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APPLICATION OF A SCIENCE-BASED, MULTI-SCALED APPROACH TO WATERSHED PROTECTION AND REHABILITATION IN THE RIFLE RIVER WATERSHED, MICHIGAN

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APPLICATION OF A SCIENCE-BASED, MULTI-SCALED APPROACH TO WATERSHED PROTECTION AND REHABILITATION IN THE RIFLE RIVER WATERSHED, MICHIGAN

By

Andrea Barbara Ania

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ABSTRACT

APPLICATION OF A SCIENCE-BASED, MULTI-SCALED APPROACH TO WATERSHED PROTECTION AND REHABILITATION IN THE RIFLE RIVER WATERSHED, MICHIGAN

By

Andrea Barbara Ania

Currently, there are many different watershed analysis and planning procedures being used across the nation to address watershed health and halt the decline of aquatic species. The primary goal of this project was to apply a science-based, landscape-level approach to watershed protection and rehabilitation utilizing an existing watershed analysis and planning procedure. I used *Ecosystem Analysis at the Watershed Scale: The Federal Guide for Watershed Analysis* (EAWS) to describe hydrologic and land use trends, determine the current stream temperature regime, predict the impacts of global warming on stream temperature, and qualitatively assess stream channel morphology in the Rifle River watershed, Michigan. The results of EAWS analysis were used to recommend areas within the Rifle River watershed to protect and enhance fish habitat. Results suggest base-flow has increased over time and there has been an increase in developed land, grassland, and shrub land. Temperatures upstream of river kilometer 33 are satisfactory for salmonids under current and predicted global warming conditions; temperature does not appear to be a limiting factor downstream where warmer temperatures occur. Problems (e.g., erosion, silt) in the mainstream and tributaries were identified along with their potential causes (e.g., channelization, culverts).

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INTRODUCTION

Healthy watersheds play a beneficial role in supporting human, aquatic, and terrestrial life. Some of these benefits include the availability of clean water for human consumption, recreational opportunities, quality of life, and maintaining viable fish and wildlife populations. Fresh water comprises less than 1% of the global water supply (Fetter 2001); therefore, it is imperative that these finite fresh water resources remain suitable for human consumption and sustaining diverse, resilient aquatic ecosystems.

Watersheds are the interface where physical, biological, and chemical processes interact with each other and with human economic, recreational, and cultural activities. Watersheds, also called catchments or basins, are geographic areas where surface and groundwater flow drains into a common outlet such as river, stream or other surface channel (Armantrout 1998). Watersheds can vary in size from individual to multiple river basins and include all the land that drains into the river system. Due to the terrestrial linkages of the aquatic components of watersheds, land-use practices (e.g., urbanization, roads, agriculture) significantly contribute to the physical and biological degradation of aquatic ecosystems.

A healthy watershed is one that supports the native biotic community and exists in what is referred to as a dynamic equilibrium. In the state of dynamic equilibrium, the system is capable of recovering from perturbations and can maintain native aquatic community structure and diversity (Heede 1986). Physical and chemical watershed processes create the available habitat for fish and aquatic organisms, which ultimately determines the diversity of species a watershed can support. Characteristics such as water temperature, food availability, in-stream cover, spawning substrate, and chemical properties such as dissolved oxygen and nutrients collectively determine the type and diversity of habitat accessible to fish. Human land use choices such as removal of streamside vegetation can alter these characteristics, resulting in a shift in the abundance and type of aquatic organisms a watershed can support, which is also referred to as the loss of aquatic habitat.

Loss of aquatic habitat due to land use/land cover (LULC) change is becoming a global issue (Lambin et al. 2001). As the world's population continues to expand, natural resources are increasingly exploited to fulfill human needs at the expense of sustainable and diverse ecosystems (Foley et al. 2005). The collective land-use effects of urbanization, agriculture, grazing, mining, logging, damming, and water withdrawals are some of the activities directly and indirectly impacting our nation's fish populations through habitat loss, degradation, and fragmentation (National Fish Habitat Initiative 2006; Williams et al. 1997).

