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# Applying Biological and Physical Templates to Perform Instream Habitat Mapping in the Northeast

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# APPLYING BIOLOGICAL AND PHYSICAL TEMPLATES TO PERFORM INSTREAM FISH HABITAT MAPPING IN THE NORTHEAST

A Thesis Presented

by

DIANA L. WALDEN

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# DEDICATION

To my extremely patient husband Micah, and to my parents for raising me in an environment that fostered my interests in the natural world.

# ACKNOWLEDGMENTS

I wish to thank my advisor, Piotr Parasiewicz for the enthusiasm and energy he imparts towards the study and protection of rivers and aquatic communities.  I also extend great appreciation to Piotr and the members of my committee, Betsy Dumont, Sean Werle, Timothy Randhir, and previously Michael Ross, for their invaluable recommendations, input, advice and time spent in reviewing and guiding this process.

Financial support for the Eightmile River study was provided by the National Park Service and the Eightmile River Wild and Scenic Study Committee. Thanks to the Inland Fisheries Division of the Connecticut Department of Environmental Protection for providing reference survey data and essential advice. Thanks to all of the private landowners who graciously granted us access to the river through their properties. My gratitude goes to the staff and students of NEIHP and Rushing Rivers Institute, particularly Jeff Legros, Joe Rogers, and Jenn Hogue who assisted in field work, data collection, and analysis.

I am also indebted to my employer, Ingeborg Hegemann and the BSC Group, whose understanding and support allowed me to pursue my education while continuing to work at a reduced schedule.

Finally, I am forever grateful to my husband, family, and friends for supporting, cheering, and encouraging me through this extended and sometimes painful process.

# ABSTRACT

## APPLYING BIOLOGICAL AND PHYSICAL TEMPLATES TO PERFORM INSTREAM FISH HABITAT MAPPING IN THE NORTHEAST

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Most northeastern river basins are stressed by the effects of development but the complexity of evaluating rivers often hinders the establishment of effective management regulations. Many methodologies have been proposed for assessing instream habitat, determining critical flow levels, and evaluating biological communities, but no one approach is universal. The overall objective of this thesis is to move towards standardizing components of river modeling. Rather than examine a full model, I investigated individual steps of MesoHABSIM, an instream habitat modeling approach. The two components studied involved applying the Reference Fish Community (RFC) method to identify a biological reference; and using depth and velocity data to standardize the description of hydraulic types.

The RFC approach identifies the fish species and the expected proportions that should be present in a less impacted version of a river system. The Eightmile River watershed, was the focus of the study in which the RFC approach was employed to determine whether the fish community of this rural watershed, meets or exceeds a community developed using reference rivers. Similarity indices were used to identify differences between the existing (field-sampled) and expected communities. While the analysis of the Eightmile community indicates that it is in a better condition than the majority of rivers studied, it also shows some deviation from the reference, most likely due to elevated water temperatures and regional declines.

The hydraulic type characterization study was developed to reduce the effort needed in depth and velocity measurement after this was identified as the most time consuming portion of the MesoHABSIM methodology. I used a series of pair-wise, independent-sample, Kolmogorov-Smirnov tests on a large bank of depth and velocity data to determine if patterns could be confirmed for each type of hydromorphological unit (HMU) across various streamflows. Few of the data sets were statistically similar enough to be combined and the mapping effort could not be simplified based on this investigation.

Neither investigation provided the intended reference for the particular component of river modeling, further emphasizing the complexity in this area of study. However, the information gathered can be used as pioneering steps in future investigations.

## TABLE OF CONTENTS

Page

APPENDICES

# LIST OF TABLES

Table Page

# LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION TO MEASURES USED TO EVALUTE INSTREAM HABITAT, FLOW AND AQUATIC COMMUNITIES

## 1.1 Source Problem: Typical Stressors to Rivers

This thesis investigates a small portion of the complicated and multifaceted subject of evaluating and quantifying the health of rivers and associated watersheds. Most river basins in the northeast are stressed by the effects of development, including increased impervious surfaces, decreased recharge opportunities, water use withdrawals, introduction of non-native species, chemical and organic pollution, and physical alteration such as dams, channelization or bank armoring (Bain et al 1988, Armstrong et al 2001, McKinney 2002, Quinn and Kwak 2003, Roy et al 2005). Diversions, impoundments, and water withdrawals all have the potential to significantly impact the availability of suitable habitat for aquatic communities by affecting the flow regime. Flow regime is defined by the timing, frequency, magnitude, duration, and rate of change in discharge and is a major factor in the quality of habitat in a river (Poff and Allan, 1995). In the Commonwealth of Massachusetts, stressed basins are defined as those where streamflow quantity is significantly reduced or quality is degraded. Of the major Massachusetts river basins for which there is data, 40% of the drainage areas are identified as having medium to high stress[1]. (UMass Extension 2006). As instream habitat and natural flow regimes continue to be altered, the associated aquatic communities change in response, often shifting to a more stress-tolerant assemblage.

Currently, many regulatory standards are only effective for protecting the needs of individual species (usually important game species), or maintaining a low or average flow. It is becoming apparent that if a major goal is to preserve diverse, native fish communities, standards will need to take into account the complexity of natural flow (Poff et al, 1997).

### 1.2 Study Problem:The Complexity of Evaluating and Regulating Rivers

Regulatory and conservation based agencies are continuously searching for an efficient, effective method of analyzing impacts on rivers and their associated watersheds. Previously, physical and chemical measurements such as flow, temperature, turbidity, dissolved oxygen, pH, and other measures of water quality were the most important to assessment (Gordon et al 2004). Many authors now refer to the need to evaluate and then restore the overall "health" of a stream. Gordon et al 2004 state:

> We now speak of 'stream health' and measure it in terms of water quality, habitat availability and suitability, energy sources, hydrology, and the biota themselves.[2]

This includes assessing the status of and attempting to identify the deficiencies in both the aquatic faunal community and the available physical habitat. Multiple models, methods, and techniques have been proposed for assessing physical habitat structure,

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[1] The definition of stress is determined by looking at high and low streamflow statistics and comparing the amount of water lost to the natural streamflow using a hydrologic budget.

[2] Gordon, N.D., T.A. McMahon, B.L. Finlayson, C.J. Gippel, R.J. Nathan. (2004). Stream hydrology: An introduction for ecologists (2nd ed.). West Sussex: John Wiley & Sons Ltd., p.295. The literature does contain some criticism of the term 'health' because it is a subjective term based on values and is difficult to apply quantitatively to a system. (Gordon et al 2004). The use of this term is still valuable since it is easily understandable.

determining critical flow levels, and evaluating biological communities. Some have been widely accepted while others have been developed more recently and continue to build on knowledge from past models (Bain and Stevenson, 1999). Many regulators and scientists agree that the most effective approaches are physical habitat models, those that look at the interaction between organisms and physical attributes, and the availability of habitat under certain conditions. Most also agree that identifying and establishing a “healthy” flow regime is essential, as this factor sets the basis for everything else in the river system (Bain et al, 1988, Poff et al, 1997, Giller and Malmqvist, 1998).

Establishing regulations that determine appropriate flow standards is difficult for many reasons and is a major obstacle to effective protection or restoration of rivers. First, there is a lack of both historical data and examples of rivers in a natural or baseline condition from which to acquire standards. Second, even if successful standards were established, it would be difficult to re-create them in a system because true, natural flow has such variability (Karr 1991, Poff et al, 1997). Third, it is more difficult to control variables in a river than most natural systems during experimentation, and it would take an impractical amount of time to evaluate the effectiveness of standards once they are implemented. Finally, regulators/managers need to successfully balance many interests including water consumption/diversion, recreation, and ecological biodiversity.

## 1.3 Thesis Objectives

The overall objective of this thesis is to standardize or provide references for individual components of river modeling. Rather than examine a model from start to finish, I looked at evaluating individual steps of a particular methodology. This introductory chapter will present further definition of the lotic environment and types of habitat. It will discuss ways to group fish species through the type of habitat used and introduce a technique for identifying and ranking the species that should be found in a natural river community. I will follow with a brief history of the methods and models for establishing flow standards and describe how the model/methodology, MesoHABitat SIMulation (MesoHABSIM) applies. This will provide the appropriate background knowledge for the following thesis chapters which look at individual components and uses of the MesoHABSIM method.

In the second chapter, I will present the Eightmile River case study which describes a specific set of measures we used for evaluating the existing structure and status of the fish community in a relatively free flowing river with an associated rural watershed. The objective of this study was to determine whether the existing stream community would meet or exceed a reference community and possibly provide a baseline reference for physically similar rivers in the area. In the final chapter, I will present an investigation that essentially asks “what’s in a name” to determine whether hydraulic units in a stream can be categorized through depth and velocity characteristics and patterns. The objective of this study was to develop a system that quantifies HMUs in order to reduce the amount of effort required for mapping streams under the

MesoHABSIM method, which could potentially be applied to river evaluation in a broader sense.

### 1.4 Defining Hydraulic Units and Habitat Types

Streams, or the lotic environment, are comprised of a series of segment types or channel units which are typically characterized by changes in velocity, depth, turbulence, substrate, and the shape of the stream bed. The most familiar components include pools, runs, and riffles although numerous studies have identified and characterized further patterns (Bain et al 1988, Lobb and Orth 1991, Aadland 1993, Bisson and Montgomerey 1996). While these studies have wide variation in the names and divisions between the hydraulic types, it is likely that they may actually be investigating similar areas in the streams. By researching these studies, we quickly concluded that Bisson and Montgomery’s (1996) statement remains true: that no one standard for identifying stream segments exists. This is confirmed by Arend (1999) who states that the variation in terms causes confusion when trying to compare studies. Complications also arise when researchers or regulators think of these hydraulic units interchangeably as habitat types. However, Parasiewicz (2001, 2007) uses a set of eleven hydraulic/ hydromorphologic units (HMUs) in combination with additional physical attributes such as shading, woody debris, and other available cover to characterize mesohabitats. The eleven HMUs were modified from the more extensive geomorphic unit classifications proposed by Bisson and Montgomerey (1996), and the condensed classifications used by Dolloff et al (1993). Adjustment of the set also came from an undergraduate honors thesis concluding that several fairly simple visual observations made in the field described fifteen hydraulic patterns or types which classified 90% of stream segments in the study river (Perkins 2002). The final set of eleven includes backwater, cascade, fast run, glide, plunge pool, pool, rapid, riffle, ruffle, run, and sidearm (Parasiewicz 2007).

### 1.4.1 Fish Association with Stream Features

Regardless of the name used, most studies conclude there is a correlation between certain fish species, or even life stages of species, and physical and hydraulic characteristics. Aadland (1993) reported that young of the year fishes were most often found in shallow pools (defined by depth < 60cm and velocity < 30 cm/s), while Lobb and Orth (1991) described channel edges and vegetated areas as nursery habitat. Bain et al (1988) also concurred that small species and size classes were found along slow, shallow pool or riffle habitat at the margins of streams. Bain et al (1988) grouped all slow, shallow habitat and found an association with a fairly diverse complex of small fishes, and noted that fast and/or deep habitats were utilized by larger individuals of several species. Aadland (1993) had a more divided habitat set, defining slow riffles (< 60 cm deep and velocity between 30-59 cm/s), fast riffles (< 60 cm deep and velocity >60 cm/s), raceways (60-149 cm deep and velocity =30 cm/s), medium pools (60-149 cm deep and velocity < 30), and deep pools (=150cm). Specific size classes or species of fish were associated with each one. Lobb and Orth (1991) investigated eleven stream features and found fish densities highest in edge pool, backwaters, snags, edge riffles, and riffles. They also demonstrated specific associations, including smaller and younger fishes along edge habitats and larger individuals in the deeper portions.

Since the connection between fish and hydraulic features is so well documented, it can be inferred that flow alteration would impact the status of a fish community because the presence and abundance of certain hydraulic types is dependent on the flow regime. When flows are high, habitat tends to be fairly homogenous and usually consists of swift, deep runs (Bisson and Montgomery 1996). While this is natural and sustainable during the spring in the northeast, rivers regulated by dams or hydroelectric operations or affected by high connectivity to urbanized areas and run-off will have high flow pulses throughout the year (Poff and Allan1995). Edge habitat is quickly lost to encroachment of deeper, faster flow and its presence is unstable and unreliable as flow recedes (Bain et al 1988). Extended periods of extreme low flow can also severely limit the presence of essential edge and shallow habitat, as well as riffles. Riffles provide areas for spawning and cover as well as production of dissolved oxygen and food sources, i.e. macroinvertebrates for the rest of the stream (Armstrong et al 2001).

#### 1.4.1.1 Classification of Habitat Use Guilds

Fish community studies tend to group species into guilds based on the types of habitat they are observed using, either within a stream or across a landscape. The use of guilds can be on a finer scale such as the studies performed by Aadland et al (1991) and Lobb and Orth (1991) that describe species associations with specific portions of the stream habitat such as edge pool, middle pool, edge channel, shallow pool, deep pool, riffle, raceway, etc. Guilds can also be used at a fairly coarse scale such as the ones described by Armstrong et al (1999), Bain and Meixler (2000), and Quinn and Kwak (2003), which identify strictly riverine fishes versus those species that are habitat generalists. All three studies use the term “fluvial specialists” to describe obligate river species which require a lotic environment for all portions of their life cycle. “Fluvial dependent” (Armstrong et al 2001 and Bain and Meixler 2000) or “fluvial restricted” (Quinn and Kwak 2003) species can survive in a wider range of habitats but need rivers for at least one portion of their life cycle, usually spawning. Therefore, the fish community of a stream should naturally be comprised of a majority of fluvial (specialist and dependent) species. However, as streams are impacted by channel alteration, surrounding development, and altered flow regimes, the community tends towards macrohabitat generalists that can survive in isolated pools or the center of the stream when edges and habitat heterogeneity are lost (Armstrong et al 2001). These generalist species are found in many streams but are also adapted to living in ponded areas and can complete their entire life cycle in other habitat types (Armstrong et al. 2001; Parker et al. 2004). Therefore, when river flow standards are set based on individual target game species such as bass (*Micropterus spp*), they may actually be considered generalists or use rivers facultatively, and are not as sensitive as other species (Aadland 1993). Figure 1.1 shows a comparison of the hypothesized composition of coarse habitat guilds in a natural river community versus the actual Ipswich River community which is impacted by frequent extreme low flow/no flow events (Armstrong et al 2001).

#### 1.4.1.2 Identifying a Reference: The Target Fish Community

While the symptoms of degradation in streams are well documented, there is a lack of information in identifying reference or baseline conditions for streamflow, habitat, and ecological communities. According to hypothetical ecosystem development or succession models, restoration of structure and function in a damaged system happens fairly quickly and linearly. This is not always the case, especially with more complex systems in more highly impacted settings (Zedler and Callaway 1999). However, if a damaged system is going to be restored to any degree, the target system and goals have to be identified and the rate of recovery has to be predicted. (Bradshaw 1984, Zedler and Callaway 1999).

If the goal is to determine the flow regime needed to support a "healthy" fish community, the species and proportions of a natural, reference population need to be identified. Rather than establishing flow based on a single game species, it is important to identify representative species that either dominate the existing community or need a variety of instream habitats to complete their life cycle. If the flow regime supports these species, especially during their most sensitive life stages, it is likely that most other members of the community will be able to persist (Aadland 1993, Poff et al 1997). The Reference Fish Community (RFC) method (Parasiewicz 2007) has been used as a means to quantify or gauge the general level of impairment as well as set goals in some small to medium-sized, northeastern rivers. The RFC is a modification of the Target Fish Community (TFC) concept developed by Bain and Meixler (2000, 2008). Both the TFC and RFC concepts attempt to identify the appropriate fish species and the expected proportions that should be in a less impacted and relatively unaltered version of the system. To establish a TFC or RFC, a number of reference rivers in a desired state (i.e. with low level of impairment) are selected based on their similarity in size, ecoregion, and physical characteristics of the study river. Existing records of fish sample data from these rivers are used to project the composition and a ranking of species in a healthy, reference fish assemblage. The relative abundance/community proportion of each species is projected from its rank using a rank-weighting technique. Bain and Meixler (2008) found that this technique often used in social research, provides results consistent with double logarithmic relations, also known as power laws. The actual fish community of the study river is determined through sampling and is then compared to the reference community in order to identify obvious diversions between the two. Since the fish assemblage present can be expected to change seasonally (Peterson and Rabeni 2001b), the TFC/RFC concept has been successfully applied thus far to the summer adult life phase (Parasiewicz 2007).

The TFC (and RFC) approaches acknowledges that very few true references exist for a river in a completely natural state (Bain and Meixler 2000, 2008). Even if one did exist, it is often physically, practically, and economically impossible to replicate in a modern landscape (Bain and Meixler 2008). Instead, they suggest working with the existing status of the watershed and choosing reference rivers that are in a reasonable, if not pristine, state. Essentially, the objective is to be realistic about the level of recovery that can be achieved in the particular landscape and to select reference rivers that reflect that condition. (Bain and Meixler 2008, Jacobson 2008). Identifying the most expected species in the reference fish community establishes the basis for the biological component of the MesoHABSIM model/approach, as the various species are associated with physical habitat characteristics needed to guide restoration scenarios (Parasiewicz 2007, Jacobson 2008).

## 1.5 Instream Flow Setting Standards and Habitat Modeling

As previously stated, an adequate flow regime is an important factor in preserving habitat for an aquatic community. Several categories of methodologies to assess stream flow regulations or standards exist, each with a specific level of effort and supporting assumptions. Within each methodology are techniques or practices that were created to provide guidance using the respective concept. Each general methodology and technique has its own strengths and weaknesses.

### 1.5.1 Standard Setting Methods

"Standard setting methods" look at historical hydraulic data as well as channel characteristics, but do not directly address habitat availability (Aadland et al 1991). These methods assume that most habitats are protected at a certain flow and are fairly conservative in establishing those limits. The methods are largely based on existing data and calculations and do not require fieldwork (WAPAC 2004). Standard Setting methods include the Tennant method and the Aquatic Base Flow (ABF) method which relies on the average historical data in a region to set a different minimum flow for the spring, the summer and the fall/winter (Gordon et al 2004). The United States Fish and Wildlife Service (USFWS) had developed a New England ABF (NEABF) for this region. The NEABF considers seasonal variability of flow and life history needs of aquatic species, and is usually conservative enough to use in most situations (WAPAC 2004). However, it does require a long history of unregulated gauging data which is not always available. The method is also so general that it doesn't consider specific habitat or special cases, particularly streams that are already highly altered (Aadland 1991). Some

New England states have modified the NEABF to reflect even more localized conditions and to further minimize the weaknesses (WAPAC 2004).

### 1.5.1.1 Mid-range Standard Setting Methods

The “Mid-range” or Hydraulic Rating methods are Standard Setting methods that involve low-intensity field work to gather hydraulic data (Stalnaker 1995, Gordon et al 2004, WAPAC 2004). These methods generally assume the flow required to maintain specified critical habitat will support the remaining stream habitat types. Examples include the R2CROSS method and the Wetted Perimeter method which both consider riffles to be the critical limiting habitat type due to their importance in spawning and food production (macroinvertebrates) for some fishes. However, both of these techniques tend to focus only on low flow periods when riffles are present and both are field intensive in limited areas (Armstrong et al 2001, Gordon et al 2004, WAPAC 2004). It would be questionable whether data could be extrapolated across a river without repeating the process in many locations.

