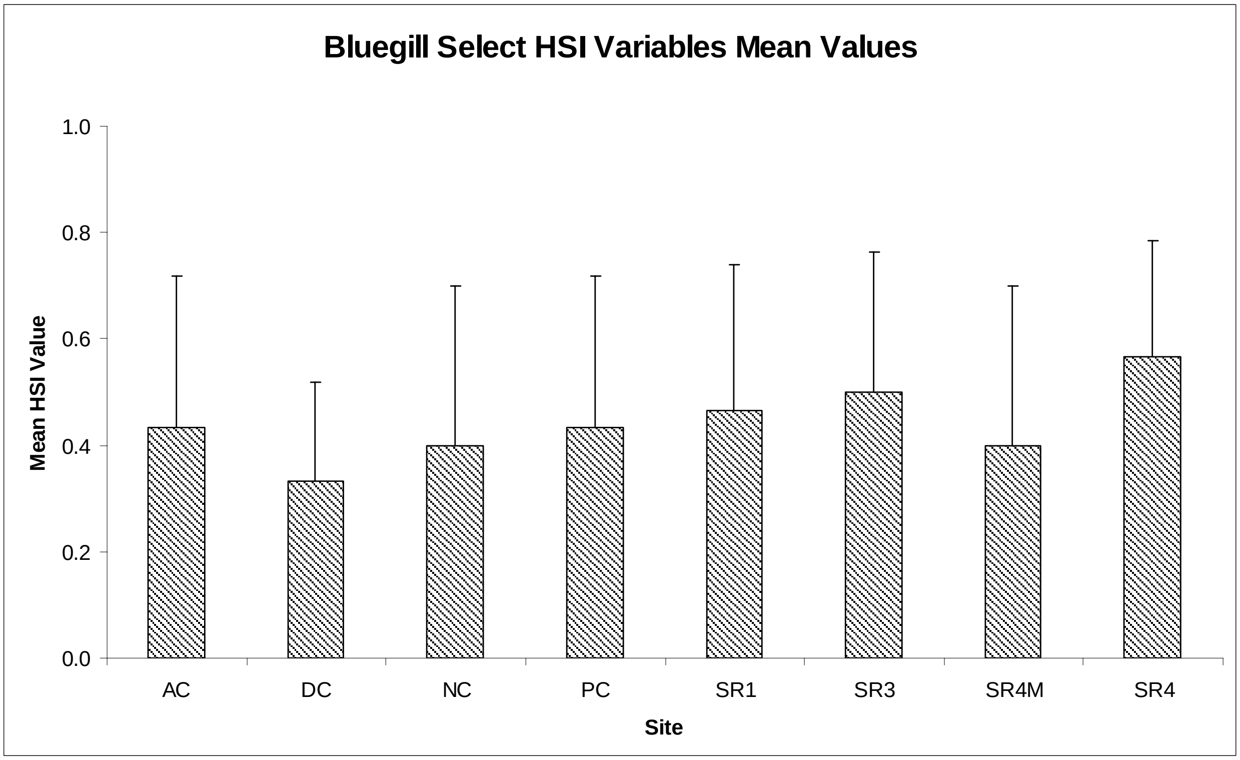

Figure A53. Bar Chart of Mean of Select HSI Variables for Bluegill
(Bars represent one standard error)

Table A9. Descriptions and Means of Select Bluegill HSI Values*

HSI Variable	V_1	V_{18}	V_{20}		
Description	% pools	stream gradient	pool substrate	Mean+	SEM
AC	0.2	0.1	1.0	0.433	0.285
DC	0.2	0.1	0.7	0.333	0.186
NC	0.1	0.1	1.0	0.400	0.300
PC	0.2	0.1	1.0	0.433	0.285
SR1	0.3	0.1	1.0	0.467	0.273
SR3	0.4	0.1	1.0	0.500	0.265
SR4M	0.1	0.1	1.0	0.400	0.300
SR4	0.4	0.3	1.0	0.567	0.219

*See Stuber et al. (1982a); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

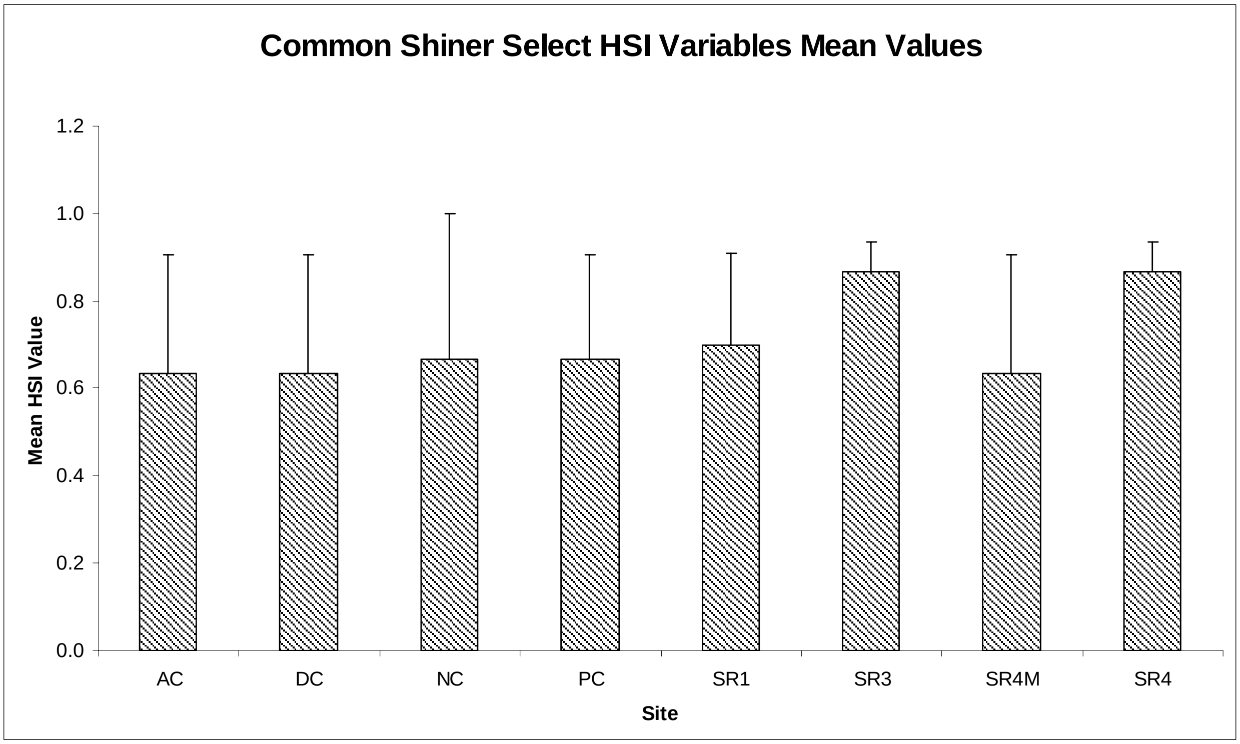

Figure A54. Bar Chart of Mean of Select HSI Variables for Common Shiner
(Bars represent one standard error)