Both point source pollution (i.e., sewage or industrial waste) and nonpoint source (NPS) pollution contribute to water quality impairment and the overall health of a watershed. Nonpoint source pollution occurs when rainwater or snowmelt transports pollutants (e.g., sediment, fertilizers, pesticides, oil, grease) into surface or ground waters. The U.S. Environmental Protection Agency (USEPA) estimates NPS pollution comprises 60% of all water pollution (Maine

Department of Environmental Protection 1998), making it the nation's primary source of water quality degradation. Sediment and nutrients are the principal sources of NPS pollution in aquatic environments (USEPA 1997).

Agricultural land use is responsible for the majority of NPS pollution in the United States. Agricultural activities such as cattle grazing and crop production accelerate erosion due to land-disturbing activities that facilitate the removal and transport of sediment into lotic (i.e., flowing water) environments (Hairston et al. 2001). Excessive sediment entering a stream can reduce salmonid productivity by suffocating fish eggs and clogging interstitial spaces that are used by young fish and invertebrates. After agriculture, urbanization is the second leading cause of stream impairment. Urban areas negatively impact stream hydrology, geomorphology, and biotic community richness by making the stream more flashy, widening the stream channel, and reducing fish and aquatic insect diversity due to increased runoff from impervious surfaces (e.g., paved roads, roofs) and nutrient loading from municipal wastewater discharge plants (Paul and Meyer 2001).

Although agricultural land-use is the major source of NPS pollution in the United States, environmental degradation has not been observed until >50% of upstream land-use is agriculture (Wang et al. 1997). In urban areas, watershed health (e.g., biotic integrity, habitat quality) begins to deteriorate around 10% impervious surface and severe degradation is observed in excess of 30% (McClintock and Cutforth 2003; Wang et al. 1997). Impervious surfaces prevent rainfall from infiltrating and percolating through the ground, resulting in increase runoff and elevated water temperatures, which can lead to habitat degradation and loss of aquatic habitat important to fish and wildlife.

Streambank vegetation, also called riparian vegetation, provides many ecosystem services to fish and wildlife. For example, 30m vegetated buffers provide benefits such as sediment removal, reduced erosion, and water temperature stabilization (USDA-USFS 2003; Schultz et al. 1994). Sixty meter riparian buffers function as effective flood control and 90m buffers provide the greatest benefit to wildlife (USDA-USFS 2003). Thus, as buffers increase in size they provide more ecosystem services. Some studies have investigated whether land use at the watershed scale or the 100m riparian buffer scale is more reflective of the physical habitat available and thus, aquatic ecosystem health; however, these studies have produced incongruous results (Richards et al. 1996; Wang et al. 1997). For example one study found 100m buffers were better predictors of sediment-related variables while the entire watershed was more important for maintaining overall stream health (Richards et al. 1996). Since the influence of riparian buffers varies by width and physical site characteristics (e.g., slope, stream order, vegetation type and condition), it is essential to understand how buffers and whole catchment land use is influencing a watershed (USDA-USFS 2003).

Restoration and Rehabilitation

Habitat rehabilitation is a necessary tool for improving ecosystem health. The terms *rehabilitation* and *repair* will be used in this paper to describe habitat manipulation efforts commonly referred to in the literature as stream or aquatic habitat "restoration." Rehabilitation projects begin with a degraded condition (e.g., streambank erosion) and initiate ecosystem improvement of watershed processes and function, but preclude the establishment of a historical goal (Bradshaw 1987). The term *restoration* will not be used in this paper because true restoration implies the return of ecosystem processes and function to a relatively original or indigenous state (Whisenant 1999). Defining an original, indigenous, or historical state is complicated (e.g., pre-humans, pre-colonial settlement, pre-logging) and often this information is unavailable, making it difficult to set and achieve restoration goals. Furthermore, the introduction of non-native invasive species can impede true restoration because a purely indigenous ecosystem may no longer be unattainable due to their presence. Watershed rehabilitation projects are often focused on improving water quality and recovering fish habitat.