### 1.5.2 Monitoring/Diagnostic Methods

“Monitoring/ diagnostic” methods look at how conditions change over time and under different circumstances (WAPAC 2004). The Range of Variability approach uses Indicators of Hydraulic Alteration (IHA) and statistical analysis to look at the before-and-after effects of a distinct change or human alteration on the same river system (Gordon et al 2004, WAPAC 2004). It also takes natural flow variability into account (Armstrong et al 2001). This method lends clear evidence towards the effects of future proposals for dam installation, dam removal, water withdrawal or other alterations, but requires a long record of gauging data before and after the specified change (WAPAC 2004).

### 1.5.3 Incremental Methods

"Incremental methods" such as the Instream Flow Incremental Methodology (IFIM) developed by the USFWS, deal directly with the habitat available for target species during specific flows (Aadland 1993, Stalnaker 1995, Bovee et al 1998, Gordon et al 2004). Gordon et al (2004) state that IFIM is "the most scientifically and legally defensible method" in many portions of the United States.[3] It is most often used in evaluation of larger streams while the Mid-Range/Hydraulic Rating methods are more typical for small streams (Gordon et al 2004). The Physical Habitat Simulation model (PHABSIM) is a computer model within the IFIM methodology that can predict the result of a particular flow on the amount of useable habitat for a particular species, often a managed game species as previously described (Aadland et al 1991, Aadland 1993, Parasiewicz 2008). It was created to make recommendations for regulating water withdrawals and other stream channel modifications. It was widely recognized and applied across the country (Bovee et al 1998). However, PHABSIM had been developed for habitat modeling at the micro-scale and is therefore very work intensive when used correctly for surveying an entire river. It has commonly been extrapolated (against its original intent) to make predictions for entire river systems, without doing the work required to get sufficient results. Peterson and Rabeni (2001a) note that extrapolating micro-scale features is a poor predictor of fish assemblage.

#### 1.5.3.1. MesoHABSIM

Standards or techniques based on IFIM are typically considered Instream Habitat Models as they express the relationship between aquatic species and the available habitat. Instream Habitat Models therefore have both a physical/hydraulic model that describes the spatial arrangement of habitat attributes and a biological/ecological model that identifies a pattern of use by aquatic species (Lamouroux et al 1998, Parasiewicz 2007). The MesoHABSIM model used by the Northeast Instream Habitat Program (NEIHP) builds upon the concept of PHABSIM, providing further modification to the method (Parasiewicz 2001). In contrast to the micro-scale mapping used in PHABSIM, MesoHABSIM involves mapping larger areas of the river and gathering habitat information at a meso-scale, which makes it more appropriate to use at a watershed or river level. MesoHABSIM also uses multivariate habitat suitability criteria in contrast to the univariate habitat suitability criteria used in PHABSIM.

The entire study river is initially mapped for proportions of HMUs (previously described) and other characteristics important to fishes. Sites are selected throughout the watershed in an effort to capture representative features (Parasiewicz 2007). The sites are fully mapped into HMUs, and habitat characteristics including depth, velocity, substrate,

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[3] Gordon, N.D., T.A. McMahon, B.L. Finlayson, C.J. Gippel, R.J. Nathan. (2004). Stream hydrology: An introduction for ecologists (2nd ed.). West Sussex: John Wiley &

and cover are recorded. The same sites are mapped several times during varying low flows over a summer season in order to see the change in habitat type availability during incremental changes in flow (Parasiewicz 2007). Sites are then sampled for fish during electroshock surveys. Additional physical characteristics are recorded at each fish grid so the data can be analyzed for fish/habitat associations. The results from the RFC/TFC investigation determines which species will be the focus of the model. A regression model is used to determine what are suitable and optimal habitat characteristics for these target species and this information is applied to the mapped sites to calculate the amount of useable habitat for one or more species in the sites (Parasiewicz 2007).

Even though MesoHABSIM requires less effort to get information about larger portions of a river than methods that map microhabitat or specific features, it is still fairly work intensive (Parasiewicz 2007). The final chapter in this thesis will use data from multiple rivers to determine if MesoHABSIM can be further improved by better categorizing HMUs and developing standard templates. Depth and velocity measurements will be analyzed to find patterns and identify reasonable combinations of hydraulic types. The overall goal is to develop a simpler yet concrete process for modeling and eventually restoring streams.

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Sons Ltd., p.295.

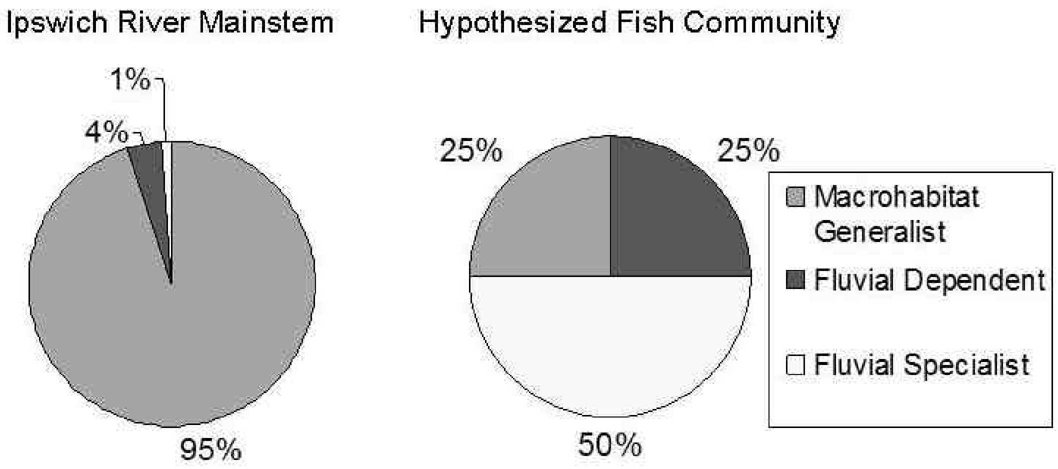

**Figure 1.1: The charts compare the hypothesized river fish community composition to the actual community of the Ipswich River which is impacted by high water withdrawal and extreme low flow events (Armstrong et al 2001).**

# CHAPTER 2

# INVESTIGATING A POTENTIAL BENCHMARK IN THE NORTHEAST: A CASE STUDY OF THE EIGHTMILE RIVER

## 2.1 Introduction

While the northeast is considered to be fairly “water-rich”, these states share the common management goal of balancing demands for drinking water, development, and industrial uses with the ecological needs of aquatic communities. River systems and watersheds in New England are facing similar pressures and patterns of anthropogenic development and alteration. Trends include increased impervious surfaces, decreased recharge opportunities, interbasin transfers and other withdrawals of water, chemical and organic pollution, and physical alteration (McKinney 2002; Quinn and Kwak 2003; Walsh et al. 2005). The effects are so uniform that the term “urban stream syndrome” has been used to describe the nutrient inputs, changes to hydrology, increased sediment loads, warming water temperatures, and erosion and reshaping of the channel that occur in streams with developed catchments (Meyer et al 2005 and Walsh et al 2005). This may lead to a future, long-term crisis as some streams regularly experience extreme seasonal low-flow or no-flow conditions as a result of water withdrawals. Conversely, severe flooding is also becoming more prevalent as rivers have been dammed, channelized, armored, and cut off from their floodplain. Instream fauna are especially vulnerable to these stressors and aquatic communities have changed in response, often reflecting the level of impairment in a system. Fausch et al (2002) describes a considerable overall decline in riverine fish biodiversity and relative abundance in the last 50 years.

The continued alteration of existing habitat as well as introduction of non-native species throughout the United States leads to homogenization of the fish population and an aquatic community consisting of fish and macroinvertebrate species that can tolerate stress (Rahel 2000 and Paul and Meyer 2001). For instance, the community may reflect a transition from cold or coolwater species to those that can withstand elevated water temperatures, or a transition from pollution sensitive species to pollution tolerant species (Kemp and Spotila 1997, Roy et al. 2005, Walsh et al. 2005). In addition, the composition of a community may shift from species which require strictly riverine or fluvial habitat for all or part of their lifecycle to those known as generalists which can survive in multiple habitat types and are not as affected when habitat variety is lost (Bain and Meixler, 2000; Armstrong et al., 2001; and Quinn and Kwak, 2003). Habitat use, pollution tolerance, and water temperature can all be used to establish fairly coarse-scale guilds to which species can be assigned. Many fish community studies tend to group species into these types of guilds as they are easy to understand and provide a larger picture of the system than looking at individual species alone. Since shifts in species composition from more sensitive/river dependent guilds to less sensitive/generalist guilds are considered symptoms of stream degradation, these shifts also have the potential to be used as a rough quantification of the extent a stream has been altered. This is a similar idea to Karr's (1991) Indices of Biological Integrity (IBI) that use multiple characteristics of a fish community to identify the level of stream degradation. Biological monitoring has also been widely applied to benthic macroinvertebrates (Karr 1991, Resh et al 1996).

If the eventual goal is to restore or improve a damaged community, a target community or preferred state has to be identified so that the deviation between the two can be evaluated (Bradshaw 1984). However, there is an overall lack of information in identifying reference or baseline conditions for aquatic ecological communities as it is unlikely to find a river in a completely natural state (Bain and Meixler 2000). In addition, Bain and Meixler (2000, 2008) acknowledge that it would be impractical and likely impossible to replicate a true reference community in a modern landscape due to the introduction of non-native but desired game species, and the highly developed condition of some watersheds. Instead, they propose measures known as the Target Fish Community (TFC) concept for providing a reasonable basis or goal for restoration with an “alternative sustainable aquatic community in a human-dominated landscape” (Bain and Meixler 2008). The TFC concept and our modification, the Reference Fish Community (RFC) concept, attempt to predict the types and expected proportions of fish species that would have comprised the aquatic community if the system had limited human alteration. This is done through the use of fish capture data from the best available, physically similar rivers that are considered to have a low level of impact (e.g. dams, water withdrawal), and are therefore in a desired state. Noticeable departures between the expected and actual communities can be used to identify problems or deficiencies in the study river. This information can be evaluated through shifts in individual species or shifts between the various guilds, as previously described.

Occasionally, there are instances where the study river may actually have faired better than others based on the surrounding land use, and the existing community may remain close enough to a natural or desired condition to be considered the benchmark or reference for the alternative but sustainable goal proposed by the TFC and RFC methods. It is especially important to detect and protect these rivers which are invaluable for research and can be used to provide restoration standards. One such opportunity to identify a potential benchmark was presented in the study of the Eightmile River. In 2001, Congress authorized a Wild and Scenic River study for the Eightmile River and its major tributary, the East Branch. The Eightmile watershed was nominated due to a concerted effort by local citizens and groups who wanted to see this resource recognized and further protected. The resulting study is managed by the Eightmile River Study Committee and supported by the National Park Service (NPS). The Northeast Instream Habitat Program (NEIHP) was contracted with the overall goal to use coarse scale reconnaissance to identify and characterize the status of the existing faunal community and determine which habitat features affect it the most. We used an established protocol as part of a physical habitat model and approach called MesoHABSIM (Parasiewicz 2001, Parasiewicz 2007) that provides an integrative physical and biological analysis of the river.

This paper will only be presenting select methods and results from our study, specifically those that identify the reference fish community of the Eightmile River and demonstrate various similarity indices that were used to analyze the difference between actual and expected data. We hypothesized that the existing fish community of this seemingly intact river, would be similar to or exceed its projected RFC in terms of individual species and proportion as well as its allocation into habitat, pollution and thermal guilds. Additional information and findings of the study are presented in extensive detail in a large, summary report completed in 2005 and available online.

### 2.1.1 Study Area

The Eightmile River watershed is located in a rural portion of southeastern Connecticut and remains largely undeveloped, even though adjacent areas are densely populated. In the study area, the Eightmile River is a second to fourth order river with approximately 80-90% forest cover. It is rare for a watershed in coastal Connecticut to remain so highly forested, with relatively few point and non-point pollutant discharge sources. At the turn of the twentieth century, a widespread, agricultural lifestyle had resulted in the large scale absence of forest cover in this region. Since then, farming has been largely abandoned and the forest has been allowed to re-establish for decades. Although the area has been settled for hundreds of years, low population density, large parcels of privately held land, and a conscious effort to prevent sprawl have kept the watershed in this condition. The lack of industrial development and associated water withdrawal, as well as a low number of major dams, means a consistent, more natural flow regime for the river and the associated aquatic community. Its baseline condition may serve as a target for other rivers in the state.

The watershed has high water quality and unique geology that includes numerous deposits of sand and gravel, which tend to export clean, cold groundwater to the river. These types of stream reaches typically support many fish species due to high water quality, low temperature, and good bedding sites for spawning. The watershed also contains a high diversity of coarse, physical habitat types as the river runs from higher gradient, boulder-filled, tributary streams to a lower elevation, tidally influenced, brackish cove.

## 2.2 Methods

### 2.2.1 Reference Fish Community

Based on the difference in relief and stream orders between the Eightmile River above and below its confluence with the East Branch, we determined it would be necessary to develop two separate RFCs with separate sets of reference rivers. This decision is supported by observations of longitudinal zoning or changes in fish communities along the stream corridor and continuum described in the literature. The differences between the ecological communities of lower order streams and higher order streams can be substantial (Vannote 1980; Ward and Stanford 1983; Creed 2006). The first RFC was created for the East Branch, the Upper Branch of the Eightmile, and the tributary Beaver Brook, which range in stream order from second to third. The second RFC was developed for the Eightmile Mainstem below its confluence with the East Branch where it becomes a fourth order stream. Figure 2.1 provides a relief map of the Eightmile watershed.

Using Bain and Meixler's (2000) TFC protocol, we acquired the list of potential reference rivers and associated fish sampling data from the Connecticut Department of Environmental Protection (DEP) Inland Fisheries Division. These rivers were from the same or similar major river basin as the study river and were as free from anthropogenic impact or influence as possible. Based on DEP's recommendation, all sites to the west of the Connecticut River were eliminated from the list due to the difference between native fauna in the eastern and western portions of the state. We then used the draft Stream and Lake Classification GIS layers generated by The Nature Conservancy (TNC) to evaluate the stream order, drainage area at the sampling locations, the percent of calcareous geologic formations, gradient, and level III ecoregion of the rivers. Ranges which would be appropriate for the Eightmile River were specified for each of these parameters. All rivers that did not fall into the acceptable ranges were removed through a process of elimination. As per the method described by Kearns et. al. (2005), any rivers that were identified by DEP as significantly impacted by human development, had poor data, or had unique geology or fauna were also eliminated from the list. A list of the reference rivers used for each RFC is provided in Table 2.1.

In keeping with the methods of Bain and Meixler (2000), the total number of adult fish at each of the reference river samples were then summed. The total of each species was divided by the respective sum, yielding a proportion of the total catch per site. The proportions were summed across all rivers for each species. After consultation with the Inland Fisheries Division, any species found outside the ecological range or historical catch of the Eightmile River were removed from the list. The remaining species were then ranked, with the species having the greatest sum ranked as “1”. All non-native or introduced species were then removed from further calculation. The reciprocal of each species rank (1/rank) was taken and the reciprocals were summed. The reciprocal rank of any given species was divided by the sum of the reciprocal ranks to yield that species’ expected proportion in the reference community for the Eightmile. The rank weighting technique is used due to the log-log relation or power law between the species rank and proportion, which is similar to patterns seen in other types of studies (Bain and Meixler 2008).

Within the NEIHP/MesoHABSIM framework (Parasiewicz 2007), the TFC is eventually used to derive the habitat structure of a river that would support a healthy fish population. Bringing this concept one step further, we modified the TFC into the RFC by taking into account native species that were already known to be missing or underrepresented, because of the lack of true historical references. Instead of the fish collection data, we relied on the expertise of the Inland Fisheries Division to estimate abundance rankings for American eel (*Anguilla rostrata*), Atlantic salmon (*Salmo salar*) and brook trout (*Salvelinus fontinalis*). Using extensive fish data from the Division's database, (347 and 891 sample sites for Atlantic salmon and American eel respectively), average densities for these species were computed in third and fourth order rivers in the state (Gephard and Hagstrom, unpubl. data). To simulate the proportion of these under-represented species in the fish samples in reference rivers, we replaced the actual American eel and Atlantic salmon numbers with the proportion of the provided means relative to the total fish abundance in the sample. If the actual count/proportion of these species was higher in the reference river data, the simulated number was not used. Subsequently, we calculated the rank and expected proportions of these species in the RFC. Finally, to establish the proportion of brook trout, we asked these experts to estimate a historical or desired rank of this species in each reference river's community. The rank estimates were used to compute expected proportions of the species in the community.

### 2.2.2. Field Sampling and Temperature

Collecting data on the actual fish community in the Eightmile River began with delineating the watershed in a stratified approach, in order to identify representative sites. With the help of local experts, we identified twenty-two locations that represented varying physical circumstances including low order, high gradient headwaters and tributaries, various confluences, and the higher order, lower gradient main channel. The locations were aggregated into 11 sites of specific character. Three were located on the Upper Branch, three along the East Branch, one was within the Beaver Brook tributary, and four were located at or below the confluence on the Mainstem of the Eightmile. The hydromorphology or distribution of hydraulic units (e.g. runs, riffles, pools) as well as physical attributes (e.g. cover, substrate, woody debris) were mapped in each site.

Electro-fishing surveys were conducted in the summer of 2004 using a grid technique developed by Bain et al. (1985). Grids were placed in various locations throughout the survey area in an attempt to capture the different habitat types and hydraulic units in an approximately proportionate representation of their abundance. Figure 2.2 provides a photograph of a typical grid set up in the river. Physical characteristics were also recorded within the grids in an attempt to determine associations between fish species densities and physical habitat for the larger study. Each grid consists of two, 6-meter (m) long cables running parallel to the stream channel and each other. The cables are attached to a PVC pipe at each end of the grid in order to maintain a width of 1-meter (m). Grids were pre-positioned in groups, and allowed to settle for at least 15 to 20 minutes prior to sampling. After settling, the grids were exposed to an electric pulse and investigators gathered the stunned fish with dipnets. Fish were identified by species and measured prior to their release. Young-of–the-year individuals were separately noted but were not included in the analysis if they could not be positively identified. Since the fish data used to develop the RFC did not include any fish smaller than 30mm, we attempted to make our data as similar as possible for appropriate comparison.

As part of the study, we also placed hourly-recording, temperature probes into the river in predetermined locations throughout the watershed. Fourteen probes were initially submerged on April 22, 2004. All but one of the probes were recovered and downloaded in place in early July 2004. The remaining thirteen probes were reset and continued to collect data until September 21, 2004 when they were removed from the watershed. In order to get full representation of the watershed, three probes were placed in headwater streams to the Upper Branch of the Eightmile and the East Branch, three probes were placed directly in the Upper Branch of the Eightmile, four probes were placed in the East Branch and the remaining four were placed in the Mainstem of the Eightmile. The locations were not coordinated exactly with the sampling sites although some did overlap.

### 2.2.3. Existing Fish Community

The field survey results of the actual Eightmile fish community are considered to be a “snapshot” of the river in time, while the expected proportions in the RFC are calculated as a multi-year, power law-based, projection. In order to have a viable comparison, we altered Bain and Meixler’s original TFC methods by determining that the field survey results must also be displayed as a rank weighting or power law-based projection. Therefore, the same calculations used to determine the RFC were applied to the survey results, transferring the observed relative abundances to projected proportions across sites instead of reference rivers. In contrast to the RFC, this generalized existing fish community or XFC, also includes introduced species. The species and expected proportions of the reference and existing communities were then compared using a percent affinity model as described by Novak and Bode (1992). The percentage similarity is calculated by $100- 0.5 ? |a-b|$ where a and b equal the percentage or proportion of the species in each of the respective communities.