Table A10. Descriptions and Means of Select Common Shiner HSI Values*

HSI Variable	V_4	V_5	V_7	Mean+	SEM
Description	predom substrate type	% pools	pool class		
AC	0.8	0.1	1.0	0.633	0.273
DC	0.8	0.1	1.0	0.633	0.273
NC	1.0	0.0	1.0	0.667	0.333
PC	0.8	0.2	1.0	0.667	0.240
SR1	0.8	0.3	1.0	0.700	0.208
SR3	0.8	0.8	1.0	0.867	0.067
SR4M	0.8	0.1	1.0	0.633	0.273
SR4	0.8	0.8	1.0	0.867	0.067

*See Trial et al. (1983b); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

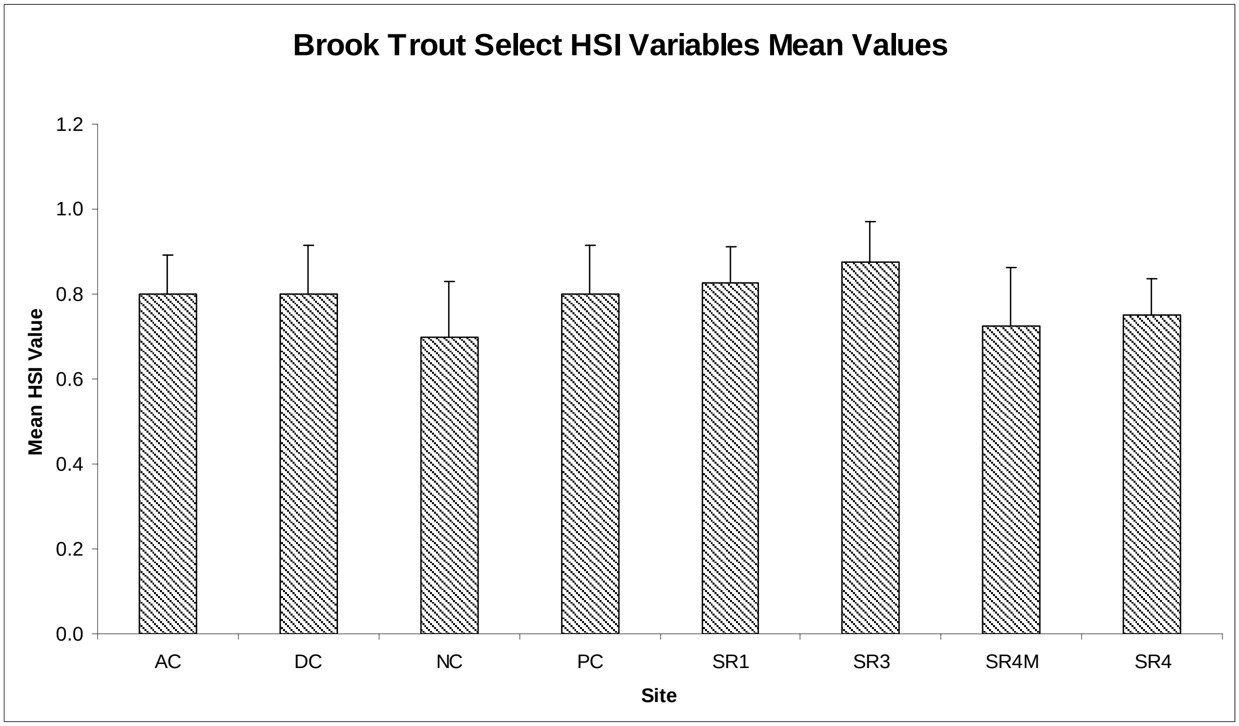

Figure A55. Bar Chart of Mean of Select HSI Variables for Brook Trout
(Bars represent one standard error)

Table A11. Descriptions and Means of Select Brook Trout HSI Values*

HSI Variable	**V_9**	**V_{10}**	**V_{16}**	**V_{17}**	**Mean+**	**SEM**
Description	**dom run/riffle substrate**	**% pools**	**% fines riffle/run**	**% stream shade**		
AC	0.6	0.7	1.0	0.9	0.800	0.091
DC	0.6	0.6	1.0	1.0	0.800	0.115
NC	0.6	0.4	0.8	1.0	0.700	0.129
PC	0.6	0.6	1.0	1.0	0.800	0.115
SR1	0.6	0.8	1.0	0.9	0.825	0.085
SR3	0.6	1.0	1.0	0.9	0.875	0.095
SR4M	0.6	0.4	1.0	0.9	0.725	0.138
SR4	0.6	1.0	0.7	0.7	0.750	0.087

*See Raleigh (1982); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

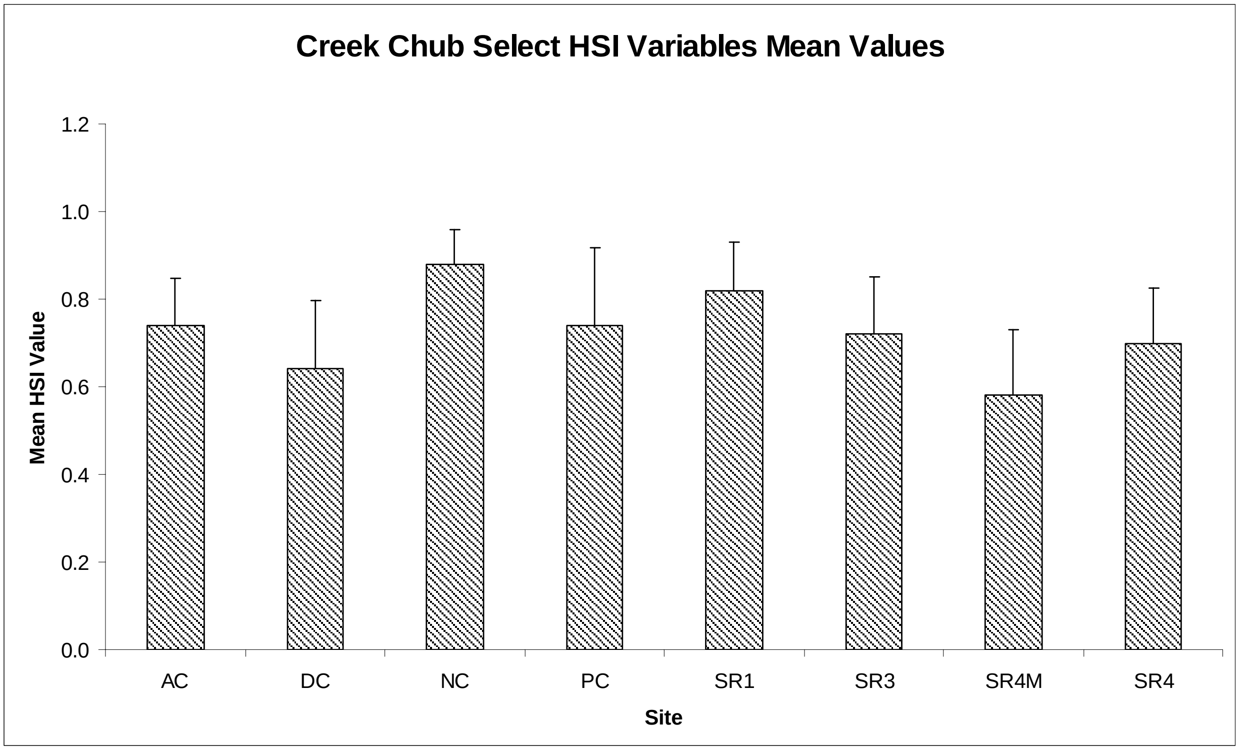

Figure A56. Bar Chart of Mean of Select HSI Variables for Creek Chub
(Bars represent one standard error)