Physical Processes

Although numerous factors contribute to the biological diversity of river ecosystems, physical processes create the habitat (or structure) necessary for aquatic life and determine the range of aquatic organisms a watershed can support (Gordon et al. 2004). In watershed systems, physical processes include climate, geology, topography, hydrology, geomorphology, LULC, and components of water quality (Figure 1). Physical processes interact with each other and the biological community; thus it is important to understand these complex interactions to develop effective watershed management plans.

Physical processes operate on a number of spatiotemporal scales. On a regional scale, climate is affected by the topography of a basin and respectively influences the geology, vegetation, and hydrology of the area. Infiltration and runoff within the watershed are controlled by the area's geology, topography, and vegetation (Fetter 2001). On a local level, the presence, abundance, and type of riparian vegetation (i.e., streambank vegetation) influence in-stream habitat, biota, channel structure, and organic input.

The hydrologic regime of a watershed is the collective input of water from precipitation, surface water, and groundwater plus the amount of water leaving the watershed due to evaporation and transpiration (Armantrout 1998). The natural flow regime (or hydrology) of a basin is defined by the magnitude, frequency, duration, predictability, and flashiness (i.e., rapid increase in stream flow) of a river (Poff et al. 1997). Watershed hydrology "determines the biotic composition, structure, and function of aquatic, wetland, and riparian ecosystems;" therefore, understanding the degree that the natural flow regime has been altered by humans is essential to effective watershed management planning (Richter et al. 1996, p. 1163). When natural hydrologic processes are altered, geomorphic processes (e.g., sediment size, channel stability, floodplain morphology) change correspondingly and this influences the quality of aquatic insect and fish habitat available (Heede and Rinne 1990; Poff et al. 1997). Watershed rehabilitation that fails to acknowledge the significance of hydrology, geomorphology, and land use can produce ineffectual results; for example, stabilizing eroded streambanks that have resulted from urbanization and increased runoff fails to address the source of the problem and may transfer the problems downstream or upstream of the site (Brooks et al. 2003).

Groundwater (water that accumulates underground) discharges into streams when the water table rises above the streambed and water emerges through a system of slow seepages or as a spring. During base-flow conditions (i.e., drought or low flow), groundwater provides the entire stream flow and is characteristic of the geology, topography, soils, and climate of the basin (Hendrickson and Doonan 1972). Groundwater-dominated rivers provide cooler, more stable water temperatures and flows, which are important for supporting a diversity of fauna and maintaining healthy salmonid populations (Sear et al. 1999). Land-use activities that remove riparian vegetation can alter hydrological processes by disconnecting the floodplain or destroying adjacent wetland habitat. This can result in diminished groundwater recharge and increased surface runoff, thus altering groundwater-surface water interactions (e.g., flood attenuation, lower base-flow, increased water temperature; Winter et al. 1998).

The temperature and chemistry of the water also influences lotic community structure and composition. Water temperature has a strong influence on many fish species, ranging from acute lethal consequences to regulating migration (Bartholow 2000; Gallagher 1999; Bond 1996). Water temperature plays a vital role in determining fish and aquatic species composition, growth rates, and life-stage(s) a watershed can support (Roni 2005). For example, coldwater fish like trout, are typically found in waters with mean daily temperatures below 65°F (20.6°C; Holton and Johnson 1996). Dissolved oxygen, rates of allochthonous decomposition, and nutrient availability are functions of water temperature and water chemistry, ultimately shaping the spatial and temporal distribution of aquatic organisms (Bain and Stevenson 1999).

Understanding the relationship between physical and ecological processes is essential for managing and predicting ecosystem response (Richards et al. 1996). Varying physical and ecological processes emerge at different spatiotemporal scales and reveal processes interacting among scales (Fausch et al. 2002); thus, well planned rehabilitation and monitoring projects require small, intermediate, and large-scale habitat information (e.g., pool→reach→ watershed) to be effective. A multi-scaled approach to aquatic rehabilitation advocates the assessment of ecological systems at the local, reach, and watershed scales to achieve rehabilitation goals through understanding natural processes that create fish and wildlife habitat (Roni 2005).