### 2.2.4. Additional Similarity Indices

In addition to the percent affinity index, we also analyzed the species data using several other indices, including Jaccard's index, the Sorenson's Quotient of Similarity (often used with the Jaccard index), and the Bray-Curtis index of similarity for abundance used by Brown and Veneman (2001) in a study comparing wetland plant species composition between replication and natural sites. Jaccard's index takes the total number of species common to both communities (j) divided by the sum of common species and species specific to one community (a) or the other (b); ex. $j \div (a+b+j)$. The Bray-Curtis index or distance formula, calculated by $? |n_{ix}-n_{iy}| \div (n_{ix}+n_{iy})$ where n is the proportion of each of i species in the communities x (RFC) and y (XFC). The closer the index result is to zero, the closer the samples or communities are to each other. The Sorenson's Quotient of Similarity takes the number of species common to both communities (j) multiplied by 2 and divided by the sum of total species in each community; (m, n); ex. 2j ÷ (m+n).

### 2.2.5. Identification of Guilds: Habitat, Temperature and Pollution

As a final evaluation of the existing community, all fish species were assigned to a fluvial habitat guild (fluvial specialist, fluvial dependent or macrohabitat generalist), a pollution tolerance guild (pollution intolerant, moderately tolerant, or tolerant), and a thermal guild (coldwater, coolwater, or warmwater), based on available life history data. Bain and Meixler (2000) also promoted using habitat use and pollution tolerant guilds to describe the community, and cited a number of studies they used for cataloging the species. We used the assignments provided by Bain and Meixler where applicable and corroborated and supplemented their information through additional research. A list of fish species common to our study and their habitat, pollution, and thermal guild assignments are provided in Table 2.2. Following assignment to guilds, we totaled the proportions of the species within each category and compared the composition of the RFC to the XFC.

For further clarification of the habitat guild, fluvial specialists are described as obligate river species which require a lotic environment for all portions of their life cycle. Fluvial dependent species can survive in a wider range of habitats, but need rivers for at least one portion of their life cycle; usually spawning (Armstrong et al. 2001; Bain and Meixler 2000). Generalist species are found in many streams but are also adapted to living in ponded areas and can complete their entire life cycle in other habitat types (Armstrong et al. 2001; Parker et al. 2004).

## 2.3. Results

### 2.3.1. Community Composition

The RFC for the East Branch and Upper Branch of the Eightmile consists of an assemblage of 18 species. The top seven most abundantly expected species include American eel, Atlantic salmon, blacknose dace (*Rhinichthys atratulus*), longnose dace, white sucker (*Catostomus commersoni*), fallfish (*Semotilus corporalis*), and tessellated darter (*Etheostoma olmstedi*). The simulated counts of American eel and American salmon places these species in the two most dominant or expected positions. In comparison, the XFC for the East Branch and Upper Branch of the Eightmile consists of 19 species with 16 native and 3 introduced. Fallfish were the most dominant, followed by blacknose dace, common shiner (*Luxilus cornutus*), white sucker, American eel, tessellated darter, and pumpkinseed (*Lepomis gibbosus*). Fallfish were among the top seven most expected species in both communities but they were over five times more common in the XFC than predicted.  In contrast, American eel were almost five times more common in the simulated amounts predicted in the RFC than they were in the XFC. Simulated Atlantic salmon numbers were 7.5 times higher in the RFC than in the XFC and this species was not listed among the top seven most expected. Figure 2.3 presents the charts of the species and proportions calculated in the RFC and XFC for the upper assemblage.

The RFC for the Mainstem of the Eightmile consists of an assemblage of 17 species. The seven species expected to be most abundant are white sucker, common shiner, fallfish, American eel, tessellated darter, blacknose dace, and Atlantic salmon. Again, these proportions are also based on the American eel and Atlantic salmon simulations, but for typical fourth order streams. In comparison, the projected XFC for the Eightmile Mainstem, consists of 19 native species and 4 introduced species. The seven most dominant species are now led by the tessellated darter, followed by redbreast sunfish (*Lepomis auritus*), American eel, common shiner, spottail shiner (*Notropis hudsonius*), white sucker and yellow perch (*Perca flavescens*). Tesselated darter were among the top seven most expected species in both communities but they were 4.5 times more common in the XFC than predicted. Spottail shiner were not represented in the RFC at all but were among the top seven species in the XFC.  In contrast, white sucker were almost six times more common in the amounts predicted in the RFC than they were in the XFC. Fallfish were also five times higher in the RFC than in the XFC and this species was not listed among the top seven most expected. Figure 2.4 presents the charts of the species and proportions calculated in the RFC and XFC for the lower assemblage.

### 2.3.2. Similarity Indices

Using the percent affinity model described by Novak and Bode (1992), the similarity between the RFC and XFC species assemblages of the East and Upper Branches of the Eightmile is 53%. The Jaccard index, essentially comparing species shared between the two communities versus total species represented, was 0.68. The

Sorenson Quotient was 0.81 and the Bray-Curtis index or distance was 0.47. In comparing the RFC and XFC assemblages of the lower Eightmile Mainstem, the percent affinity is 50%. The Jaccard index was 0.74, the Sorenson Quotient was 0.85 and the Bray-Curtis index was 0.48.

### 2.3.3. Fluvial Habitat Guild

The total proportion of fluvial species (specialist and dependent) in the East Branch and Upper Branch of the Eightmile XFC is 79% in comparison to the 86% projected for the RFC. A slight (7%) increase in the total proportion of macrohabitat generalist species occurred in the XFC. However, out of the total proportion of species identified as fluvial, there was a 10% increase in fluvial specialists in the XFC. This indicates there is a higher proportion of species that rely solely on riverine habitat to complete their life cycle, than the proportion predicted by the RFC.

The total proportion of fluvial species in the XFC of the Eightmile Mainstem is 60% in comparison to the 84% projected for the RFC. While the proportion of fluvial dependent species in the XFC (22%) was less than half of what was expected in the RFC (55%), there was also an almost 10% increase in fluvial specialists. The proportion of macrohabitat generalists in the XFC more than doubled what was expected in the RFC, from 16% to 40%. This indicates that while the number of strictly riverine fish was higher in the Eightmile XFC, there was also an obvious shift towards generalist species. Comparison of the proportions of fluvial habitat guilds in the RFC and XFC for both the upper and lower river assemblages are presented in Figure 2.5.

Overall, macrohabitat generalists tend to be more prominent in the Mainstem than the Upper Eightmile community. This is generally expected, as the Mainstem is larger, slower, and deeper on average than the Upper Branch and East Branch. However, the fauna of the Mainstem XFC are shifted towards macrohabitat generalist species in comparison to the projected RFC by approximately 24%, while we saw only a 7% reduction in the combined proportion of fluvial specialist and fluvial dependent species projected in the Upper Eightmile.

### 2.3.4. Pollution Tolerance Guild

The RFC of the East Branch and Upper Branch of the Eightmile is comprised of over 50% species categorized as pollution tolerant. The XFC however, is made up of 61% moderately tolerant species. While the proportion of pollution intolerant species has decreased in the XFC by 11% in comparison to the RFC, the overall composition of species requiring lower pollution levels is higher in the upper Eightmile than what was projected in the reference by almost 20%.

Similar to the RFC of the Upper Eightmile, almost 50% of the RFC for the Mainstem consists of species categorized as pollution tolerant. In comparison, the XFC consists of 23% of pollution tolerant species and has 73% moderately tolerant species. The proportion of pollution intolerant species has decreased in the XFC by only 2% in comparison to the RFC. The total proportion of species requiring generally lower pollution levels is higher in the Eightmile Mainstem XFC by almost 25%. Comparison of the proportions of the pollution tolerance guilds in the RFC and XFC for both the upper and lower river assemblages are presented in Figure 2.6.

### 2.3.5. Thermal Regime Guild

When analyzing the thermal regime, both the XFC and RFC of the East Branch and Upper Branch of the Eightmile are comprised of over 70% of species that are characterized as coolwater species. The composition of the communities are very similar but there was an 11% reduction in the proportion of coldwater species in the XFC. This indicates there is an overall increase in species that tolerate warmer water temperatures in the upper Eightmile.

In looking at the Mainstem of the Eightmile , the largest difference between the two communities is a 16% reduction in coolwater species and an 18% increase in warmwater species in the XFC. Both the RFC and XFC still consist of a majority of coolwater species with 82% and 66% respectively, but there appears to be an observable shift towards warmer temperatures in the lower Eightmile. The expected proportion of coldwater species was less than 10% in both the RFC and XFC. Figure 2.7 presents a comparison of the proportions of the thermal guilds in the RFC and XFC for both the upper and lower river assemblages.

### 2.3.6. Water Temperature

As stated, temperatures were measured by hourly recorders throughout the watershed. Figure 2.8 presents a map of the watershed with the location of the recorders in relation to the fishing sites. The maximum temperature recorded in the East Branch was approximately 30ºC and the Eightmile River reached approximately 29.5 ºC. The average maximum temperature in both the Eightmile and the East Branch was 25.5-26 ºC. The higher temperature ranges did not last for extended phases and mean temperatures over the entire recording period were closer to 18.5-19 ºC. Table 2.3 provides the average and maximum temperature recorded at each probe.

## 2.4. Discussion

When compared to other regional rivers surveyed by NEIHP, (i.e. the Pomperaug or the Fenton River), the Eightmile river system has a diverse community with high species richness, but moderate relative fish densities or abundances. Introduced species make up less than 10% of the existing fish community and based on analysis presented in the larger study, there is a good recruitment for the majority of common fish species. However, the existing fish community corresponds to the projected reference community only roughly, and some lead species such as longnose dace, Atlantic salmon and American eel in the Upper Eightmile and white sucker and common shiner in the Mainstem, are present in abundances lower than expected. On the other hand, the Upper Eightmile existing community has higher than expected proportions of fallfish and blacknose dace and the Mainstem supports a high density of tessellated darter and redbreast sunfish.

The results of the percent affinity index and the Bray-Curtis distance between the RFC and XFC in both of the river system assemblages appear to concur. The closer the percent affinity index is to 100% and the closer the Bray-Curtis distance is to zero, the more similar the communities are. Both the Upper Eightmile and Mainstem RFC and XFC are essentially in the 50% range with the results of both indices leaning slightly towards being more similar. The original affinity index results from Novak and Bode’s (1992) study of aquatic macro-invertebrate communities indicated that pristine locations had up to 86% affinity to the model assemblage. It was determined that non-impacted or unpolluted sites were therefore =65% similar and those between 50-64% were considered slightly impacted. If these ranges could be applied to our fish community data, both the upper and lower Eightmile would fall in the category of slightly impacted. However, it is unclear whether this is an appropriate comparison. The Jaccard index and Sorenson quotient do not appear to be as valuable for our purposes as they focus on shared types of species in the communities. However, the Sorenson quotient was over 80% for both the upper and lower river communities, indicating the RFC and XFC in both cases have a similar list of species, even if the rank and proportions are varied.

The data lends itself to numerous hypotheses and potential types of evaluation, and no one theory can explain the results. However, when we look at the results in terms of guild composition and using information from our larger study with methods that are not fully described in this article, we can speculate on several causes. For deviations in fluvial habitat, we suspect a lack of woody debris in a still-recovering system. We also acknowledged possible deviations from target populations on a regional scale. When evaluating pollution, the Eightmile River appears to support a fish community that is more intolerant of poor water quality than what was predicted. We are assuming the high water quality in the watershed supports our original hypothesis of the Eightmile River meeting or exceeding its RFC projections in this category. For shifts in thermal guilds, we were able to confirm elevated temperatures in the watershed and provide potential causes.

### 2.4.1. Fluvial Habitat

#### 2.4.1.1. Fluvial Habitat - Structure

In comparison to the reference community developed, we see a small (upper Eighmile) to moderate (lower Eightmile) reduction in the total proportion of fluvial specialist and fluvial dependent species, as well as moderate affinity indices results in terms of individual species. This suggests a shift in the community composition between and within the macro-habitat use guilds. When comparing habitat guild results with other northeastern rivers, we find that only 5% (mainstem) and 20% (tributaries) of the sampled community of the highly impacted Ipswich River consisted of fluvial species (Armstrong et al 2001). The Quinebaug River, determined to be somewhat impacted by human use, had a target projection of 82% fluvial species but actually had only 63% fluvial composition. Finally, the existing fish assemblage of the more natural, free-flowing Lamprey River was comprised of 58% fluvial species while the target was 70% (Legros draft 2007). This indicates that the community composition of the upper Eightmile system is in even better standings than other wild and scenic designated rivers (i.e., the Lamprey), but the Mainstem appears to be similar to most study streams, including those considered moderately impacted streams (i.e., the Quinebaug).

The lower than expected proportion of brook trout and longnose dace in the upper Eightmile XFC could be attributed to a lack of structures (e.g. boulders or large woody debris) that create flow concentration or variety. The longnose dace is a fluvial species often associated with typical trout habitat and prefers fast-flowing, riffle habitat, usually in the center of the channel (Mullen and Burton 1995; Steiner 2000). The higher than expected ratio of blacknose dace tends to correlate this observation as this species specializes in shallow margins and slower velocity areas of riffles, as well as some fluvial pools. (Mullen and Burton 1995; Steiner 2000). Regular tree fall of large individuals in higher gradient streams creates small, permeable, natural dams, changes velocity and flow patterns, and leads to the habitat diversity and increased pool/riffle complexes essential to trout and other fluvial species (Flebbe and Dolloff 1995; Neumann and Wildman 2002). In order to be effective at altering channel hydraulics and increasing habitat heterogeneity, the individuals must be large enough to lodge in the channel without being removed by the next significant flood event. Flebbe and Dolloff (1995) found trout to always be associated with sampled habitat units that contained abundant large woody debris and noted increased trout density in streams with higher amounts of this feature. In our larger study, only three of the eleven sites had higher than 20% coverage of abundant woody debris, but it was mostly small in size with few large trees or logs noted.

The lack of woody debris in a watershed that is so heavily forested was surprising until we acknowledged the fact that the surrounding area and river still carries the scars of centuries of intensive agricultural use. This is confirmed through historical accounts of land use as well as direct observation of anastomosed channels, which are potentially created in lower velocity areas by sedimentation resulting from large-scale deforestation. Despite reforestation of the majority of the watershed, this area still consists of relatively young (80-100 yrs), second-growth forest that is typical of the previously farmed or logged New England landscape (Neumann and Wildman 2002).

Flebbe and Dolloff (1995) compared trout density and abundance in streams draining old growth forests with those located in previously cleared second growth forests. All sample sites were in areas managed as wilderness. They found a much higher density of abundant large woody debris and associated trout biomass in the old growth forest stream. A younger forest will not have trees or debris of significant size naturally falling into the stream and contributing to structure the way a mature forest will.

#### 2.4.1.2. Fluvial Habitat - Regional Declines and Deviations

Another factor in the difference between the RFC and XFC was that the simulated numbers put American eel and Atlantic salmon as the top two most expected species in the upper Eightmile RFC. However, the projected proportions for both species were multiple times higher than what was seen in the XFC. Both are considered fluvial species for our purposes and their relative absence would contribute to the difference in the fluvial guild comparison between the RFC and XFC. For these diadromous species, the deviation between the proposed and actual presence in the community could be attributed to limited migration passage and general regional decline in populations created by numerous dams on the rivers along the East Coast, which detract from the recovery efforts of Atlantic salmon. American eels have been noted by many sources to be in serious decline and the Atlantic States Marine Fisheries Commission has recommended the U.S. Fish and Wildlife Service review the Atlantic stock as a species of concern and consideration for the federal Endangered Species List (Haro et al 2000, Nedeau 2005). The difference between reference and existing expected proportions of these species is also further intensified by the efforts to simulate a more accurate historical presence. The Eightmile study was the first to compare the existing fish community to the modified reference fish community with the simulated diadromous and trout data, so it is also unclear whether an approximately 50% affinity actually reflects the moderate deviation it appears to. The same comparison would have to be performed for each of the reference rivers in order to ascertain typical range of affinity. It is also important to note that the Eightmile Mainstem XFC had higher abundance of eel and salmon than the reference rivers, prior to replacement with the simulated numbers. Despite these questions, it does make sense that the diadromous American eel and Atlantic salmon should be the principal components in the Eightmile community due to the close proximity of the river to the ocean.

### 2.4.2. Pollution Tolerance

In both the upper and lower XFCs, there was a noticeable decline in pollution tolerant species and an increase in moderately tolerant species from the RFC. In the upper XFC, there was also a decline in pollution intolerant species. Kemp and Spotila (1997) stated that salmonids, longnose dace (*Rhinichthys cataractae),* and darters (Percidae) are known to be less tolerant of pollution while some sunfish (Centrarchidae) and creek chub (*Semotilus atromaculatus)* are more tolerant. The relative lack in the pollution intolerant Atlantic salmon and brook trout in the upper XFC likely contribute to the loss in this guild category. However the American eel is considered tolerant of pollution and the relative lack of this species in the XFC, and “replacement” by the moderately tolerant fallfish in the most dominant spot also reflects the movement to moderately tolerant species. In the lower XFC, the moderately tolerant tessellated darter and redbreast sunfish “replace” the pollution tolerant white sucker as the most dominant species.

While these transitions are likely coincidental and better explained through the changes in temperature or habitat, this overall increase in species less tolerant of pollution may also be attributed to the high water quality of the Eightmile River. While we did not perform water chemistry sampling during our study, we can generalize on the water quality based on existing classifications in the watershed. According to the State of Connecticut’s Water Quality Standards and Classification (General Statute 22a-426), almost all of the tributaries in the watershed and the Upper Branch are considered Class A (high quality, potential drinking water supply) waters while the East Branch and Mainstem are B/A or B/AA. A small portion of the East Branch is considered Class B, an acceptable state but not considered a drinking water supply. Over 99% of the groundwater in the watershed is classified as GA, high quality groundwater that can be used as drinking water without further treatment (Albietz & Pokhrel 2004). The surficial geology of the Eightmile Watershed consists of thick deposits of glacial till with areas of sand and gravel found in various locations along the river valleys. This results in increased filtration and direct connection between the surface water and the high quality groundwater.

### 2.4.3. Temperature

Elevated water temperature seems to be a major factor in the variation of the Eightmile River community from the projected reference, especially when looking at the almost 20% increase of warmwater species (including redbreast sunfish) in the

Mainstem and the 11% reduction of coldwater species (including Atlantic salmon) in the Upper Eightmile. Since the composition of the XFC of both assemblages is shifted towards warmer temperature tolerant species than predicted in the RFC, we concluded that the niches usually occupied by cold water species, such as salmonids and longnose dace, are filled by cool water species, such as fallfish, tessellated darters, and redbreast sunfish. Brook trout tend to have a preferred water temperature around 15 ºC (59 ºF), with a critical upper limit of 20-29 ºC (68-84ºF). Coolwater species such as fallfish, have a preferred temperature range of 18-24 ºC (65-75 ºF) with critical upper temperatures of 28-32 ºC or (82-89 ºF), while the upper range for some species of sunfish are temperatures as high as 25-38 ºC (77-100 ºF) (Elliott 1994; Horne and Goldman 1994; Armstrong et al. 2001). Creed (2006) also identifies salmonids, suckers (Catostomidae) and some minnows (Cyprinidae) as cold or coolwater species, while bullheads (Ictaluridae), other cyprinids, and centrarchids, including bass, tend to prefer warmwater.