Table A12. Descriptions and Means of Select Creek Chub HSI Values*

HSI Variable	V_1	V_2	V_5	V_{10}	V_{17}	V_{19}	Mean+	SEM
Description	% pools	pool class rating	stream gradient	% subs type--food	% subs type--reprod	% stream shade		
AC	0.4	0.6	1.0	0.5	1.0	0.6	0.740	0.108
DC	0.5	0.6	0.1	0.6	1.0	0.9	0.640	0.157
NC	0.2	1.0	0.8	0.6	1.0	1.0	0.880	0.080
PC	0.5	1.0	0.1	0.6	1.0	1.0	0.740	0.178
SR1	0.6	1.0	1.0	0.5	1.0	0.6	0.820	0.111
SR3	0.8	1.0	0.3	0.6	1.0	0.7	0.720	0.132
SR4M	0.3	0.6	0.3	0.2	1.0	0.8	0.580	0.150
SR4	0.8	1.0	0.4	0.5	1.0	0.6	0.700	0.126

*See McMahon (1982); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

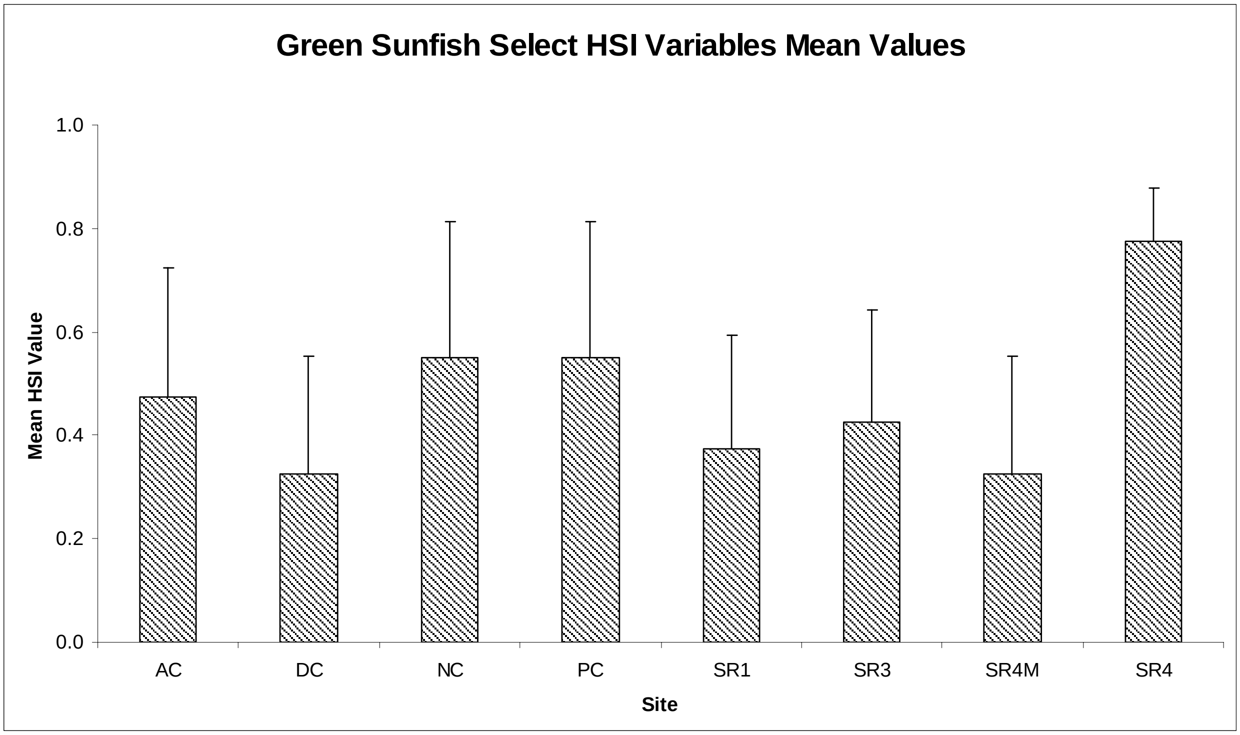

Figure A57. Bar Chart of Mean of Select HSI Variables for Green Sunfish
(Bars represent one standard error)

Table A13. Descriptions and Means of Select Green Sunfish HSI Values*

HSI Variable	V_2	V_3	V_{10}	V_{14}	Mean+	SEM
Description	% pools	stream gradient	substrate	stream width		
AC	0.1	0.0	0.8	1.0	0.475	0.250
DC	0.1	0.0	0.2	1.0	0.325	0.229
NC	0.0	0.2	1.0	1.0	0.550	0.263
PC	0.2	0.0	1.0	1.0	0.550	0.263
SR1	0.3	0.0	0.2	1.0	0.375	0.217
SR3	0.5	0.0	0.2	1.0	0.425	0.217
SR4M	0.1	0.0	0.2	1.0	0.325	0.229
SR4	0.5	0.8	0.8	1.0	0.775	0.103