Small-scale sites can range in size from a few meters to 100m and data is typically collected at points (e.g., habitat units) within the watershed (Roni 2005). Some examples of small-scale data include stream temperature, dissolved oxygen, or in-stream habitat-features (i.e., pool, riffle, run). Unique habitats or disturbance events at specific sites (points) along a stream can have profound effects, influencing properties of the entire system at great distances in either direction (Fausch et al. 2002). Thus, point data alone has limitations and may not reflect the complexity of physical, chemical, and biological interactions within the watershed.

Intermediate-scale stream habitat features (e.g., reach, segment) typically range from 100m to several kilometers and exemplify the scale of most rehabilitation and monitoring efforts (Roni 2005). Qualitative habitat evaluations and quantitative longitudinal profile surveys are some examples of stream reach measurements (Armantrout 1998). Collecting stream reach data is a valuable fisheries tool because it enables biologists to characterize the type of habitat available to fish during different life stages (Fausch et al. 2002). By understanding the quality, quantity, and connectivity of in-stream fish habitat, rehabilitation and protection efforts can be effective by addressing problems at a spatial scale relevant to fish and the life stage of concern. Thus, reach scale data should be gathered to ensure effective fisheries and watershed management planning occurs.

Regional or large-scale habitat features can be an entire state (Wang et al. 1997) or the catchment area above a sampling site (Roth et al. 1996), and this approach requires landscape tools to achieve a broad-based view. GIS is a useful computer-based tool for mapping, planning, and decision-making at watershed-level scales (e.g., 1:100,000-1:24,000). Geographic information systems (GIS) facilitate decision-making activities by allowing users to analyze multiple data sets to reveal complex patterns and relationships (ESRI 2004). By allowing multiple coverage overlays, GIS functions as a decision support tool that can assist managers and biologists in the decision-making process and provides a useful tool for modeling impacts on aquatic habitats (Fisher and Rahel 2004). This map-based approach allows relationships between land-use activities, the riparian zone, and in-stream fisheries to be analyzed. For example, it is possible to use GIS applications to predict the impact of hydrologic processes (e.g., spring runoff, reaches with high rates of ground water input) on trout populations (Fisher and Rahel 2004). By working with watershed-level scales, characteristics such as geology, hydrology, and LULC databases can be used to asses land-water relationships (Fisher and Rahel 2004).

National Fisheries Habitat Initiative (NFHI)

There has been a great deal of time and money invested in addressing water quality and aquatic species concerns. Unfortunately, habitat loss and degradation continues to occur. For example, over $1.8 billion was spent on restoration activities between 1992 and 2001 in the Great Lakes Basin alone, yet basic water quality and restoration problems continue to exist (USGAO 2003). In the mid-west region of the United States (Michigan, Ohio, Indiana, Illinois, Wisconsin, Minnesota, Iowa, and Missouri), 75% of freshwater mussels, 67% of crayfish, and 60% of fish are imperiled locally, imperiled range-wide, or possibly extinct (Patronski and Oetker 2004).

Due to the continued decline in fish populations, the Sport Fishing and Boating Partnership Council proposed the cultivation of a national effort focused on protecting, rehabilitating, and enhancing fisheries and aquatic habitats (NFHI 2004). In 2004, the U.S. Fish and Wildlife Service (USFWS) led this endeavor by launching the NFHI. The NFHI has received overwhelming support from state, federal, tribal, and non-governmental agencies. As a result, this national call to action has grown into the National Fish Habitat Plan (NFHAP). The NFHAP is an important on-going effort to move from opportunistic, site-specific restoration to a science-based, landscape-level approach to aquatic habitat management through the use of science and partnerships (NFHAPB 2006).