While the average maximum recorded water temperatures of 25.5-26 ºC in the Eightmile did not last for extended phases and mean temperatures over the entire recording period were closer to 18.5-19 ºC, the elevated temperatures are expected to be detrimental to coldwater salmonid species such as brook trout or Atlantic salmon. Other sources describe temperature related predator transition across a longitudinal gradient from colder, headwater streams to warmer, larger streams (Creed 2006) or across a temperature gradient related to urbanization (Kemp and Spotila 1997). Fallfish appear to replace brook trout as a top predator in coolwater versus coldwater streams while the

New Jersey DEP IBI Summary Report (2000) also indicates that trout will often replace sunfish in colder water environments.

The elevated water temperatures identified in our study were caused by shallow impoundments in the watershed and the generally limited canopy cover and shading along the East Branch. A section of channel modification with a series of small pools was also noted in the headwaters of the Eightmile. Some of the thermal recorders in the headwater region were below dams at the few impoundments in the watershed and in the general area of the channel modifications. These probes had consistently higher temperature recordings than the probes in adjacent areas, including the maximum recording of the season which was taken below the dam at Lake Hayward. This phenomenon has been reported in at least two other studies (Lessard and Hayes 2003; Maxted et al. 2005) which found that small dams and constructed ponds allow heated surface water to flow over the impoundment to the downgradient stream. Both Lessard and Hayes (2003) and Maxted et al. (2005) found a change in the species assemblage of the downstream aquatic community as a result of the warmer water temperatures. Maxted et al (2005) found the elevated temperature effects of the ponds to extend for several hundred meters past its boundary. A number of beaver dams were also observed in the headwaters of the Eightmile watershed, creating extensive, adjacent marshy areas contributing to the streams. However, these features may not contribute to elevated temperatures in the same manner as constructed, manmade impoundments, due to increased chance of breakage and the natural porosity of the beaver dam that allows cooler, non-surface water through (Hart et al 2002). Therefore, even though true dams and impoundments are relatively few and far between in the Eightmile watershed, the impacts extend downstream and may create an overall reduction of habitat and a thermal barrier to temperature sensitive species.

### 2.4.4. Conclusion

It appears that there are some deviations between the projected RFC and the XFC in terms of species and guilds, likely due to elevated water temperatures and a paucity of structure in the Eightmile. Another contributing factor seems to be the deviation between expected and actual American eel and Atlantic salmon proportions, indicating a larger, regional issue. Although the river did not quite meet or exceed its references as we predicted, there is some criticism in assuming that other rivers provide an appropriate reference for a specific stream, or in using the affinity between the reference and actual communities to determine the potential impairment (Bain pers. comm.). The intent of developing a reference fish community is not to try to restore the faunal assemblage to what was present in a stream prior to European colonization. It may be almost impossible to accurately determine what the community had been prior to many years of human influence, even in a system in the process of recovery. Instead, it should be used as guidance to focus recovery efforts towards a healthy community relative to the region (Bain and Meixler 2008). Our research into historical gauge data in the larger study of the Eightmile indicated higher flow stability, specifically during low-flow seasons. This stability is unusual for many streams in the region and is a potential signal of recovery. This observation is important as it confirms that the lack of impervious surfaces and increased forest cover of the watershed results in a less flashy flow regime which not only stabilizes low flows but also reduces the intensity of flooding.

The Eightmile River watershed is still one of the better references for how well-directed land protection efforts could guide other areas of the northeastern Unites States to recover from anthropogenic impact. Despite intensive use in the early history of colonization, the unusual land ownership structure (large, privately-owned, undeveloped tracts and strong land trust efforts) allowed for the system to rebound. Even though the Eightmile River is still on the path of recovery, it is considered to be a high quality river on the regional average, demonstrating an urgent need for a regional restoration effort. The lessons learned from the analysis of the Eightmile River may steer land management plans towards the improvement of other rivers in the Northeast. As part of Phase II of our larger study, we have developed a simulation model of habitat, flow and temperature conditions as a tool to precisely define protection/restoration targets and management options for the watershed.

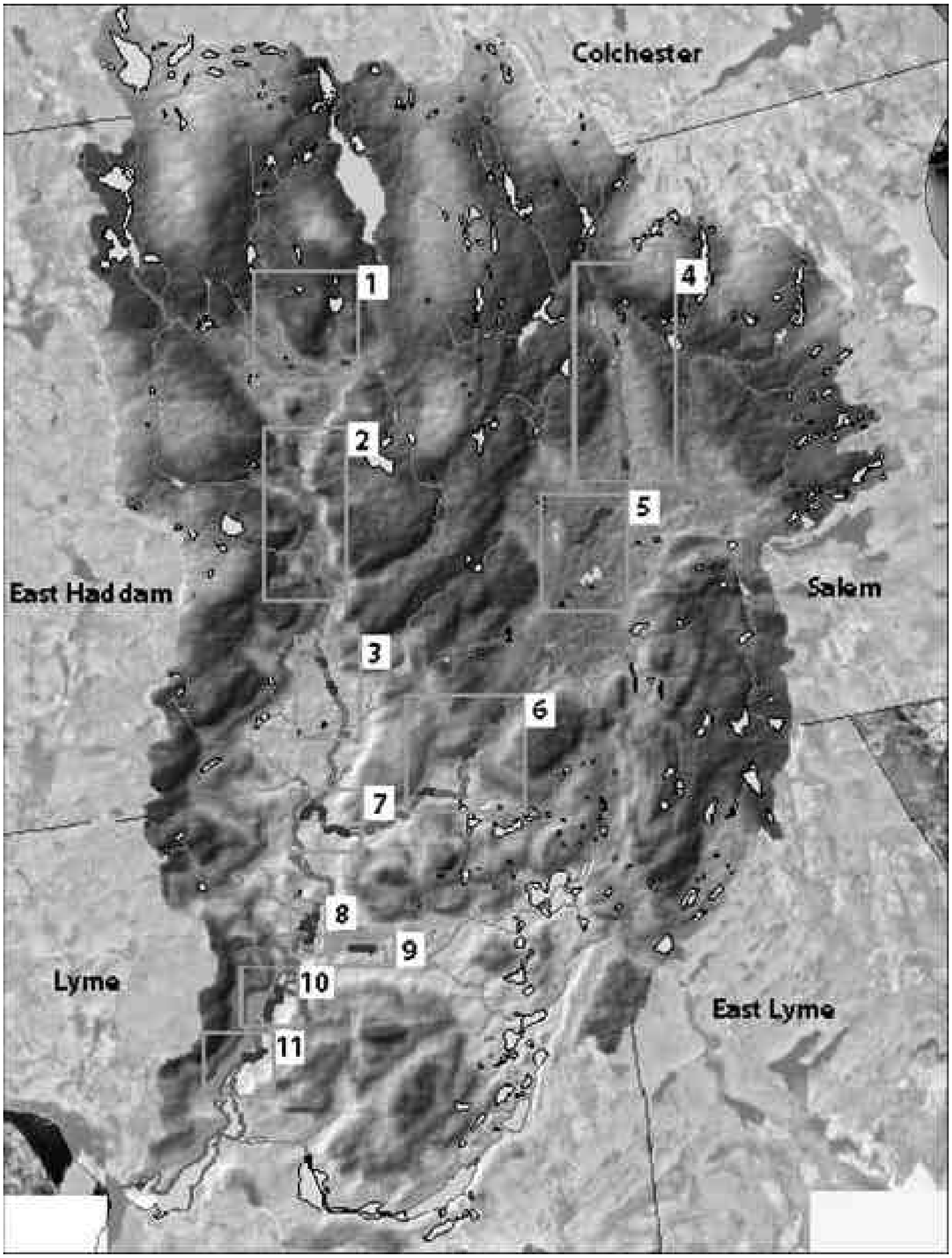

**Figure 2.1: Relief map of the Eightmile River watershed with an overlay of the eleven sites surveyed for fish during summer 2004. The clusters of dots represent the individual fishing grids.**

**Table 2.1: A list of reference rivers were provided by the CTDEP Inland Fisheries Division and those in the following table were selected to create a separate reference fish community for the upper Eightmile River basin (second to third order streams) and the Mainstem Eightmile River below the confluence (fourth order stream).**

**Upper Eightmile River and East Branch**

| Reference river | Location |
|---|---|
| Broad Brook | Thames River basin |
| Fivemile River | Western coastal |
| Hammonasset River | Central coastal |
| Moosup River | Thames River basin |
| Roaring Brook | Connecticut River basin |
| West River | Central coastal |

**Mainstem Eightmile River**

| Reference river | Location |
|---|---|
| Fivemile River | Thames River basin |
| Green Fall River | Pawcatuck River basin |
| Moosup River | Thames River basin |
| Salmon Brook (East Branch) | Connecticut River basin |
| Still River | Connecticut River basin |
| Yantic River | Thames River basin |

**Figure 2.2: The photograph presents a view of the typical electroshock grid set-up that was utilized during the fishing survey in the Eightmile River. The photograph was taken in the Upper Eightmile Mainstem in Devil's Hopyard State Park.**

**Table 2.2: Complete list of the fish species captured in the Eightmile River watershed during the 2004 electrofish survey. Species are identified as native or introduced, as Generalists (MG), Fluvial Specialists (FS), or Fluvial Dependants (FD) based on their macrohabitat use, as cold, cool, or warmwater fish, and Pollution Tolerant (T), Moderately Tolerant (M), or Pollution Intolerant (I).**

| Common name | Latin name | Native or introduced | Fluvial habitat use/guild[b] | Cold, cool or warmwater species[b] | Pollution tolerance[b] |
|---|---|---|---|---|---|
| Blacknose dace | *Rhinichthys atratulus* | N | FS | Coldwater | T |
| Brook trout | *Salvelinus fontinalis* | N | FS | Coldwater | I |
| Creek chub | *Semotilus atromaculatus* | N | FS | Coolwater | T |
| Fallfish | *Semotilus corporalis* | N | FS | Coolwater | M |
| Longnose dace | *Rhinichthys cataractae* | N | FS | Coldwater | M |
| Tessellated darter | *Etheostoma olmstedi* | N | FS | Coolwater | M |
| American eel | *Anguilla rostrata* | N | FD | Coolwater | T |
| Brown trout | *Salmo trutta* | I | FD | Coldwater | I |
| Common shiner | *Notropis cornutus* | N | FD | Warmwater | M |
| White sucker | *Catostomus commersoni* | N | FD | Coolwater | T |
| Atlantic salmon[a] | *Salmo salar* | N | FD | Coldwater | I |
| Sea lamprey[a] | *Petromyzon marinus* | N | FD | NA | NA |
| Bluegill sunfish | *Lepomis macrochirus* | I | MG | Warmwater | T |
| Brown bullhead | *Ictalurus nebulosus* | N | MG | Warmwater | T |
| Chain pickerel | *Esox niger* | N | MG | Coolwater | M |
| Golden shiner | *Notemigonus crysoleucas* | N | MG | Coolwater | T |
| Largemouth bass | *Micropteris salmoides* | I | MG | Warmwater | M |
| Pumpkinseed sunfish | *Lepomis gibbosus* | N | MG | Warmwater | M |
| Redbreast sunfish | *Lepomis auritis* | N | MG | Warmwater | M |
| Redfin pickerel | *Esox americanus* | N | MG | Warmwater | M |
| Smallmouth bass | *Micropteris dolomieu* | I | MG | Warmwater | M |
| Spottail shiner | *Notropis hudsonius* | N | MG | Coolwater | M |
| Yellow perch | *Perca flavescens* | N | MG | Coolwater | M |
| Mud minnow | *Fundulus spp.* | N | MG - coastal freshwater | Warmwater | T |

[a] Atlantic salmon and sea lamprey were designated as FD in this report for purposes of establishing guilds.
[b] Macrohabitat use and Pollution tolerance guilds established by Bain and Meixler (2000). Temperature guilds were determined through literature sources.

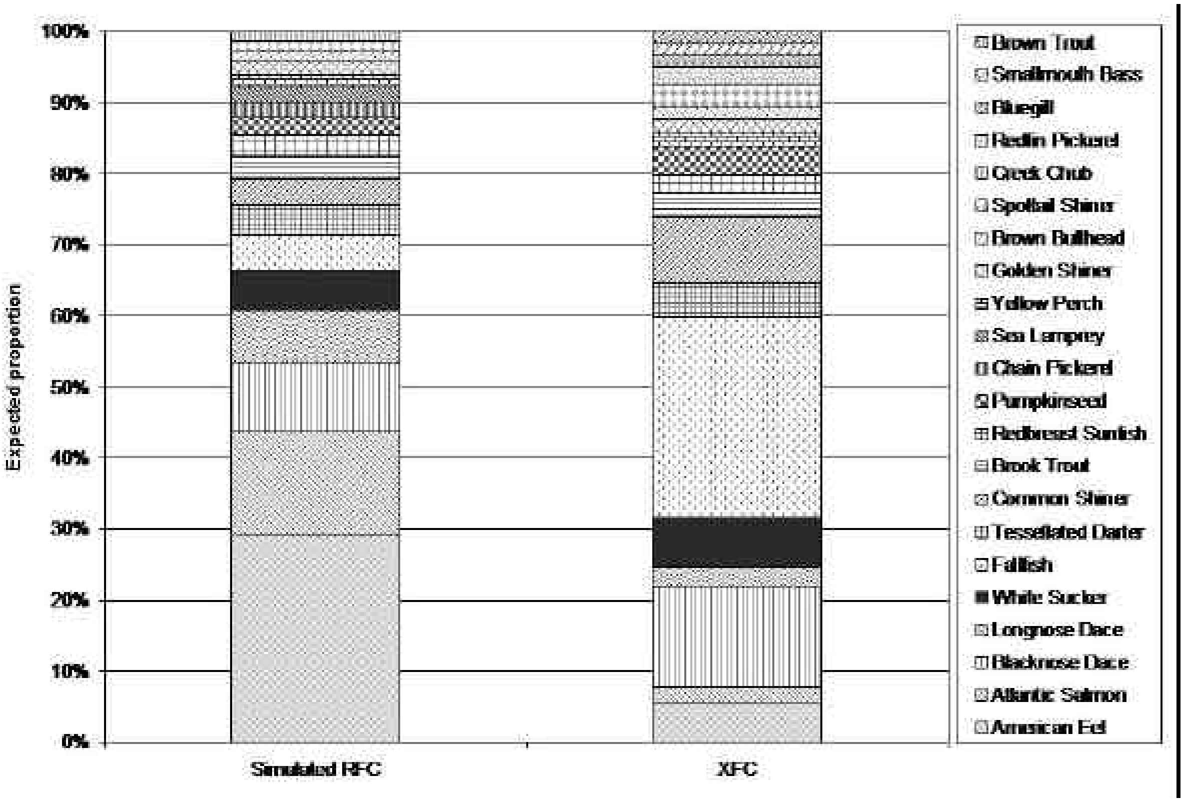

**Figure 2.3: Charts demonstrate the species and expected proportions in the Reference Fish Community with the eXisting Fish Community of the Upper Eightmile River/ East Branch. American eel, Atlantic salmon, and brook trout proportions have been simulated in the RFC.**

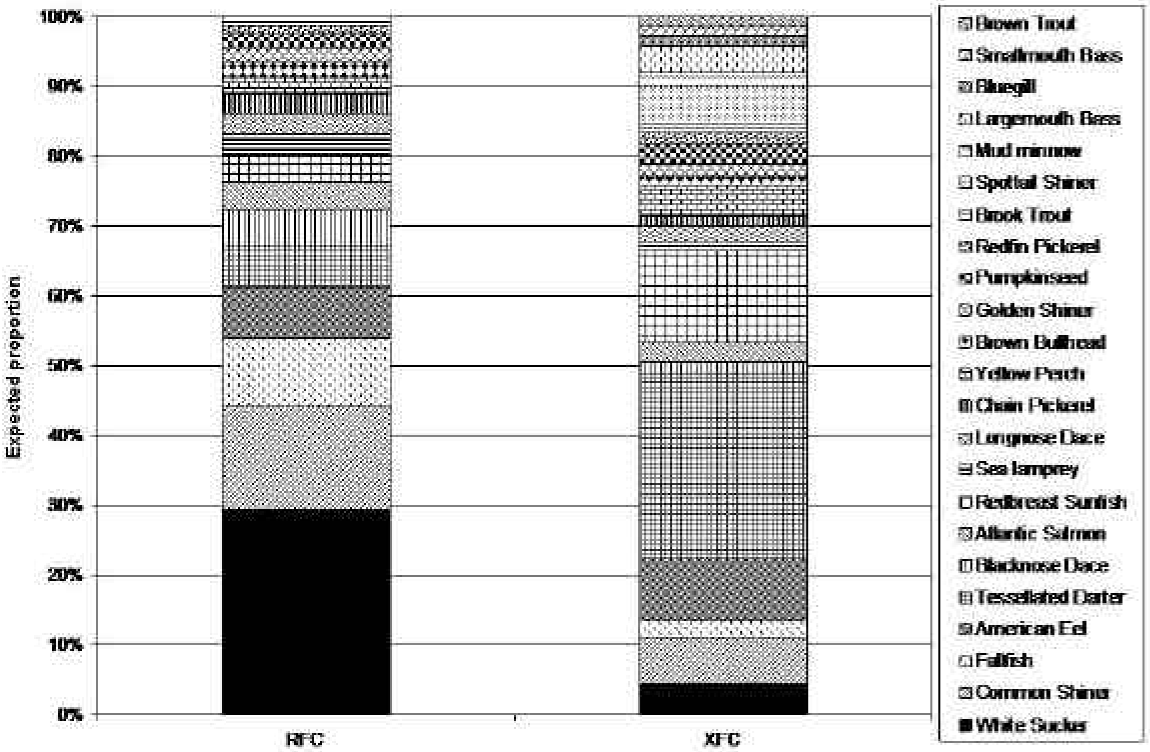

**Figure 2.4: Charts demonstrate the species and expected proportions of the Reference Fish Community with the eXisting Fish Community of the Mainstem Eightmile River. American eel, Atlantic salmon, and brook trout proportions have been simulated in the RFC**

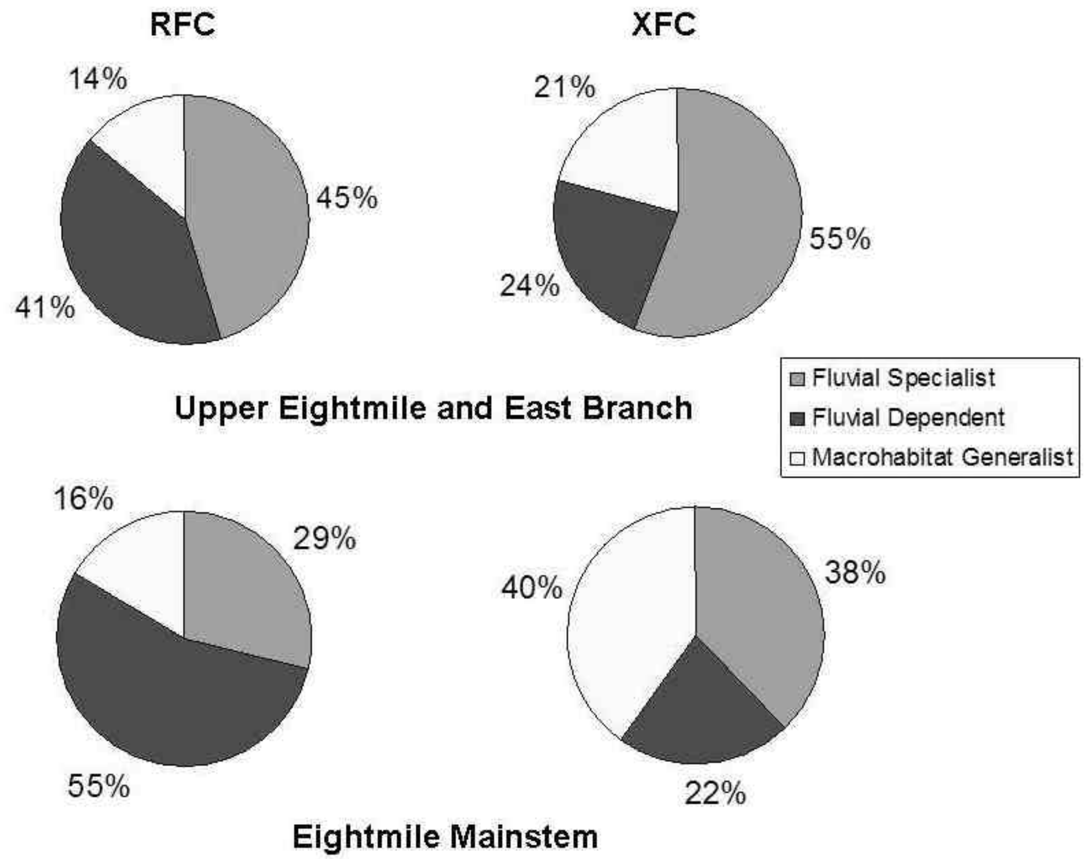

**Figure 2.5: Charts compare the proportion of the fish in the RFC with the XFC in terms of fluvial habitat use. This is shown for both the Upper Eightmile assemblage and the Mainstem Eightmile assemblage.**