*See Stuber et al. (1982b); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

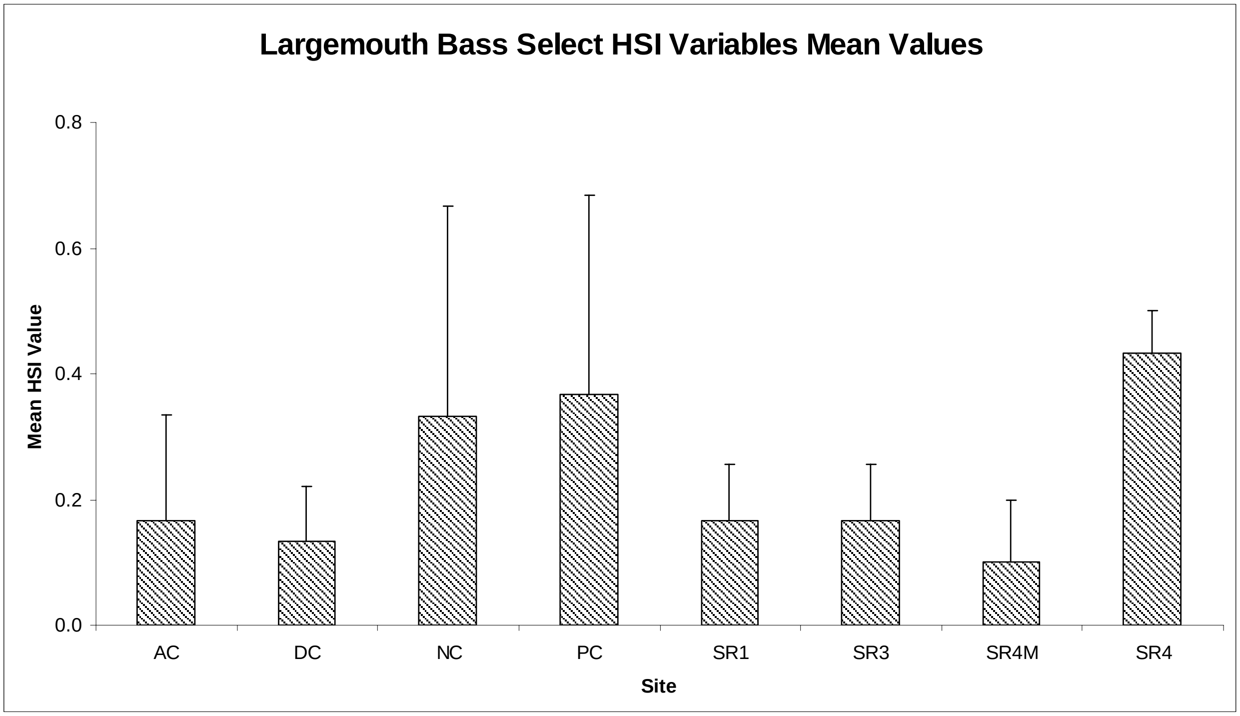

Figure A58. Bar Chart of Mean of Select HSI Variables for Largemouth Bass
(Bars represent one standard error)

Table A14. Descriptions and Means of Select Largemouth Bass HSI Values*

HSI Variable	V_1	V_{15}	V_{22}	Mean+	SEM
Description	% pools & backwaters	substrate	stream gradient		
AC	0.0	0.5	0.0	0.167	0.167
DC	0.1	0.3	0.0	0.133	0.088
NC	0.0	1.0	0.0	0.333	0.333
PC	0.1	1.0	0.0	0.367	0.318
SR1	0.2	0.3	0.0	0.167	0.088
SR3	0.2	0.3	0.0	0.167	0.088
SR4M	0.0	0.3	0.0	0.100	0.100
SR4	0.3	0.5	0.5	0.433	0.067

*See Stuber et al. (1982c); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

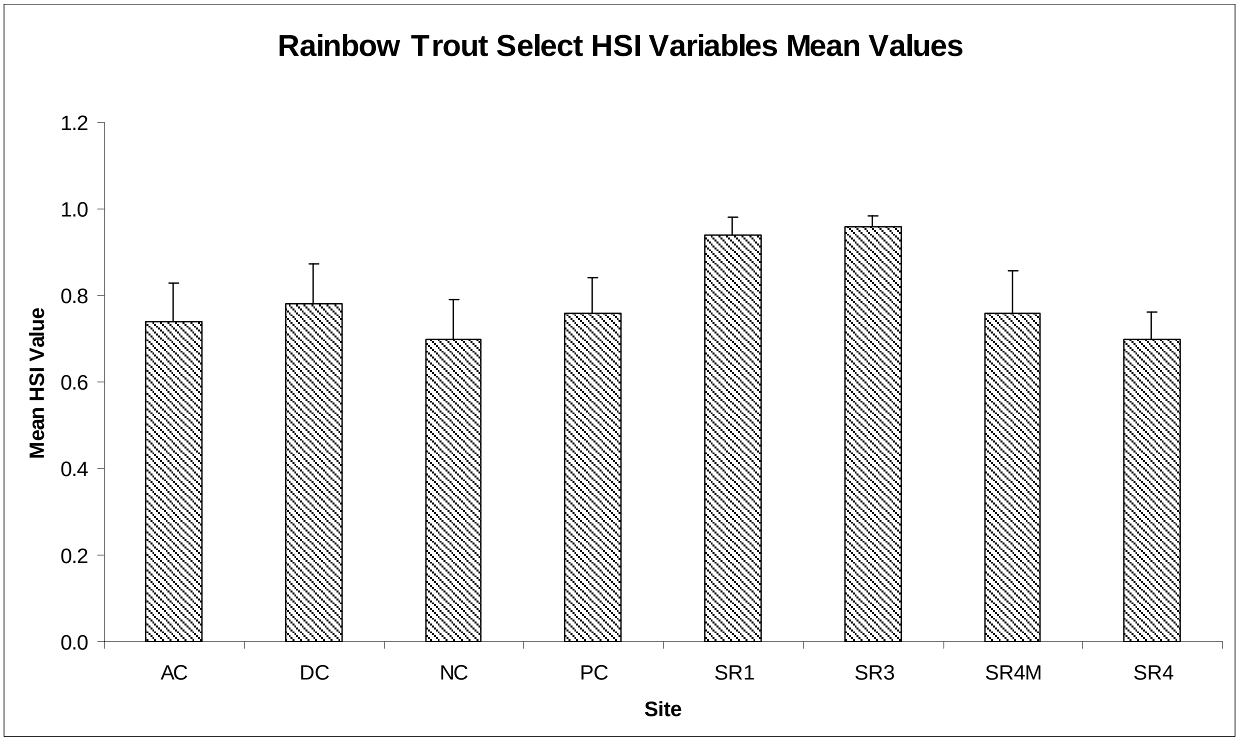

Figure A59. Bar Chart of Mean of Select HSI Variables for Rainbow Trout

(Bars represent one standard error)

Table A15. Descriptions and Means of Select Rainbow Trout HSI Values*

HSI Variable	V_8	V_9	V_{10}	V_{15}	V_{16A}	V_{17}	Mean+	SEM
Description	% substrate size class	predom subst type in riffle/run	% pools	pool class rating	% fines in riffle/run	% stream shade		
AC	1.0	0.6	0.6	0.6	1.0	0.9	0.740	0.087
DC	1.0	0.6	0.7	0.6	1.0	1.0	0.780	0.092
NC	1.0	0.6	0.5	0.6	0.8	1.0	0.700	0.089
PC	1.0	0.6	0.7	0.6	0.9	1.0	0.760	0.081
SR1	1.0	1.0	0.8	1.0	1.0	0.9	0.940	0.040
SR3	1.0	1.0	0.9	1.0	1.0	0.9	0.960	0.024
SR4M	1.0	0.6	0.6	0.6	1.0	1.0	0.760	0.098
SR4	1.0	0.6	0.9	0.6	0.6	0.8	0.700	0.063