From the inception of the NFHI to the current NFHAP, the North American Waterfowl Management Plan (NAWMP) was selected as a template for developing and implementing a successful science-based, landscape-level fish habitat program. The NAWMP was selected as a model because it is acknowledged as one of the worlds' most prominent conservation initiatives (CWS 2007). The NAWMP was initiated between the United States and Canada in 1986 and later joined by Mexico in 1994. This continental joint venture program's main purpose is to address declining waterfowl populations through protecting, restoring, and enhancing waterfowl habitat (USFWS 2007a). To-date, $4.5 billion dollars has been spent on project goals achieving 15.7 million acres of wetland and upland habitat across the participant countries (USFWS 2007b). As a result of these efforts, targeted population goals have been surpassed for three principal duck species (i.e., gadwall, green-winged teal, and northern shoveler), and two other duck species (i.e., scaup and northern pintail) continue to receive recovery efforts as outlined in the Plan.

In addition to the NAWMP, there are other successful conservation initiatives; for example, the Oregon Plan for Salmon and Watersheds, the Chesapeake Bay Program, and The Nature Conservancy's Conservation Initiatives. The success of these initiatives has been attributed to a unique mix of characteristics such as being partnership-driven, science-based, and geographically-focused. In addition, project efficacy is determined through monitoring, which also allows long-term projects to be adaptively managed and improves accountability. In fact, the NFHAP was designed by stakeholders to incorporate these common characteristics that have been proven to mature into successful conservation initiatives.

The NFHAP is a national effort to halt and recover declining fish populations by establishing regional partnerships, using the best available science to guide the decision-making process, and monitoring project effectiveness. The plan also strives for partnerships to address problems at spatiotemporal scales most meaningful to fish species and life stage of interest. The success of this program is expected to be gauged by comparing stated protection, rehabilitation, and enhancement goals (e.g. social, economic, biological, and ecological benefits) against final, observed outcomes. Additionally, monitoring and reporting measurable results will increase accountability to political, peer, and public stakeholders to ensure fish population and habitat goals are being achieved. Ultimately, the efficacy of the NFHAP will be measured by meeting fish population recovery goals.

Currently, there are many different approaches to watershed protection, rehabilitation, and enhancement efforts. These efforts range from being general to specific and having different strengths and weaknesses. There has not been a watershed planning and analysis framework selected or implemented for the NFHAP; thus, a component of my research was to apply an existing approach that may be helpful in accomplishing the goals of the NFHAP.

Goal

The primary goal of this project is to apply a science-based, landscape-level approach to watershed protection and rehabilitation utilizing an existing watershed analysis and planning procedure. The specific objectives were to:

1) Apply the *Ecosystem Analysis at the Watershed Scale: The Federal Guide for Watershed Analysis* (RIEC 1995) to Michigan's Rifle River watershed to describe hydrologic and land-use trends, and determine the current stream temperature regime.
2) Recommend areas within the Rifle River watershed to protect and enhance fish habitat.

First, I will discuss the watershed analysis and planning framework that was selected and how it facilitates a science-based, landscape-level approach to watershed protection and rehabilitation. Second, I will apply the watershed analysis procedure to describe and quantify physical watershed processes. Third, I will recommend areas to protect, rehabilitate, and enhance fish habitat based on results of the selected watershed analysis procedure.

The results of this study should provide insight to watershed management professionals challenged with selecting, implementing, and predicting ecosystem response to rehabilitation projects by using the best available science. Additionally, a science-based approach improves accountability for money and resources used for rehabilitation. Local governments could also use the results of this study to advocate for sustainable ecological and economic growth by protecting sensitive habitats; this should reduce the need for rehabilitation funds, and protect aquatic species and their habitats. Lastly, knowledge gained from this study may assist partners in selecting a watershed planning framework that considers physical processes operating on multiple scales and halt the decline in aquatic species populations.

PROTOCOL SELECTION

The design and implementation of science-based watershed rehabilitation projects should involve the expertise of an array of disciplines such as, biologists, entomologists, geomorphologists, hydrologists, and engineers. These teams of experts should possess the scientific competency to ensure the best available information is collected and used. The term "sound science" (or science-based) will be used in this document as defined by the Society of Environmental Toxicology and Chemistry as "organized investigations and observations conducted by qualified personnel using documented methods and leading to verifiable results and conclusions" (SETAC 1999). Using the best available science to guide decisions will enhance accountability, and augment the field of watershed rehabilitation (Williams et al. 1997).