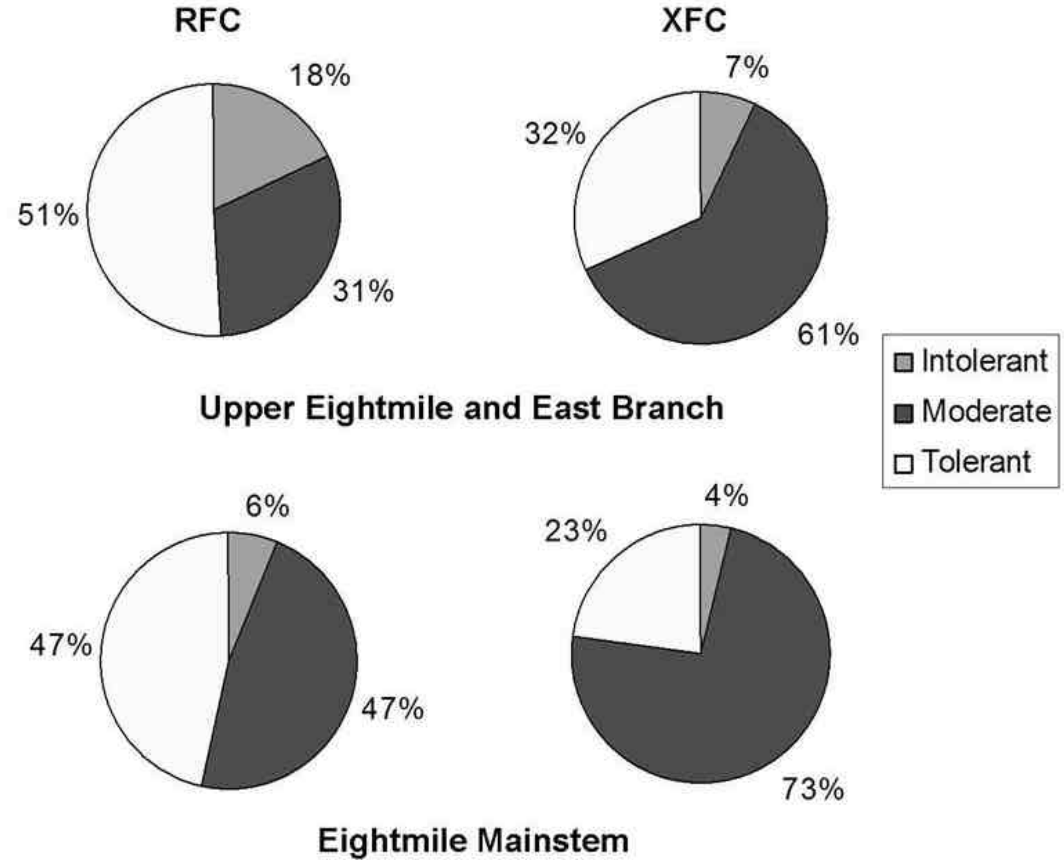

**Figure 2.6: Charts compare the proportion of the fish in the RFC with the XFC in terms of pollution tolerance. This is shown for both the Upper Eightmile assemblage and the Mainstem Eightmile assemblage.**

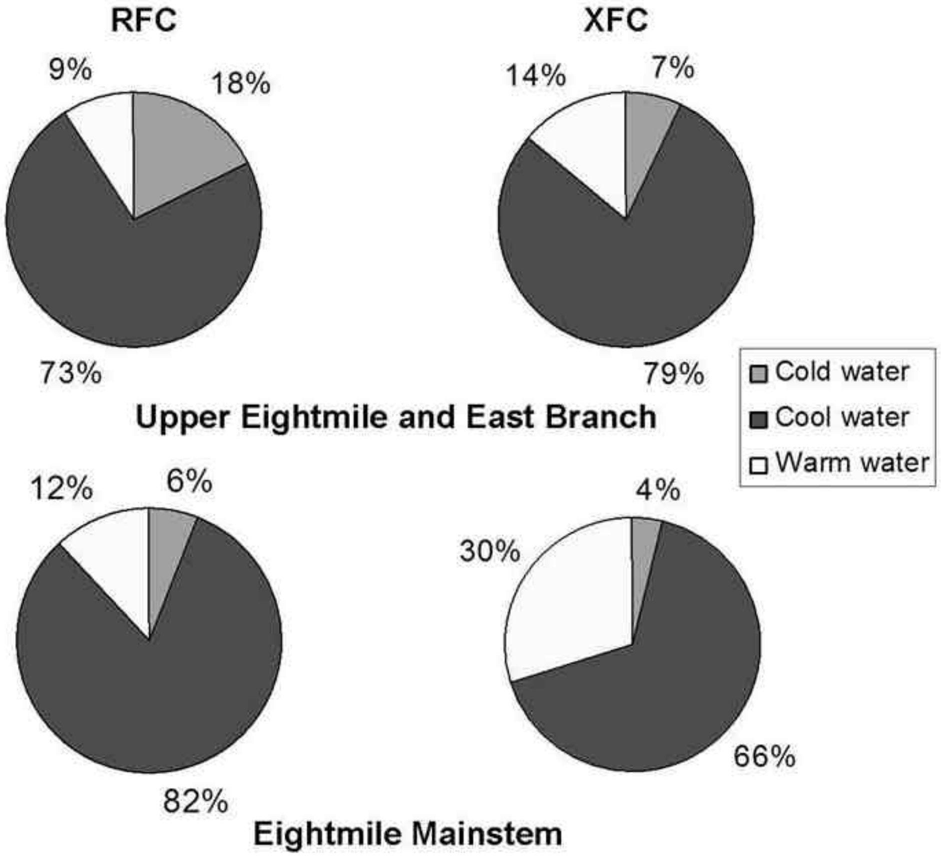

**Figure 2.7: Charts compare the proportion of the fish in the RFC with the XFC in terms of water temperature requirements. This is shown for both the Upper Eightmile assemblage and the Mainstem Eightmile assemblage.**

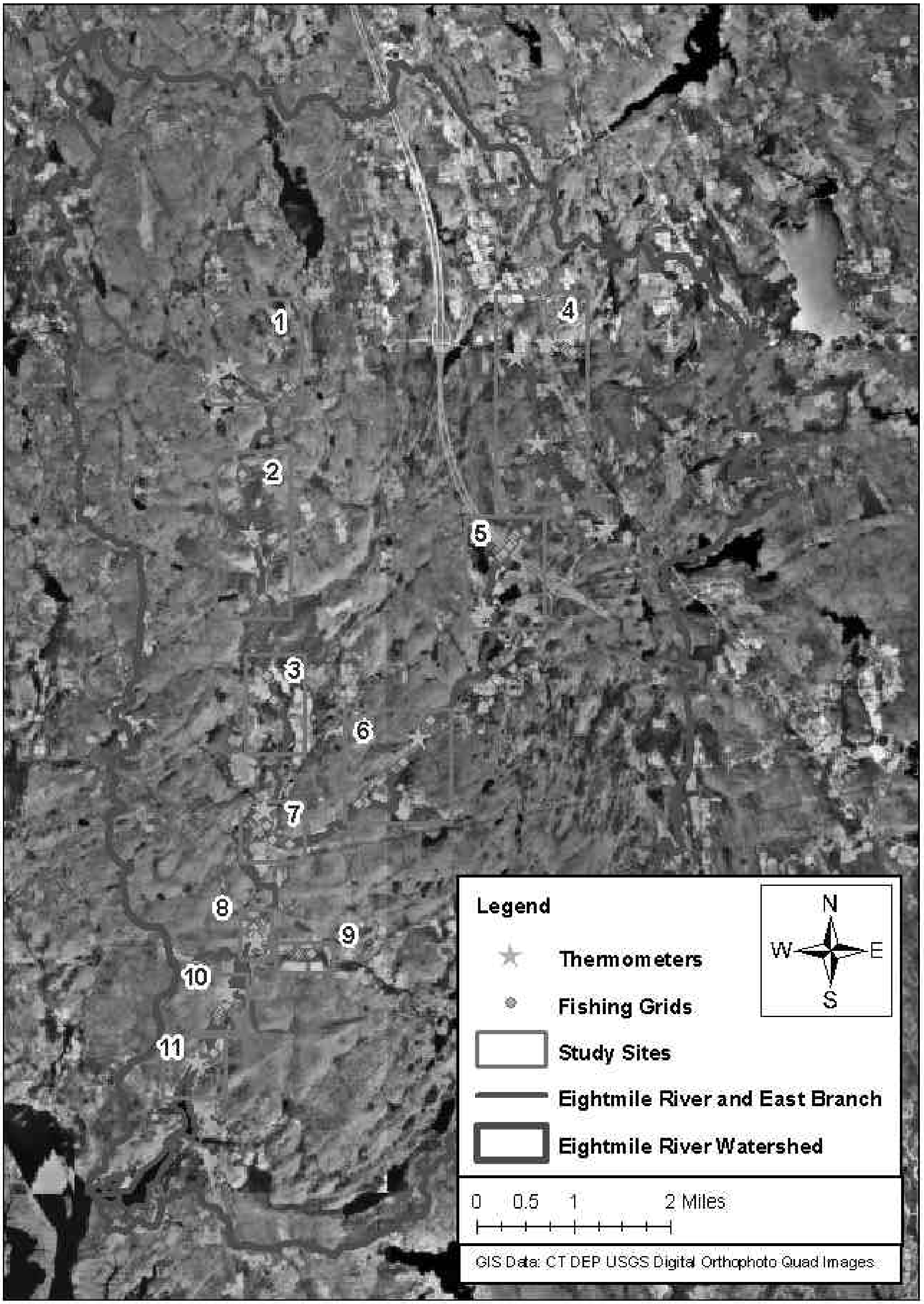

**Figure 2.8: The aerial photo presents the Eightmile River watershed with the sites, fishing grids and thermal recorders indicated.**

**Table 2.3: Results for the mean and maximum temperature recorded by each of the temperature probes placed in the Eightmile River during the 2004 study period (April-September). Temperatures are shown in degrees Celsius. Distance represents the distance in river km that the probe was located from the confluence with Hamburg Cove.**

| | **Eightmile** | | **Warmest Day** | |
|---|---|---|---|---|
| **Probe #** | **Distance (km)** | **Mean temp °C** | **Date** | **Max Temp °C** |
| 9 | 0.00 | 18.8 | 8/3/2004 | 29.5 |
| 6 | 1.72 | 18.9 | 8/4/2004 | 26 |
| 2 | 2.94 | 18.5 | 8/2/2004 | 26 |
| 1 | 11.12 | 17.9 | 8/1/2004 | 23.3 |
| 8 | 15.03 | 16.3 | 8/1/2004 | 21.7 |
| 7 | 15.01 | 18.0 | 8/2/2004 | 24.8 |
| 12 | 16.55 | 21.4 | 8/4/2004 | 28.7 |
| | **East Branch** | | **Warmest Day** | |
| **Probe #** | **Distance (km)** | **Mean temp °C** | **Date** | **Max Temp °C** |
| 14 | 9.122 | 18.8 | 8/3/2004 | 25.2 |
| 11 | 12.229 | 18.9 | 8/3/2004 | 26 |
| 13 | 16.048 | 18.8 | 8/2/2004 | 26.8 |
| 10 | 15.829 | 19.4 | 8/1/2004 | 26 |
| 5 | 17.509 | 19.9 | 8/4/2004 | 30.3 |
| 3 | 18.241 | 18.3 | 8/3/2004 | 22.9 |

# CHAPTER 3

# CHARACTERIZING STREAM HYDROMORPHOLOGIC UNITS THROUGH DEPTH AND VELOCITY MEASUREMENTS

## 3.1 Introduction

Streams are comprised of a series of hydraulic types which are characterized by flow, depth, turbulence, and the shape of the stream bed. The most familiar components include pool and riffle complexes although numerous studies have identified and characterized further units. Much as in taxonomy, investigators can be classified as “lumpers and splitters”. Bisson and Montgomery (1996) presents Hawkins et al’s (1993) scheme with a central division between fast water and slow water habitats. Fast water habitats are then divided between turbulent and non-turbulent types, and slow water habitats are divided between types of pools formed by scour or pools formed by dams. In total, there are nineteen separate channel units. Parasiewicz (2001, 2008) and Peterson and Rabeni (2001a) both use eleven units in their classification schemes. In contrast, Doloff et al (1993) only identify three habitat types; pools, riffles and cascades in their Basinwide Visual Estimation Technique. Walters et al (2003) use the standard pools, riffles and runs in their study and Lamouroux et al (1998) use only pools and riffles in their predictive model and rely on depth, velocity and substrate data to make distinctions. It is interesting to note that the majority of these units are only present and distinguishable in a stream during normal or low flow but they originally form during high flows through scouring/shaping the stream bed and deposition of material (Peterson and Rabeni 2001a).

Studies also demonstrate that different fish species or life stages have been linked to specific values of hydraulic variables, especially depth, velocity and substrate size (Lamouroux 1998, Stalnaker 1995). Since physical habitat modeling of streams requires drawing a connection between the physical attributes available and the presence, absence or abundance of associated species, it is important to have a simple method for categorizing the habitat (Aadland 1993, Arend 1999). Bisson and Montgomery (1996) stated

> "Stream ecologists will do well to heed the advice of Balon (1982), who cautioned that nomenclature itself is less important than detailed descriptions of the meanings given to terms"[4]

Arend (1999) confirms this in stating that the variation in terms causes confusion when trying to compare studies.

In line with this advice, Peterson and Rabeni (2001a) tested their channel unit classification scheme for predictability, first using only depth and velocity and then with a more descriptive set with additional attributes including vegetation, woody debris and substrate. They found that depth and velocity alone could predict a unit type at their first level of classification (i.e. between pool and riffle) at between 81-86% accuracy but the remaining attributes were needed to reach similar accuracy in predicting the more specific unit types (Peterson and Rabeni 2001a). It should be noted however that their classifications were not strictly based on hydraulics. Lamouroux et al (1998) developed

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[4] Bisson, P.A. and D.R. Montgomery. Valley segments, stream reaches, and channel units. pp. 23--52. In: F.R. Hauer and G.A. Lamberti (eds.) Methods in Stream Ecology, (New York: Academic Press 1996) p 25.

a predictive statistical model for frequency distributions of depth, velocity and other hydraulic variables.

To examine this idea further, I used the eleven hydromorphological units (HMUs) proposed in the MesoHABSIM method (Parasiewicz 2001, 2007) and attempted to identify a depth and velocity template or characterization for each. A review of the MesoHABSIM approach indicated the collection of depth and velocity data is the most time consuming portion of the methodology (Parasiewicz 2007). The main objective of the study was to determine if there was a standardized way to describe a particular hydraulic unit and therefore a way to reduce time spent mapping and collecting data. For example, could a riffle be described as an area of the stream where a certain percent of velocities and a certain percent of depths fall within established categories during a particular flow. The lower flow period of the year was selected for study because heterogeneity in hydraulic types is more prevalent and because it is often important to critical bioperiods for fish (Peterson and Rabeni 2001a, Parasiewicz 2007). However, HMU depth and velocity data are available from distinctly different flows within the lower flow period and we were interested whether data were similar enough to be combined across flows.

*A priori* observations suggest that similar trends in the data are present between the high, medium, and low stages that would justify describing an HMU with one “template” over all flows in the lower-flow period. It is also likely that some of the HMUs will have significantly different data between flows, resulting in more than one potential “template” in some cases. If data are similar enough across flows, we also hypothesize that some of the eleven HMUs are similar enough to each other that they could be combined, resulting in a smaller but still effective set of HMUs.

## 3.2 Methods

Through years of projects and data collection, the Northeast Instream Habitat Program (NEIHP) has recorded random depth and velocity measurements from HMUs in multiple rivers during the lower-flow period. For this study, I used the bank of data to select a set of measurements from four rivers which include the Souhegan River in southern New Hampshire, the Quinebaug River in southern Massachusetts/northern Connecticut, the Pomperaug River in western Connecticut, and Stony Clove Creek in the Catskills region in New York. This data set includes tens of thousands of recordings, representing all eleven HMUs in each of three flow categories during the lower-flow period. For purposes of our study, Low low-flow is established at 0.0-0.3 cubic feet per square mile (csfm), Medium low-flow is established at 0.3-0.8 cfsm, and High low-flow is established at 0.8-1.5 cfsm. Flows are referred to as low, medium and high from this point forward although they all describe portions of the low-flow period.

### 3.2.1 Field Measurements

As per the established methods of MesoHABSIM, selected sites within the study rivers were mapped fully into a series of HMUs. The flow category at the time of mapping was recorded through use of established USGS gauging stations. Within each HMU, seven randomly located measurements for depth (cm) and mean column velocity were collected with a Dipping Bar (Jens 1968). Mean column velocity was converted to velocity centimeters per second (cm/s). At the same time, substrate was also recorded at each of the seven random points and other physical attributes related to fish habitat were evaluated for the HMU.

### 3.2.2 Analysis

All entries from each of the eleven types of HMU were sorted out and placed in a spreadsheet specific to that HMU with one for depth and one for velocity. The data for each HMU was then sorted by the low, medium, and high flow categories. For each HMU and each flow, the measurements were sorted into established bins in order to create histograms. For depth, bins were established every 25 cm, starting with the 0-25cm bin and ending at the > 125cm bin. For velocity, bins were established every 15cm/s, starting with the 0-15cm and ending at the >105cm/s bin. These bins were predetermined as part of the NEIHP protocol and were set at divisions that have been determined to be important to adult fish based on analysis of habitat suitability curves for salmonids (Parasiewicz 2007). Therefore, we needed to keep the proportions of measurement within the established bins when we performed the analysis between the flows.

The distribution of each variable was plotted as a relative frequency histogram and standardized so the trends could be examined. For each HMU we plotted each flow as well as an ”all flows” histogram on the same graph. On first examination, many HMUs appear to have similar patterns in distribution across flows for both depth and velocity. Others had visibly different patterns based on the flow and we predicted that separate templates would be necessary to describe the HMU. Figure 3.1 presents the depth distribution for backwaters as an example of an HMU with relative frequencies that visibly appear to be similar across flows, compared to rapids as an example of an HMU that appears visibly different between at least two of the flow types. We then used statistical analysis to determine whether the *a priori* similarities between flows could be confirmed.