*See Raleigh et al. (1984); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

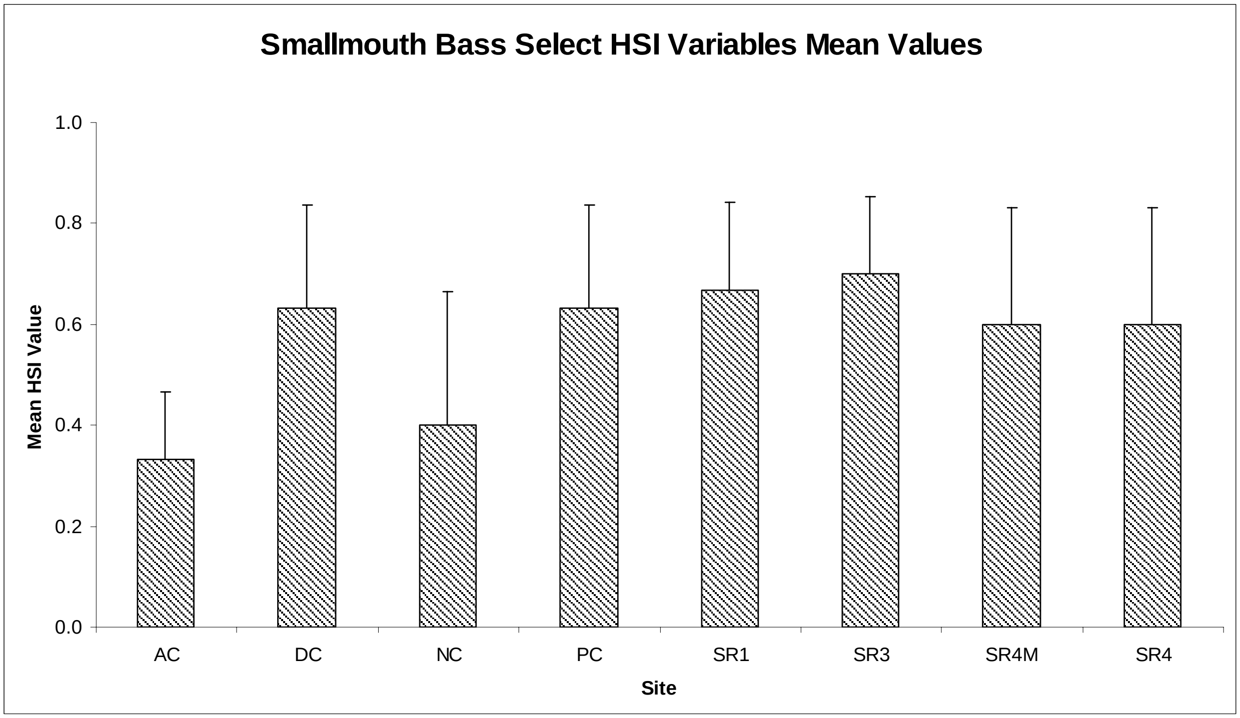

Figure A60. Bar Chart of Mean of Select HSI Variables for Smallmouth Bass
(Bars represent one standard error)

Table A16. Descriptions and Means of Select Smallmouth Bass HSI Values*

HSI Variable Description	V_1 subst type	V_2 % pools	V_{15} gradient	Mean	SEM
AC	0.2	0.2	0.6	0.333	0.133
DC	1.0	0.3	0.6	0.633	0.203
NC	0.3	0.0	0.9	0.400	0.265
PC	1.0	0.3	0.6	0.633	0.203
SR1	1.0	0.4	0.6	0.667	0.176
SR3	1.0	0.5	0.6	0.700	0.153
SR4M	1.0	0.2	0.6	0.600	0.231
SR4	0.2	0.6	1.0	0.600	0.231

*See Edwards et al. (1983); SEM = standard error; +No significant difference using Student-Newman-Keuls ($\alpha = 0.05$)

Table A17. Descriptions and Means of Select HSI Values from Other Species

Species	channel catfish[a]	channel catfish[a]	fallfish[b]	white sucker[c]	longnose dace[d]	longnose dace[d]
HSI Variable	V_1	V_4	V_5	V_{10}	V_3	V_4
Description	% pools	substrate type	substrate type	% pools	% riffles	substrate type
AC	0.4	0.5	0.4	0.4	1.0	1.0
DC	0.4	0.6	0.4	0.4	1.0	1.0
NC	0.3	0.6	1.0	0.2	1.0	1.0
PC	0.4	0.6	0.4	0.5	1.0	1.0
SR1	0.5	0.5	0.4	0.5	1.0	1.0
SR3	0.8	0.6	0.4	0.7	1.0	1.0
SR4M	0.3	0.2	0.4	0.3	1.0	1.0
SR4	0.8	0.5	1.0	0.8	1.0	1.0

[a]See McMahon & Terrell (1982); [b]See Trial et al. (1983c); [c]See Twomey et al. (1984); [d]See Edwards & Schrek (1983)

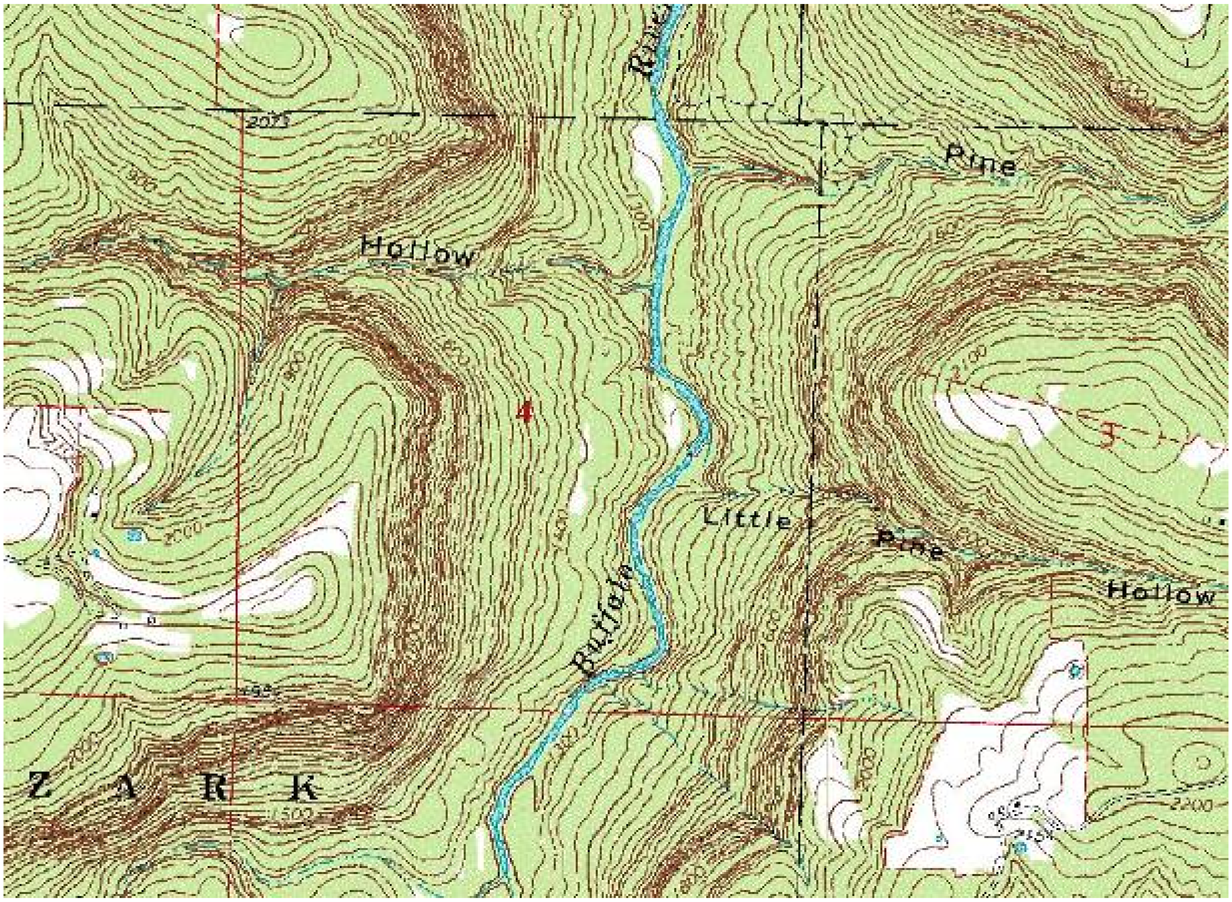

Figure A61. S1 Valley and Stream Type as Classified by McKenney (1997)

Table A18. Mean HCU Densities per Site

Site	Total LSP	SCP	Total BKP	PPL	Total Pool	Riffle	Rapid
AC	0.351	0.381	0.260	0.066	1.141	0.859	0.138
	(0.096)	(0.086)	(0.071)	(0.029)	(0.192)	(0.198)	(0.182)
DC	0.651	0.497	0.468	0.131	1.804	1.998	0.137
	(0.069)	(0.060)	(0.060)	(0.030)	(0.182)	(0.060)	(0.091)

Site	Total LSP	SCP	Total BKP	PPL	Total Pool	Riffle	Rapid
NC	0.204 (0.039)	0.262 (0.154)	0.092 (0.017)	0.000 (0.000)	0.621 (0.168)	0.660 (0.269)	0.005 (0.008)
PC	0.507 (0.181)	0.348 (0.183)	0.427 (0.064)	0.047 (0.020)	1.471 (0.465)	1.398 (0.376)	0.189 (0.130)
SR1	0.173 (0.086)	0.203 (0.074)	0.116 (0.025)	0.018 (0.010)	0.577 (0.175)	0.611 (0.214)	0.043 (0.016)
SR3	0.322 (0.037)	0.558 (0.127)	0.245 (0.062)	0.068 (0.022)	1.333 (0.217)	0.986 (0.194)	0.155 (0.025)
SR4M	0.277 (0.027)	0.389 (0.111)	0.195 (0.023)	0.054 (0.020)	0.986 (0.022)	0.784 (0.116)	0.128 (0.028)
SR4	0.056 (0.018)	0.079 (0.020)	0.072 (0.023)	0.000 (0.000)	0.273 (0.022)	0.241 (0.007)	0.000 (0.000)

(Values are number per dam^2; values in parentheses are one standard error; LSP = lateral scour pool, SCP = secondary channel pool, BKP = backwater pool, PPL = plunge pool)

Table A19. Mean HCU Densities by Criteria

Criteria	Total LSP	SCP	Total BKP	PPL	Total Pool	Riffle	Rapid
Similar	0.501 (0.085)	0.439 (0.054)	0.364 (0.062)	0.099 (0.024)	1.472 (0.190)	1.428 (0.260)	0.138 (0.052)
Diverse	0.355 (0.107)	0.305 (0.109)	0.260 (0.081)	0.023 (0.014)	1.046 (0.292)	1.029 (0.204)	0.097 (0.053)
Minimal	0.173 (0.086)	0.203 (0.074)	0.116 (0.025)	0.018 (0.010)	0.577 (0.175)	0.611 (0.214)	0.043 (0.016)
Impaired	0.300 (0.023)	0.474 (0.084)	0.220 (0.033)	0.061 (0.014)	1.160 (0.137)	0.885 (0.111)	0.142 (0.018)
Low Grad	0.056 (0.018)	0.079 (0.020)	0.072 (0.023)	0.000 (0.000)	0.273 (0.022)	0.241 (0.007)	0.000 (0.000)

(Values are number per dam^2; values in parentheses are one standard error; LSP = lateral scour pool, SCP = secondary channel pool, BKP = backwater pool, PPL = plunge pool)

Table A20. Mean Geomorphic Variables by Criteria

Criteria	FPAW (m)	Entrenchment Ratio	Width/Depth Ratio	Cross-Section Area (m^2)	Bankfull Depth (m)	Bankfull Width (m)	Riffle Bankfull Width (m)
Similar	47.20 (11.06)	2.67 (0.49)	19.74 (3.04)	249.63 (86.25)	1.18 (0.08)	17.18 (1.00)	17.12 (1.48)
Diverse	42.86 (10.67)	2.21 (0.40)	21.34 (1.36)	118.98 (26.16)	0.71 (0.03)	14.70 (0.42)	14.40 (0.97)
Minimal	34.21 (2.71)	1.57 (0.29)	32.56 (8.55)	176.52 (3.01)	0.72 (0.04)	22.95 (1.19)	25.09 (0.81)
Impaired	34.11 (4.99)	1.51 (0.18)	32.64 (3.01)	167.79 (13.57)	0.69 (0.03)	19.20 (0.81)	19.65 (0.94)
Low Grad	33.25 (4.81)	1.40 (0.18)	30.48 (8.32)	223.53 (53.39)	0.88 (0.09)	23.07 (1.01)	20.86 (2.10)

(Values in parentheses are one standard error; FPAW = flood prone area width; see text for criteria sites)