Two independent-sample, Kolmogorov-Smirnov (K-S) tests were conducted in a pair-wise fashion between each of the three flow data sets within each HMU (i.e. low vs medium, medium vs high and high vs low). combined. This was repeated for depth data and then separately for velocity data. This test was used to determine which data sets were similar enough (i.e. whether the two sets being compared come from the same "population") that they could be combined. The K-S test is a non-parametric test that evaluates differences between relative cumulative frequency distributions (Piegorsch and Bailer 2005). Since the predetermined bins and relative frequency histograms for depth and velocity were considered significant to the MesoHABSIM method, the K-S test was the most appropriate option since we could not simply compare the sets of raw measurements between the flows.

### 3.3 Results

Data from a total of 4,698 HMUs were analyzed with 32,886 measurements for both depth and velocity. A high variation in sample size between HMUs and flow types was also noted. The K-S test trials indicated that very few sets of flow data within HMUs are statistically similar. The null hypothesis of the K-S test states that there is no significant difference between the two data sets being compared, and that the data are from the same population or ones with a similar distribution. Therefore, our investigation was anticipating that most of the trials would fail to reject the null which seems counter-intuitive to most scientific researchers. However, we almost consistently rejected the null at both 0.05 and 0.01 significance levels, indicating that very few of the flow data sets within each HMU are similar enough to be statistically combined.

### 3.3.1 Depth

When comparing the depth distribution in low versus medium flow, only sidearms, cascades, plunge pools and ruffles were statistically similar. In medium versus high flow, only cascades had statistically similar results. The low versus high flow comparison did not result in any HMUs with statistically similar results. Table 3.1 presents the comparison of depth distribution between each flow type for each HMU at the 0.01 significance level. Appendix A contains the full compilation of histograms for depth distribution for each HMU.

### 3.3.2 Velocity

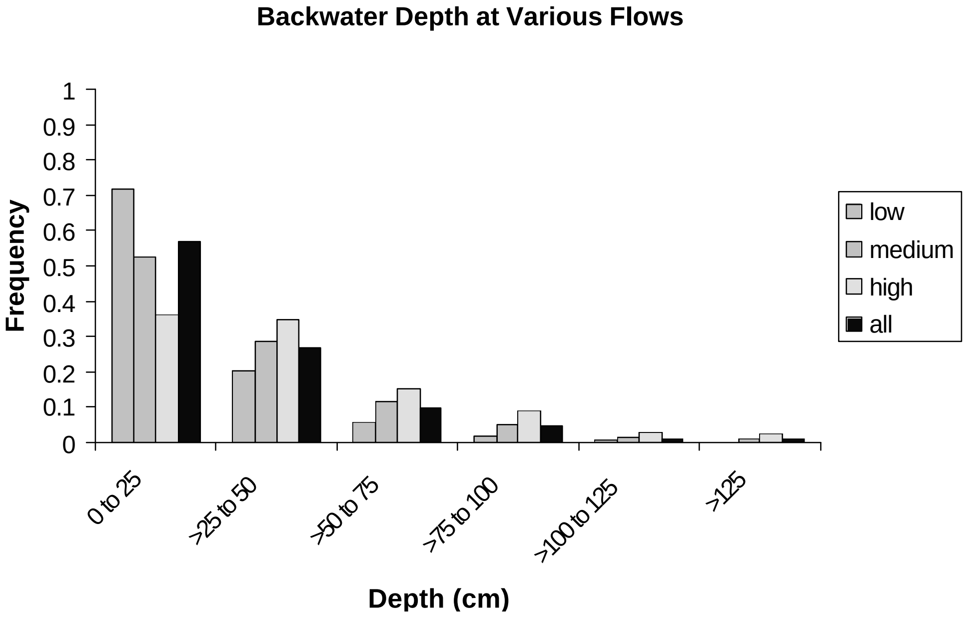
When comparing velocity distribution, there were a few more similarities when looking at medium versus high flows instead of low versus medium flows. In low versus medium flows, only plunge pools and cascades had statistically similar results. Cascades were barely similar and only when looking at the statistics to the forth decimal place at the 0.01 significance level. In medium versus high flows, sidearms, cascades, and plunge pools had statistically similar results. In low versus high flows, cascades, and plunge pools had statistically similar results, indicating that the velocity distributions for these two HMUs can be combined across all flows. In addition, backwaters also had statistically similar results in the low versus high flows which is unusual since results were not similar between the other flows. Table 3.2 presents the comparison of velocity distribution between each flow type for each HMU at the 0.01 significance level. Appendix B contains the full compilation of histograms for velocity distribution for each HMU.

### 3.4 Discussion

When viewing the data prior to applying statistics, we anticipated that a simplified, standard distribution for depth and velocity could be developed for most, if not each HMU. However, we found that the results from very few of the trials in either depth or velocity were statistically similar. Only cascades and plunge pools could reasonably be described with the same template distribution for velocity in all of the flows. Figure 3.2 presents the histogram of velocity distribution for cascades compared to riffles which had no similarity in distribution between flows. The remaining data help to create a “picture” of what a particular HMU’s depth or velocity distribution looks like, but our investigation unfortunately did not further simplify the characterizations. With the exception of the few trials where the null hypothesis was not rejected, each flow would still have its own picture for depth and velocity. Since we could not find many examples where creating a combined distribution for all flows for one HMU could be justified statistically, we were not able to move the investigation to the next level in determining whether two or more HMUs could be lumped using this method

One theory to explain the statistical results is that the data set was extremely large and very minor differences between the distributions are being identified by the K-S test. A NEIHP associate performed a recent examination where a random sample of 100 measurements (repeated with 100 bootstraps) were pulled for each flow for each HMU (Mouser unpub. data). When the sample sizes had been reduced and normalized and analyzed with the Kruskal-Wallis test, no significant differences were found between many of the flow comparisons, allowing for combinations of more of the data than indicated in my investigation. The same associate was also successful at identifying similarities in HMU depth and velocity through hierarchical cluster analysis, reducing the eleven HMUs to a set of seven. Sidearms and backwaters each remained a separate type but the groupings of cascades/riffles/ruffles, glides/runs, pools/plunge pools, and fastruns/rapids could be justified (Mouser unpub. data). The outcome resembles the dendrograms presented by Arend (1999) where the author described several classification schemes for channel units.

Finally, even though my statistical exercise indicated that the majority of data distributions should remain divided by flow, the question remains whether combining the flows or HMU types will affect the prediction of fish presence in a particular site. These questions leave room for future investigation and continued testing of this long debated topic. Several different trials could be performed using the forward stepwise logistic regression in the MesoHABSIM model. First, the template depth and velocity distribution data for a specific HMU could be entered in place of the distribution of measurements recorded in the field. If the prediction of presence and abundance of fish species shows no change between the original depth and velocity data and the replacement template, we will assume that these characteristic distributions can be used for these HMUs in future models, eliminating the need to gather the seven random measurements in the field. Second, the HMU clusters or groupings can be tested in a similar manner to determine whether the type of HMU predicts a difference in fish. A final template distribution for depth and velocity would also be developed for the new combination of HMUs. The final goal is to continue simplifying the methods used in mapping streams and to clearly identify the hydraulic unit being discussed through physical characteristics.



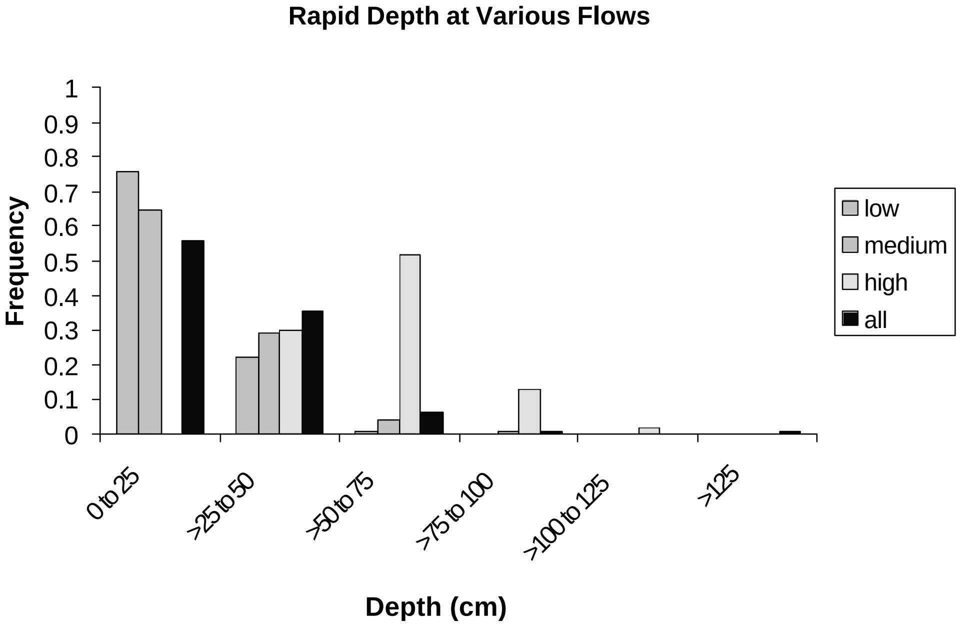


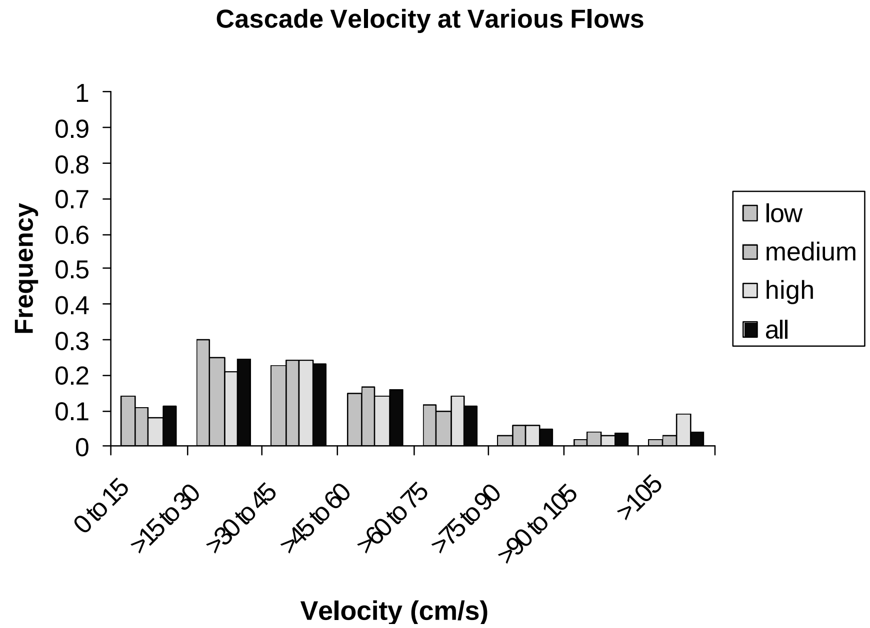
**Figure 3.1: Graphs present the depth relative frequencies of backwaters, an example of an HMU that visibly appear to be similar across flows, compared to rapids which appear visibly different between at least two of the flow types.**

### Table 3.1: The data represented is a comparison of depth relative frequency distribution between each flow type for each HMU at the 0.01 significance level. The Max. Diff. entries are the maximum absolute difference between the distributions

| | | Low vs Med | Med vs High | Low vs High |
|---|---|---|---|---|
| **Sidearm** | Max. Diff. | 0.0793 | 0.1183 | 0.1976 |
| | D 0.01 | 0.1059 | 0.1182 | 0.1186 |
| | Interpretation | Fail to reject null: Similar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Cascade** | Max. Diff. | 0.0703 | 0.0865 | 0.1569 |
| | D 0.01 | 0.1016 | 0.1372 | 0.1476 |
| | Interpretation | Fail to reject null: Similar distrib. | Fail to reject null: Similar distrib. | Reject null: Dissimilar distrib. |
| **Rapids** | Max. Diff. | 0.1075 | 0.3518 | 0.4594 |
| | D 0.01 | 0.0933 | 0.0845 | 0.0956 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Backwater** | Max. Diff. | 0.1947 | 0.1612 | 0.3559 |
| | D 0.01 | 0.0756 | 0.0872 | 0.0863 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Fast Run** | Max. Diff. | 0.2855 | 0.2585 | 0.5440 |
| | D 0.01 | 0.1952 | 0.1359 | 0.1964 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Glide** | Max. Diff. | 0.1937 | 0.1595 | 0.3532 |
| | D 0.01 | 0.0577 | 0.0642 | 0.0706 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Plunge Pool** | Max. Diff. | 0.0421 | 0.4127 | 0.3762 |
| | D 0.01 | 0.2199 | 0.2713 | 0.3177 |
| | Interpretation | Fail to reject null: Similar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Pool** | Max. Diff. | 0.0568 | 0.2700 | 0.2627 |
| | D 0.01 | 0.0500 | 0.0833 | 0.0838 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Riffle** | Max. Diff. | 0.1029 | 0.2630 | 0.3659 |
| | D 0.01 | 0.0419 | 0.0636 | 0.0655 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Ruffle** | Max. Diff. | 0.0300 | 0.2326 | 0.2622 |
| | D 0.01 | 0.0632 | 0.0673 | 0.0701 |
| | Interpretation | Fail to reject null: Similar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Run** | Max. Diff. | 0.2286 | 0.1643 | 0.3930 |
| | D 0.01 | 0.0776 | 0.0862 | 0.0540 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |

**Table 3.2: The data represented is a comparison of velocity relative frequency distribution between each flow type for each HMU at the 0.01 significance level. The Max. Diff. entries are the maximum absolute difference between the distributions.**

| | | Low vs Med | Med vs High | Low vs High |
|---|---|---|---|---|
| **Sidearm** | Max. Diff. | 0.1153 | 0.0762 | 0.1448 |
| | D 0.01 | 0.1058 | 0.1182 | 0.1185 |
| | Interpretation | Reject null: Dissimilar distrib. | Fail to reject null: Similar distrib. | Reject null: Dissimilar distrib. |
| **Cascade** | Max. Diff. | 0.1014 | 0.0702 | 0.1389 |
| | D 0.01 | 0.1016 | 0.1372 | 0.1476 |
| | Interpretation | Fail to reject null: Similar distrib. | Fail to reject null: Similar distrib. | Fail to reject null: Similar distrib. |
| **Rapids** | Max. Diff. | 0.1071 | 0.2808 | 0.3757 |
| | D 0.01 | 0.0933 | 0.0845 | 0.0956 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Backwater** | Max. Diff. | 0.1345 | 0.1588 | 0.0243 |
| | D 0.01 | 0.0756 | 0.0872 | 0.0863 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Fail to reject null: Similar distrib. |
| **Fast Run** | Max. Diff. | 0.3119 | 0.1782 | 0.4901 |
| | D 0.01 | 0.1952 | 0.1359 | 0.1964 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Glide** | Max. Diff. | 0.1923 | 0.2139 | 0.4062 |
| | D 0.01 | 0.0576 | 0.0642 | 0.0706 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Plunge Pool** | Max. Diff. | 0.1413 | 0.1349 | 0.2762 |
| | D 0.01 | 0.2199 | 0.2713 | 0.3177 |
| | Interpretation | Fail to reject null: Similar distrib. | Fail to reject null: Similar distrib. | Fail to reject null: Similar distrib. |
| **Pool** | Max. Diff. | 0.1482 | 0.1277 | 0.2588 |
| | D 0.01 | 0.05 | 0.0833 | 0.0838 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Riffle** | Max. Diff. | 0.2112 | 0.2779 | 0.475 |
| | D 0.01 | 0.0419 | 0.0636 | 0.0655 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Ruffle** | Max. Diff. | 0.166 | 0.2246 | 0.3905 |
| | D 0.01 | 0.0632 | 0.0673 | 0.0701 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |
| **Run** | Max. Diff. | 0.2767 | 0.2812 | 0.5226 |
| | D 0.01 | 0.03882 | 0.054 | 0.054 |
| | Interpretation | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. | Reject null: Dissimilar distrib. |



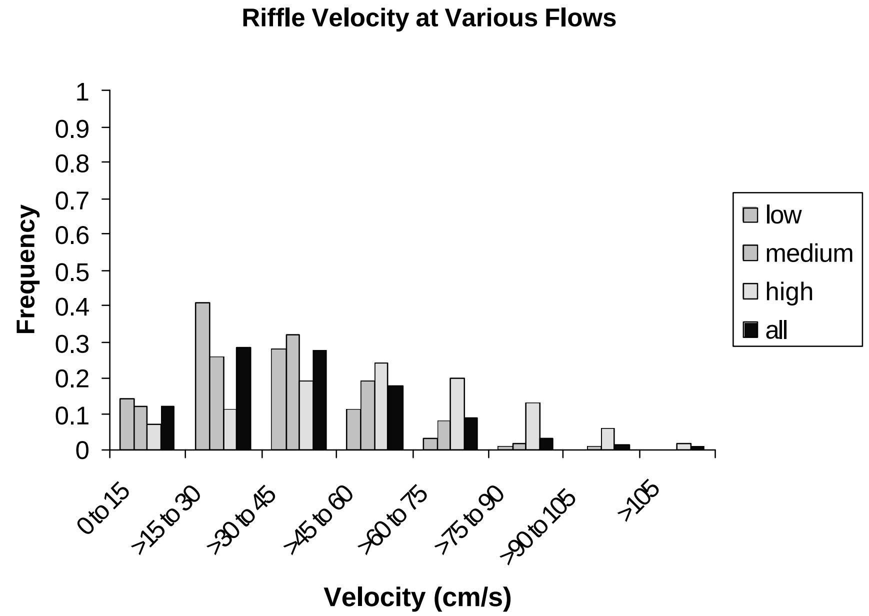


**Figure 3.2: Graphs present the velocity relative frequencies of cascades, which were confirmed statistically to be similar in distribution across flows, compared to riffles which had no statistical similarities in distribution among any flow types.**

# CONCLUSIONS

## APPLYING BIOLOGICAL AND PHYSICAL TEMPLATES TO PERFORM INSTREAM FISH HABITAT MAPPING IN THE NORTHEAST

As stated, the objective of the thesis was to standardize and therefore simplify some components of river modeling, specifically those used in the MesoHABSIM approach. I anticipated that establishing a pattern that could easily identify or categorize stream hydraulic units or identifying a river that exceeded its regional biological references; would result in wider use and implications. However, neither investigation provided the intended reference for the particular component of river modeling, further emphasizing the complexity in this area of study. The information gathered and the conclusions made do provide the opportunity for additional study, and could guide future attempts at establishing references.

The RFC investigation in the Eightmile River demonstrated that the existing community did not meet its references in the manner we anticipated, but in many instances, the Eightmile also proved to be one of the better examples of those that were previously evaluated using the RFC/TFC approach. The question of whether it is appropriate to contrast the similarity of any one river community to others has been raised, but it was not fully answered as a result of this study. As Bain and Meixler (2008) have indicated, the usefulness of the TFC/RFC may not be as a biological index that identifies deviations or impairment, but as guidance to the general structure of a “healthy “community in a particular river. This investigation also demonstrated that gaps in the expected community can be larger problems than the status of the study river, as in the case of American eel and Atlantic salmon. The elevated temperatures and shift from cold water species, and general lack of certain riverine species indicates that even seemingly “pristine” streams could still be in the process of recovery from past impacts and could benefit from restoration efforts. However, there is no question that the well-directed land protection practices in the Eightmile River watershed provides a guide for other areas and are an essential base for a reasonably intact aquatic community.