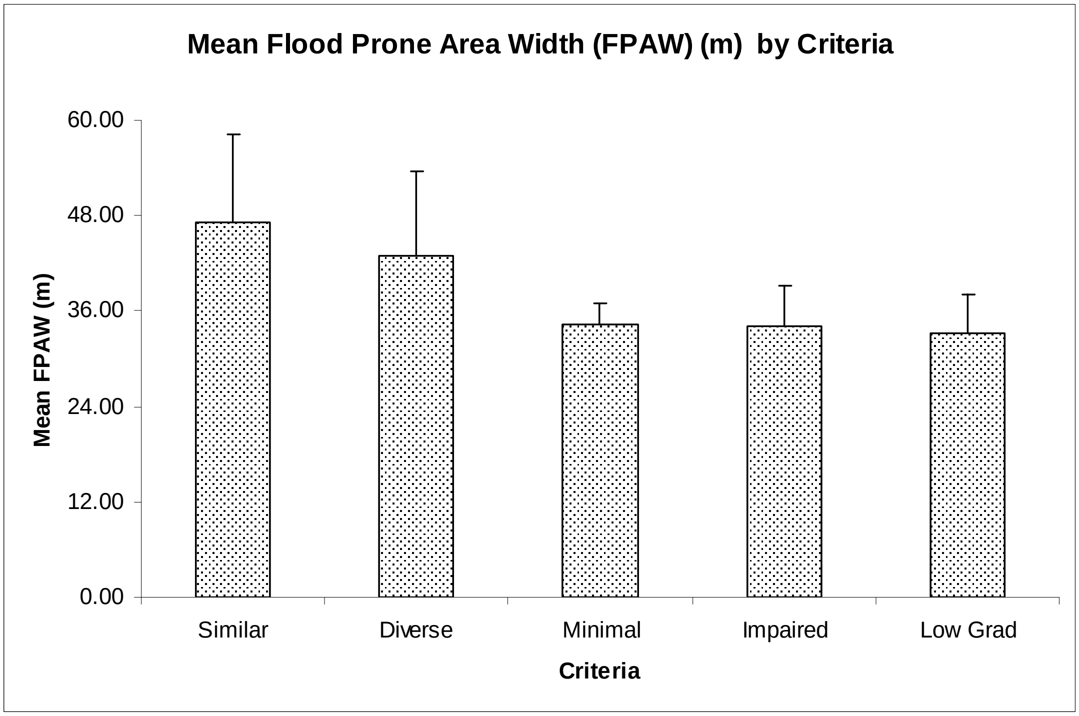

Figure A62. Mean Flood Prone Area Width by Criteria
(Bars represent one standard error; see text for criteria sites)

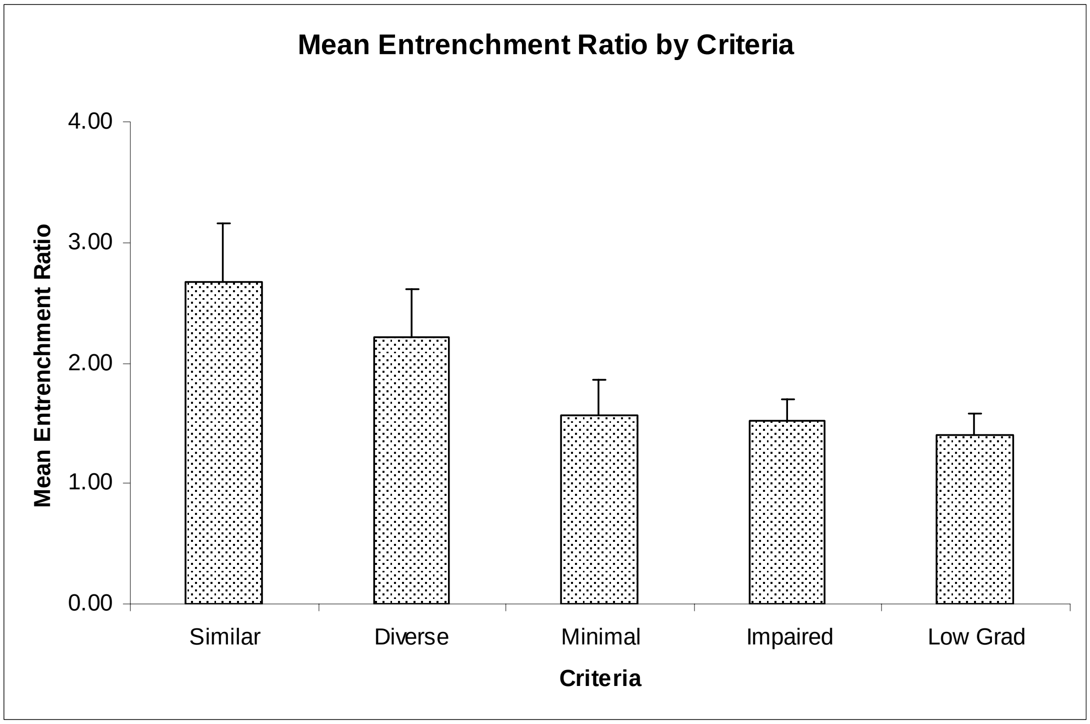

Figure A63. Mean Entrenchment Ratio by Criteria
(Bars represent one standard error; see text for criteria sites)

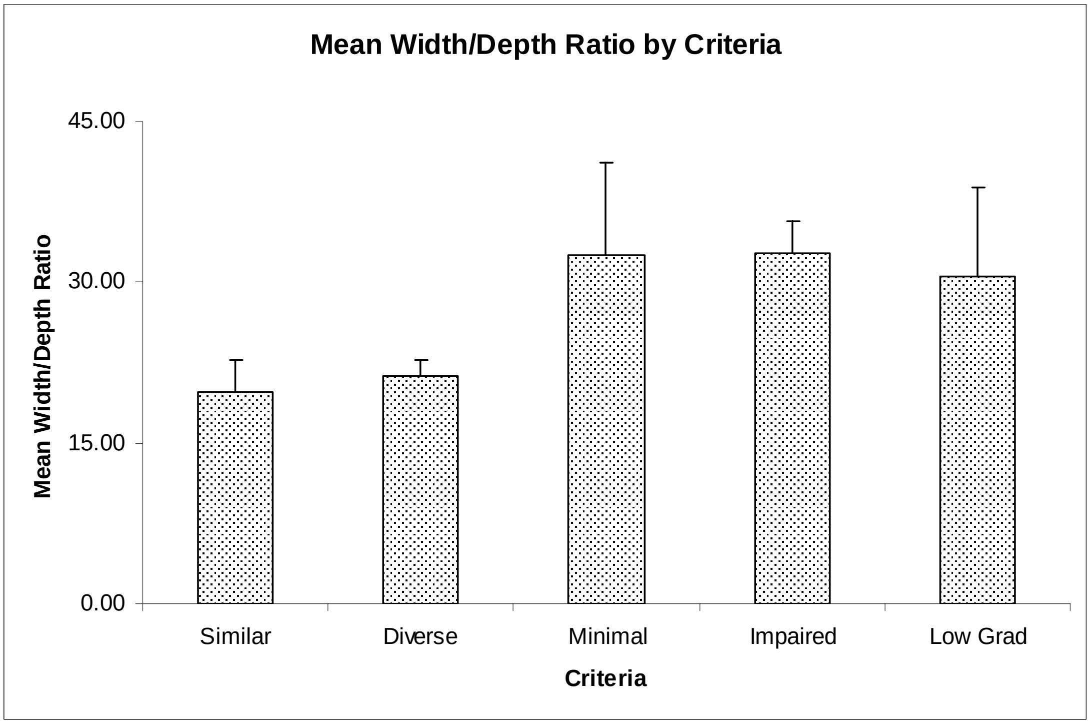

Figure A64. Mean Width Depth Ratio by Criteria
(Bars represent one standard error; see text for criteria sites)

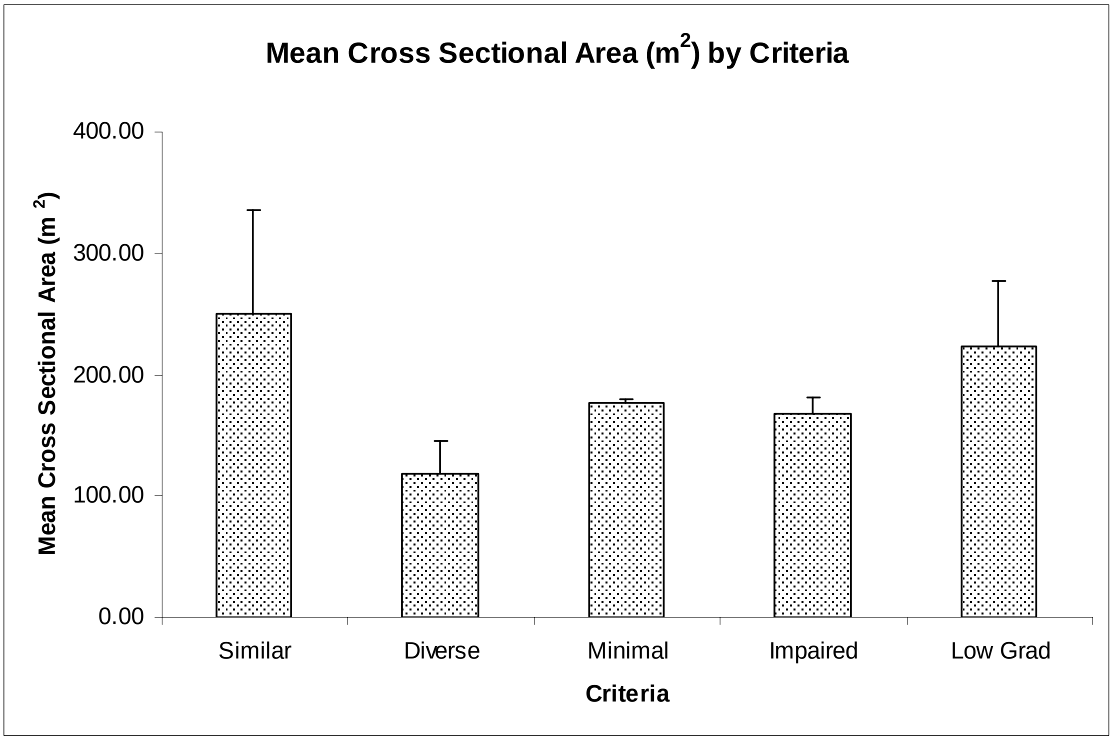

Figure A65. Mean Cross Sectional Area by Criteria
(Bars represent one standard error; see text for criteria sites)

CURRICULUM VITA

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CURRENT EMPLOYMENT

2002 – present. Student Trainee. Regulatory Branch, Huntington District Corps of Engineers.
Evaluate and write Section 404 permits. Perform jurisdictional verifications on streams and wetlands. Enforce Section 404 of the Clean Water Act.

EDUCATION

Marshall University	B.S., 2002
Marshall University	M.S., 2005 (expected)

PAPERS/PRESENTATIONS

"Size and Age Class of Shells of the Mussel Species *Quadrula pustulosa* found in the Muskingum River near Dresden, Ohio." Ohio River Basin Consortium for Research and Education 2002 Annual Scientific Symposium. Oral Presentation.

"Size and Age Class of Shells of the Mussel Species *Quadrula pustulosa* found in the Muskingum River near Dresden, Ohio." Tristate Fisheries Convention, 2003.

"Relocation success and subsequent growth rate of freshwater mussels in the Muskingum River near Dresden, Ohio." Association of Southeastern Biologists 64th Annual Meeting, April 2003. Oral Presentation.

"Relocation success and subsequent growth rate of freshwater mussels in the Muskingum River near Dresden, Ohio." 3rd Biennial Symposium of the Freshwater Mollusk Conservation Society, March 2003. Oral Presentation.

"Relocation success and subsequent growth rate of freshwater mussels in the Muskingum River near Dresden, Ohio." 2003 Sigma Psi Research Day at Marshall University, April 2003. Oral Presentation.

EXTRAMURAL GRANTS AND CONTRACTS

Resampling of Relocation Mussels. Ralph W. Taylor, Thomas G. Jones, et al. Environmental Assessment Associates, LLC. 2003.

PROJECT MANAGER: Manage and analyze data gathered from resampling effort for mussels moved in 2002 in Muskingum River, Ohio. Assist in report writing and GIS analysis.

Relocation of Mussels from Footprint of Proposed Power Plant Intake. Ralph W. Taylor, Thomas G. Jones, et al. Environmental Assessment Associates, LLC. 2003.

PROJECT MANAGER: Manage and analyze data gathered from re-survey of proposed footprint of Dresden Energy plant on Muskingum River, including relocation of mussels. Assist in report writing and GIS analysis.

Elk River Mussel Survey. Ralph W. Taylor, Thomas G. Jones, et al. Skelly and Loy, Inc. 2003.

CO-PROJECT MANAGER: Helped manage and analyze data, including GIS, gathered during freshwater mussel survey in association with West Virginia DOT bridge replacement project.

Quality Assurance/Quality Control of Fish Reference Collection. Thomas G. Jones, et al. Potesta and Associates. 2003.

Performed species-level fish identification QA/QC on reference collection.

Dresden Energy Mussel Relocation and Monitoring. Thomas G. Jones, Ralph W. Taylor, Jim Spence, et al. Ralph Taylor and Associates. 2002 – current.

Helped relocate 2,300 unionid mussels while identifying, imaging, weighing, and recording. Assisted in report writing through data analysis and GIS. Will assist in quarterly monitoring of relocated mussels using SCUBA.

Mussels of the New River Gorge. Ralph W. Taylor, Thomas G. Jones, Brian Richards, Josh Westbrook, et al. National Park Service. 2003.

Assisted in a mussel survey of this section of the river while assessing habitat using digital imagery.

Greenbrier Pipeline Project. Thomas G. Jones, Ralph W. Taylor, John Enz, Jim Spence, et al. URS Environmental Consultants. 2002 – 2003.

Performed habitat assessments for freshwater mussels of stream crossings in North Carolina.

West Virginia Department of Transportation Mussel Workshop. Ralph W. Taylor, Thomas G. Jones, Michael Little, Jim Spence, et al. Rahall Transportation Institute. 2002.

Assisted in training state permit agency employees in mussel survey technique and identification.

PROFESSIONAL SOCIETIES/CERTIFICATIONS

Freshwater Mollusk Conservation Society
National Shellfisheries Association
PADI Open-water certified since 2002
Association of Southeastern Biologists
American Fisheries Society, Tristate Chapter (KY, WV, VA)
Ohio River Basin Consortium on Research and Education