The depth and velocity study found few statistically significant patterns or distributions that could be used to define each HMU type. This leaves some of the same issues faced in other investigations in the literature; there is no common method of identifying or describing the hydraulic units found in streams. However, although it may not be statistically feasible to establish a depth or velocity template for each HMU type, it may still be appropriate to use these distribution templates if it does not affect the prediction of fish presence in a particular site. If the prediction of presence and abundance of fish species in the MesoHABSIM model shows no change between the field-recorded depth and velocity data and the characteristic distributions, it will indicate that the statistical investigations were not necessary. The HMUs could be described in this quantitative manner permanently, eliminating the need to gather the seven random measurements in the field and providing a template for others to use.

# APPENDIX A

## HISTOGRAMS FOR HMU DEPTH DISTRIBUTION

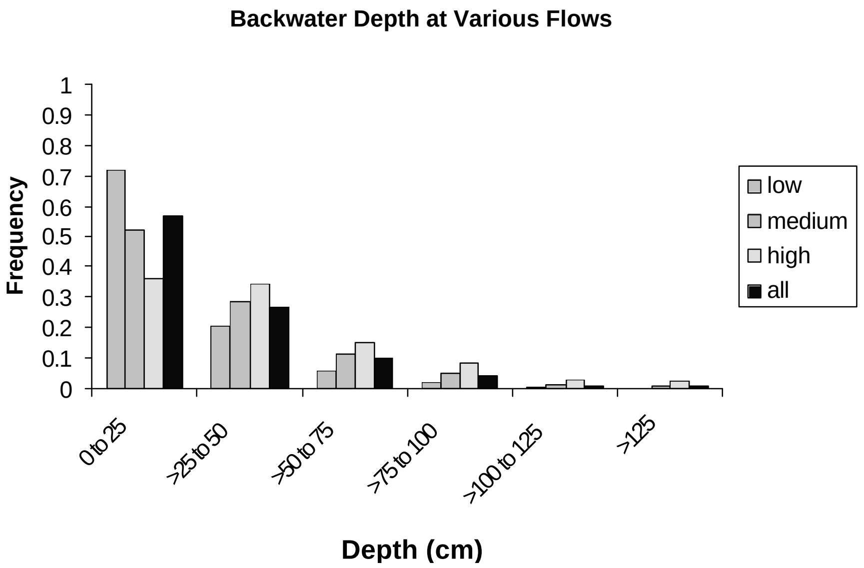


**Figure A.1: The figure presents a histogram that demonstrates distribution of depths in Backwaters over various flows.**

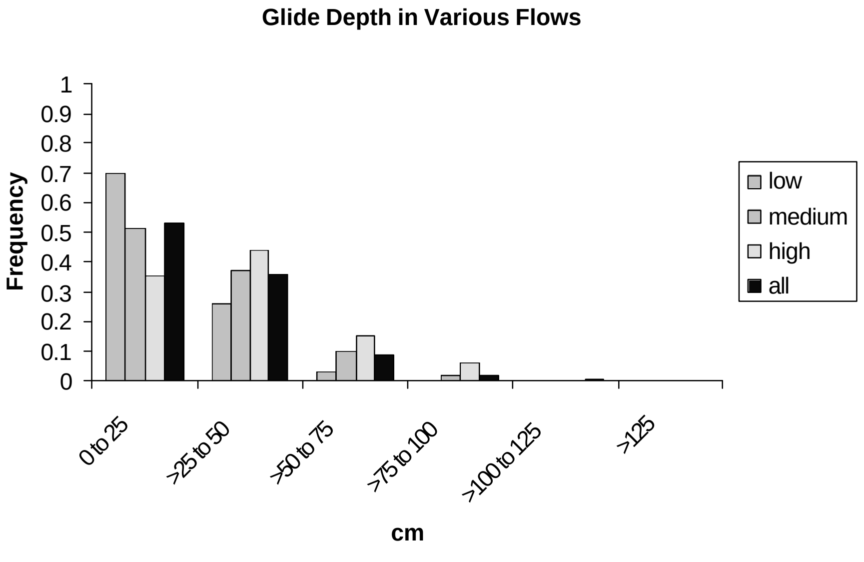


**Figure A.2: The figure presents a histogram that demonstrates distribution of depths in Glides over various flows.**

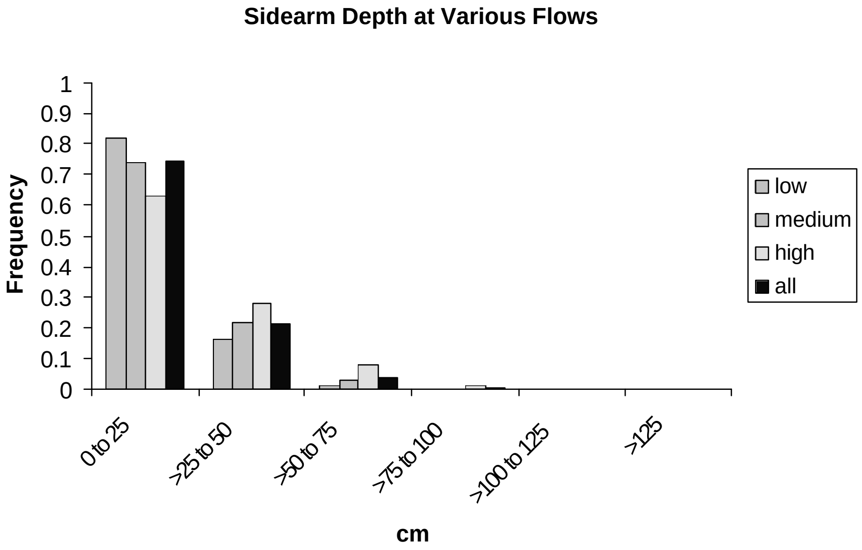


**Figure A.3: The figure presents a histogram that demonstrates distribution of depths in Sidearms over various flows.**

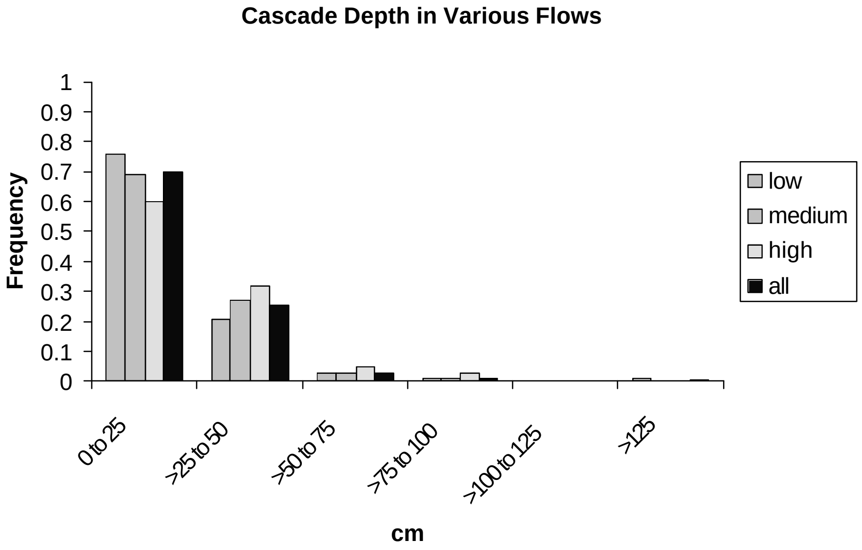


**Figure A.4: The figure presents a histogram that demonstrates distribution of depths in Cascades over various flows.**

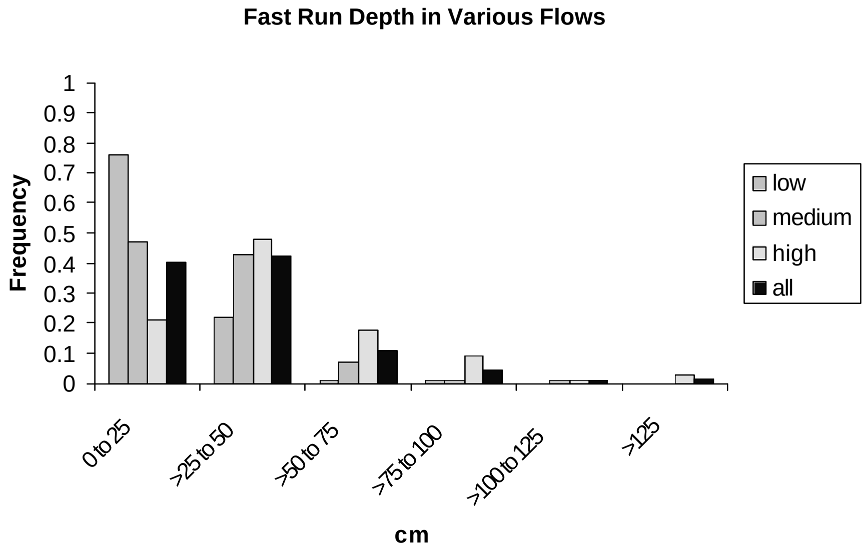


**Figure A.5: The figure presents a histogram that demonstrates distribution of depths in Fast Runs over various flows.**

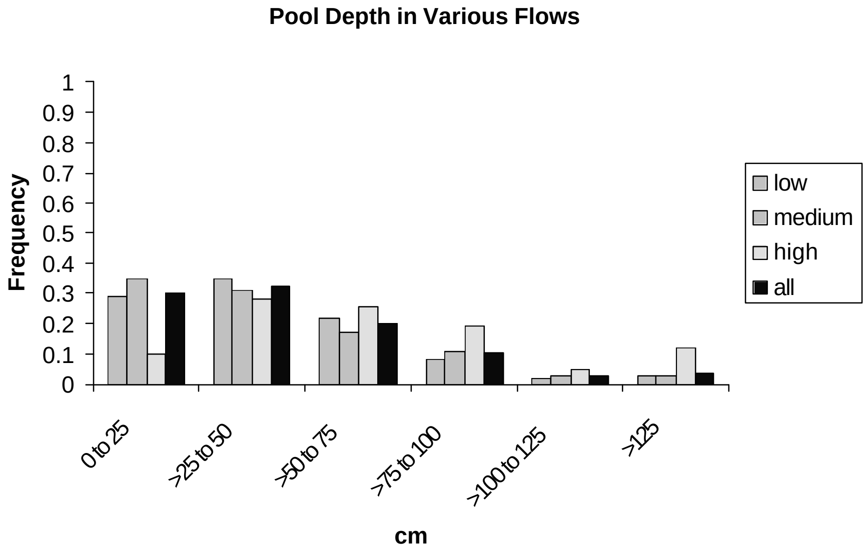


**Figure A.6: The figure presents a histogram that demonstrates distribution of depths in Pools over various flows.**

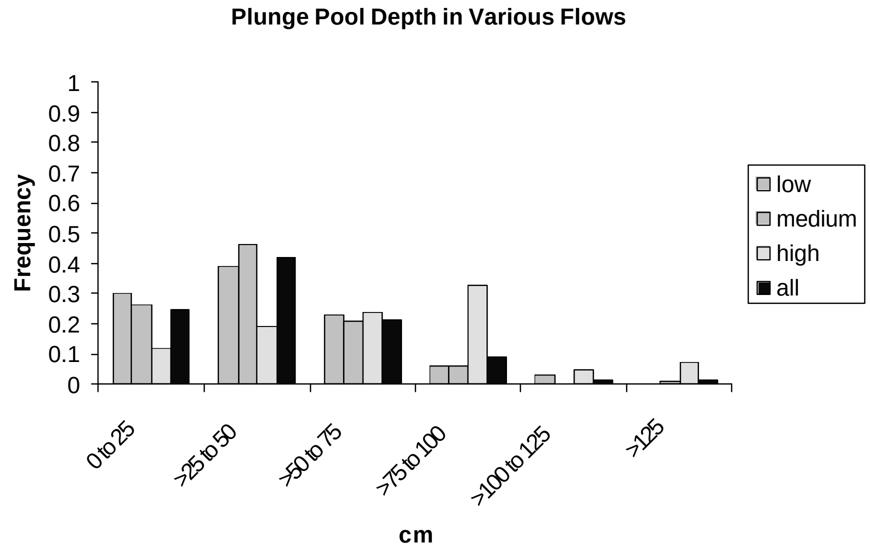


Figure A.7: The figure presents a histogram that demonstrates distribution of depths in Plunge Pools over various flows.

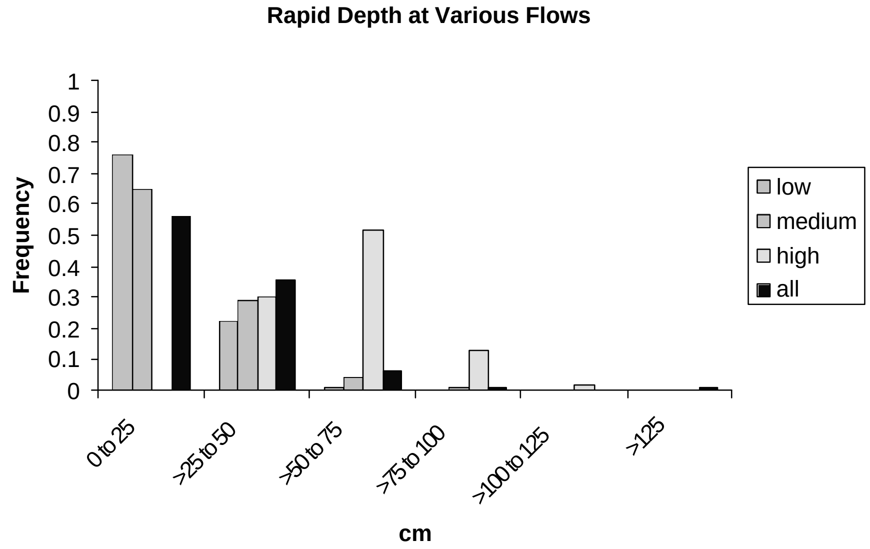


Figure A.8: The figure presents a histogram that demonstrates distribution of depths in Rapids over various flows.

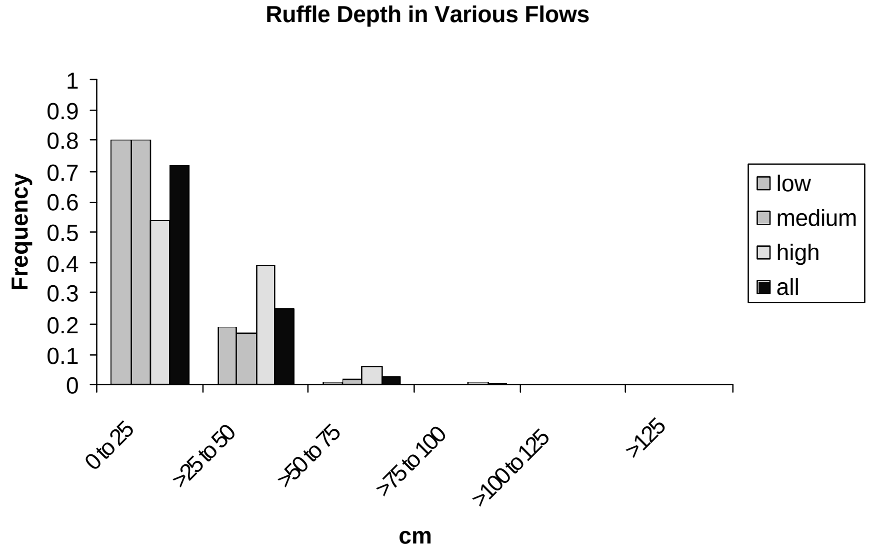


Figure A.9: The figure presents a histogram that demonstrates distribution of depths in Ruffles over various flows

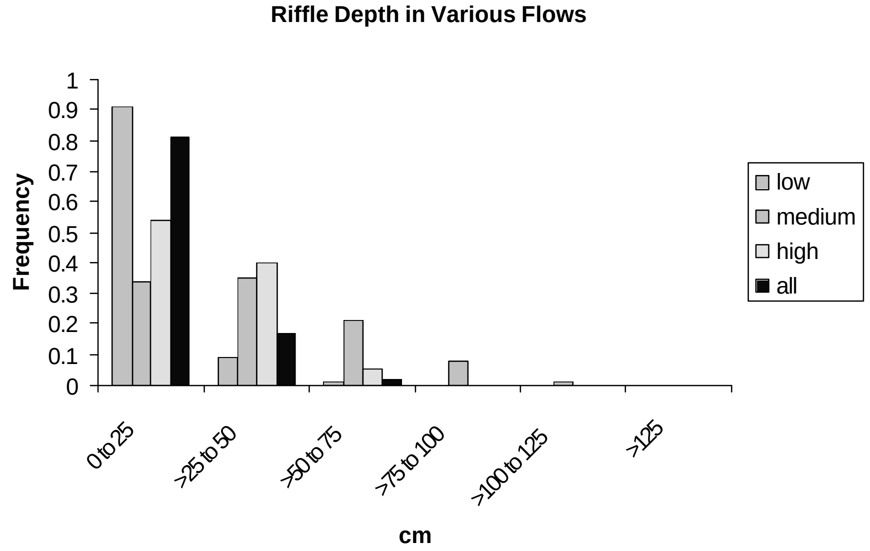


Figure A.10: The figure presents a histogram that demonstrates distribution of depths in Riffles over various flows

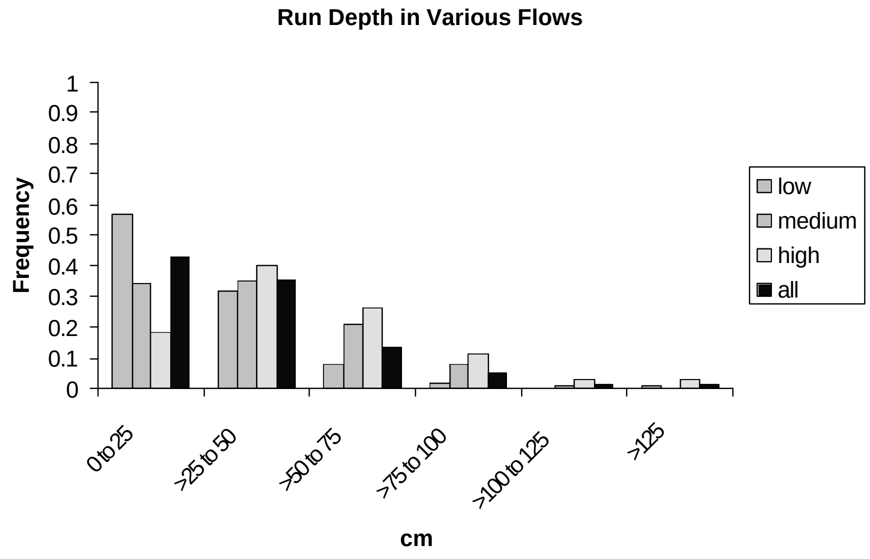


Figure A.11: The figure presents a histogram that demonstrates distribution of depths in Runs over various flows

# APPENDIX B

## HISTOGRAMS FOR HMU VELOCITY DISTRIBUTION

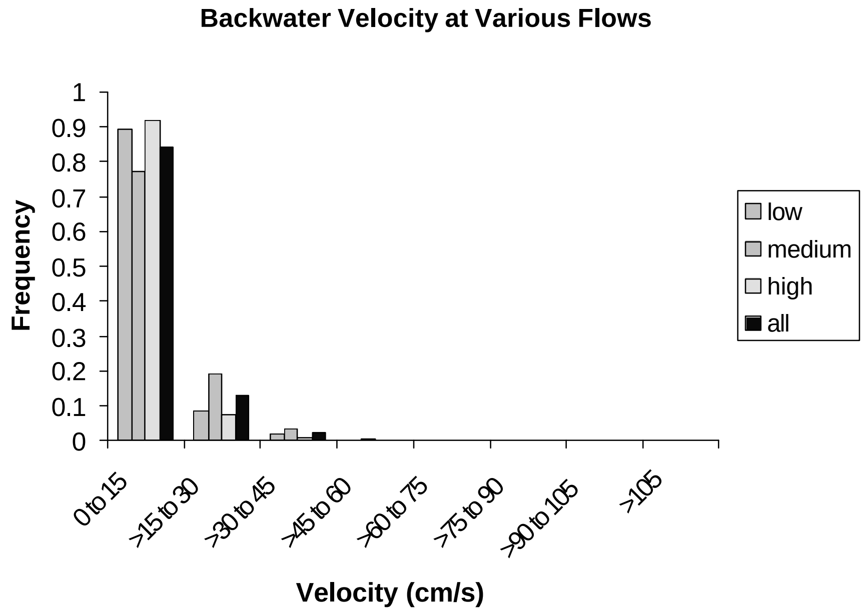


**Figure B.1: The figure presents a histogram that demonstrates distribution of velocities in Backwaters over various flows.**

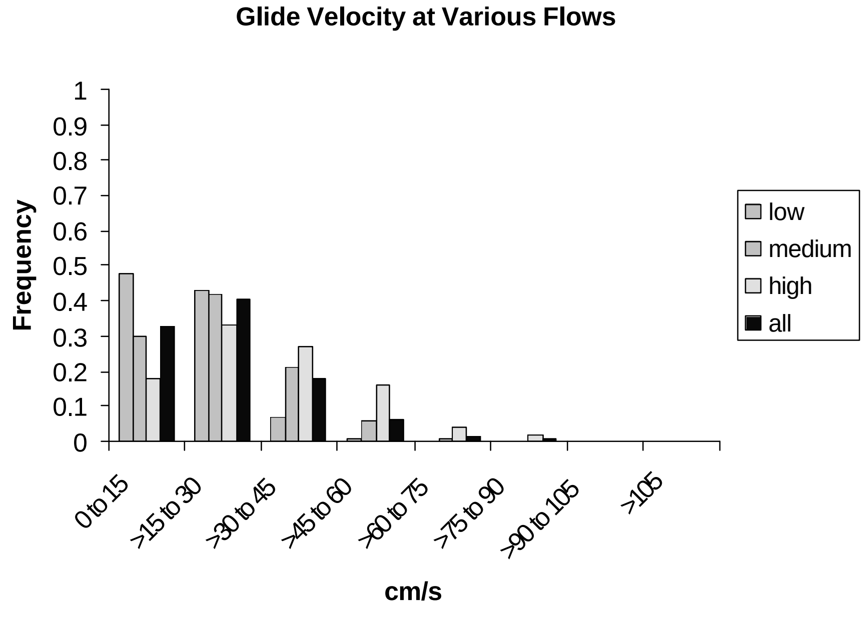


**Figure B.2: The figure presents a histogram that demonstrates distribution of velocities in Glides over various flows.**

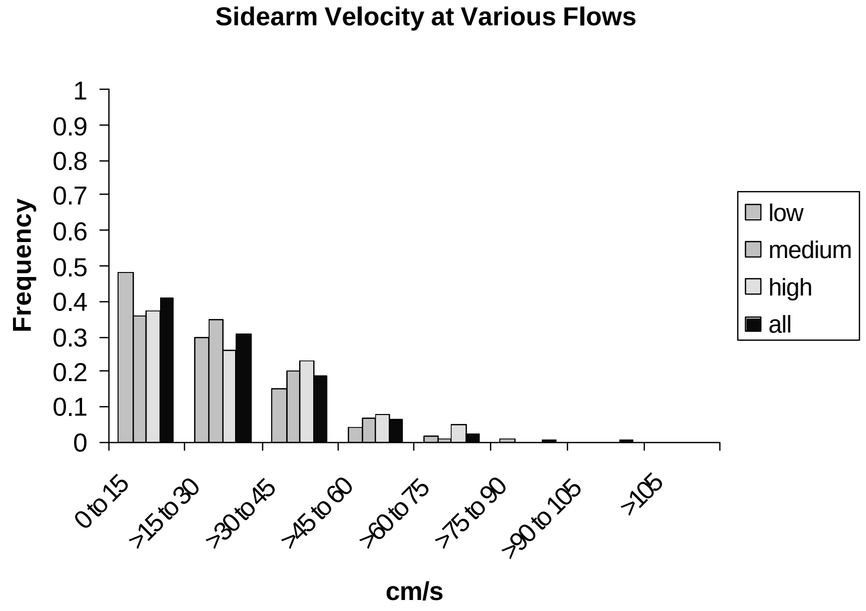


Figure B.3: The figure presents a histogram that demonstrates distribution of velocities in Sidearms over various flows.

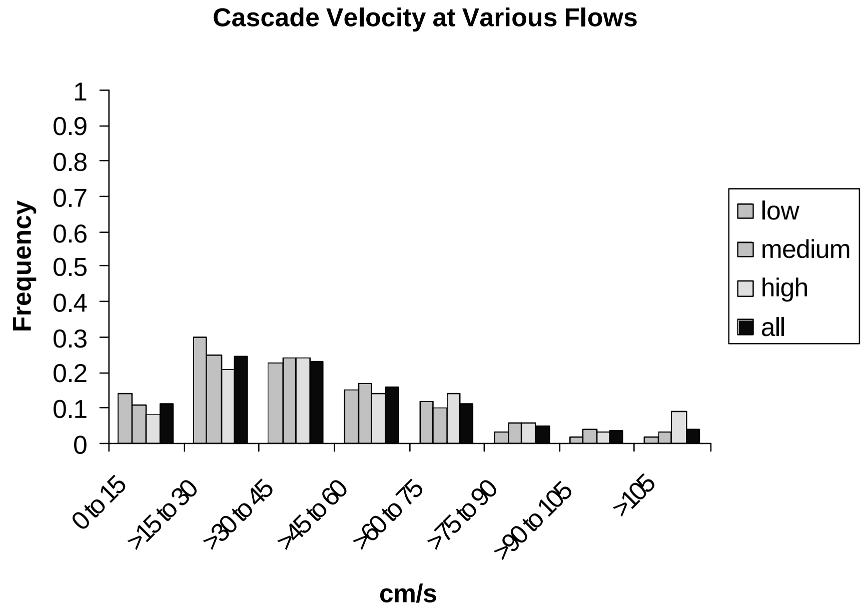


Figure B.4: The figure presents a histogram that demonstrates distribution of velocities in Cascades over various flows.

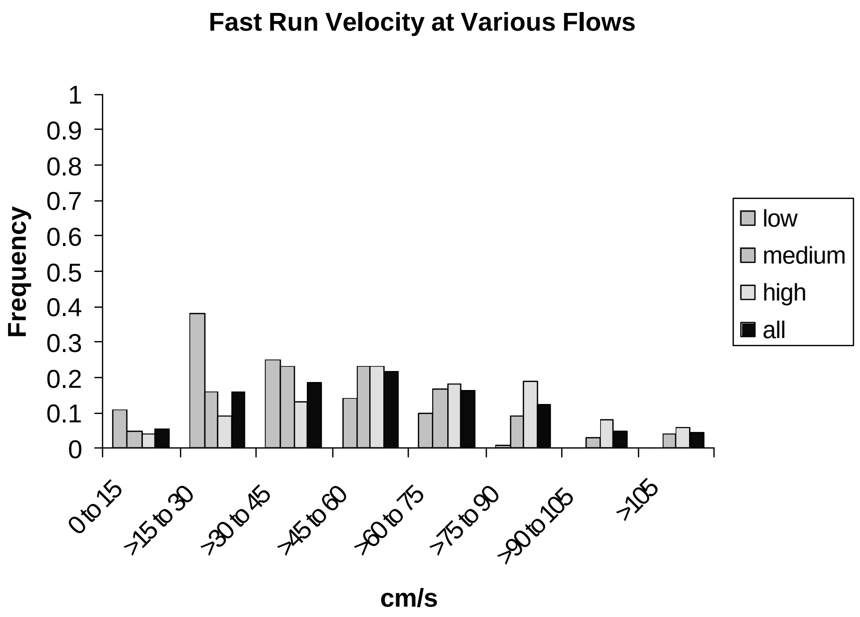


**Figure B.5: The figure presents a histogram that demonstrates distribution of velocities in Fast Runs over various flows.**

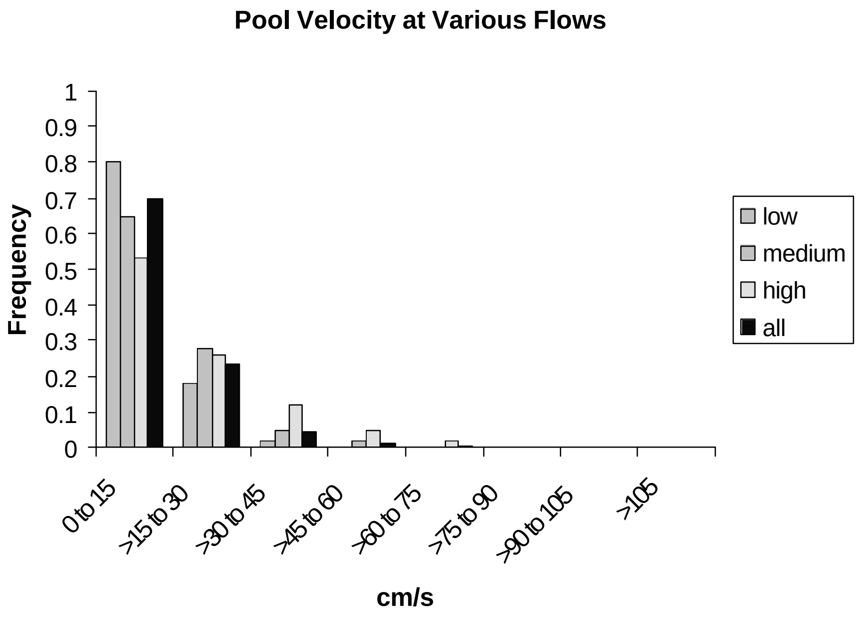


**Figure B.6: The figure presents a histogram that demonstrates distribution of velocities in Pools over various flows.**

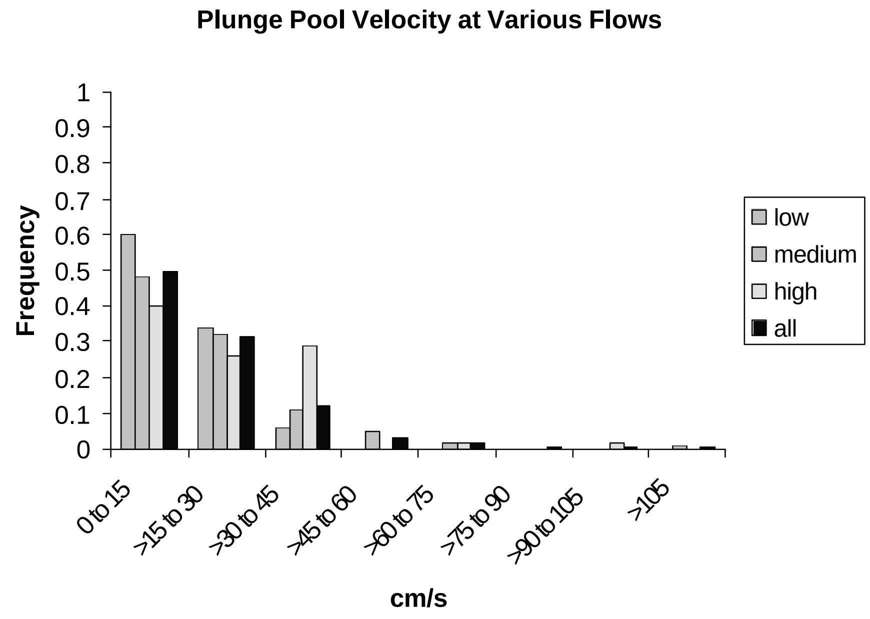


**Figure B.7: The figure presents a histogram that demonstrates distribution of velocities in Plunge Pools over various flows.**

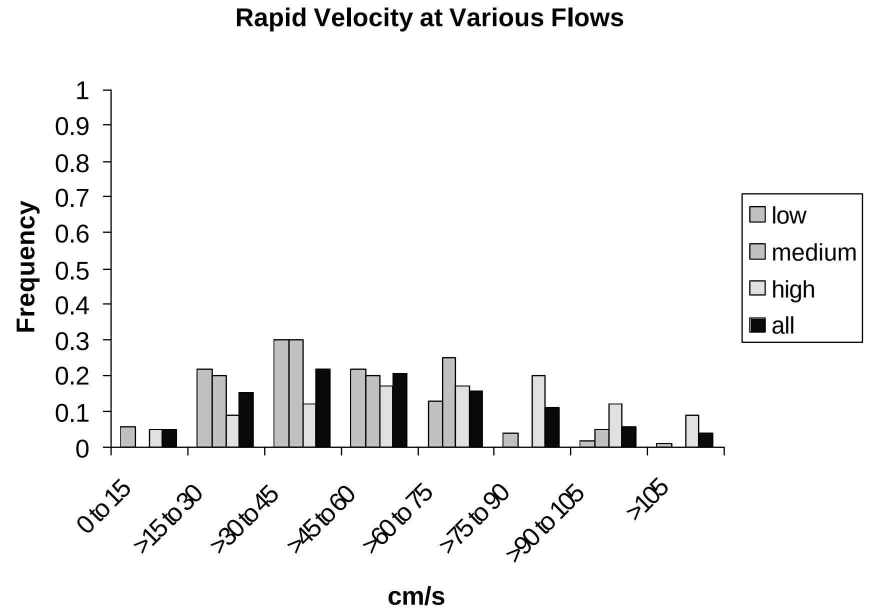


**Figure B.8: The figure represents a histogram that demonstrates distribution of velocities in Rapids over various flows.**

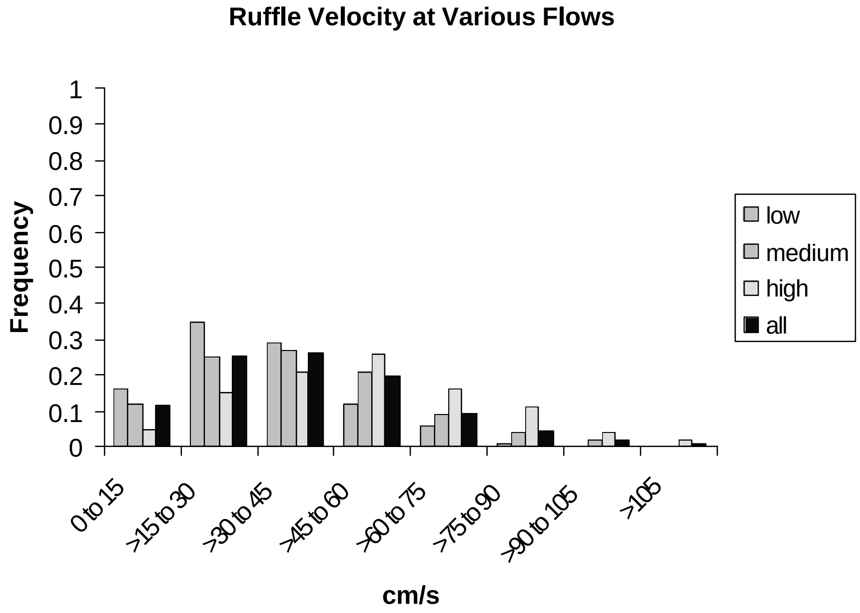


**Figure B.9: The figure presents a histogram that demonstrates distribution of veocities in Ruffles over various flows**

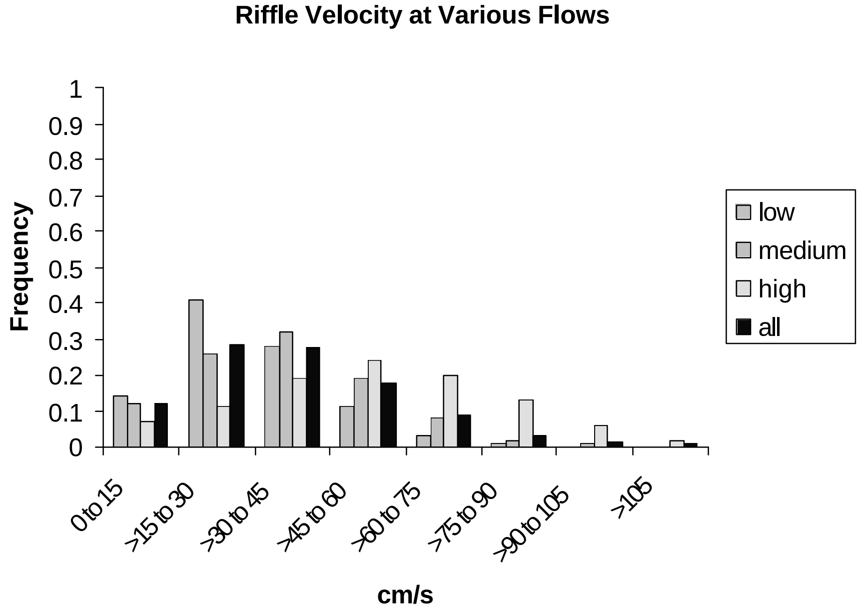


**Figure B.10: The figure presents a histogram that demonstrates distribution of velocities in Riffles over various flows**

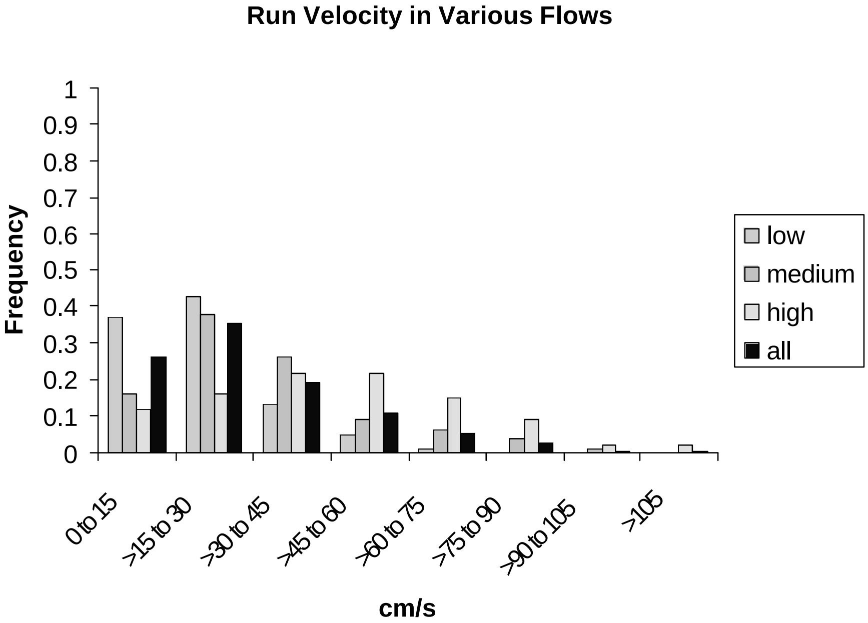


Figure B.11: The figure presents a histogram that demonstrates distribution of velocities in Runs over various flows

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University of Massachusetts Extension Issue Paper: Water Resource Protection May 2006 UMass Amherst 6 pp

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