Although this approach takes time and expertise, the benefits of science-based, multi-scale rehabilitation are gaining recognition and momentum. Many watershed groups and partners are interested in switching to this approach to address the underlying causes of ecosystem impairment and to recover system biotic and abiotic factors (NFHI 2006). By identifying and treating ecosystem (watershed) dysfunction, the primary causes of degradation can be addressed and the consequences of rehabilitation become more predictable (Williams et al. 1997).

Aquatic rehabilitation must also function as a component of regional and local land management to be effective (Hobbs 1996). One way to achieve this goal is for local watershed councils to develop partnerships with state, federal, tribal and non-governmental organizations. Watershed councils are formed from community-based concerns for ecosystem health and are typically centered-around a commitment to improve water quality and fish habitat. By partnering with governmental agencies and non-governmental organizations, watershed councils can gain access to technical expertise, coordination skills, and funding resources essential to achieving rehabilitation goals.

Many other examples of federal, state, and non-governmental successful watershed management planning guidelines and documents exist today. Watershed frameworks have been developed to facilitate coordination among partners, enhance the achievement of water resource management goals, and maintain environmental quality (USEPA 2002). Since there has not been a watershed planning and analysis framework selected or implemented for the NFHAP, a component of this research was to select an existing approach with the potential to accomplish the goals of the NFHAP.

The following overview of watershed protocols is based on a review of the literature. This information is intended to provide insight into some of the drawbacks and benefits to three different watershed planning approaches 1) the Michigan Department of Environmental Quality (MDEQ), 2) the Michigan

Department of Natural Resources (MDNR), and 3) Ecosystem Analysis at the Watershed Scale (EAWS; Table 1).

Michigan Department of Environmental Quality

The MDEQ guidelines (*Developing a watershed management plan for water quality: An introductory guide*; Brown et al. 2000) are implemented under the Clean Water Act (CWA; MDEQ 2006). Under CWA's Section 319, the federal government provides financial aid to watershed councils that are working to reduce NPS pollution and protect water resources. In Michigan, the DEQ is responsible for allocating Section 319 funds and assisting watershed councils in establishing appropriate water quality criteria goals that are then addressed through rehabilitation planning and implementation.

The MDEQ guidance document provides descriptive guidelines for watershed management planning focused on water quality. This planning process is valuable because it has a grassroots focus involving local citizens and resource professionals who share a common vision. It also draws on the expertise of multiple partners and promotes knowledge sharing among group members. However, this approach narrowly focuses on water quality to restore and protect designated uses.

Additionally, the MDEQ guidelines recommend identifying pollutants, sources, and causes through a visual assessment of the watershed. Although this descriptive approach familiarizes stakeholders with the watershed, the procedure falls short of cultivating a science-based understanding of watershed processes and identifying the true causes of ecosystem impairment.

Michigan Department of Natural Resources

Another approach to watershed management planning is through the use of MDNR's comprehensive river assessments. River assessments are documents prepared by Fisheries Division biologists for selected watersheds (e.g., Thunder Bay River Assessment, Jordan River Assessment). Biologists use the best scientific information available to describe the physical environment, dams and barriers, water quality, special jurisdictions, historical and modern fisheries management, biological communities, public comments, and management options for watershed issues. Drafts of the river assessments are available to the general public for a period of review and comment.

Although citizens and other agencies are allowed to comment and provide input prior to final publication, the lack of multi-agency expertise and public involvement does not foster and engage partnerships. As a result, watershed groups may be less willing to use a river assessment to guide protection, rehabilitation, and planning efforts. Additionally, completed river assessments are a compilation of agency findings from comprehensive literature and data reviews, but do not focus on integrating ecosystem processes.

Finally, river assessment documents do not function as effective long-term management tools because they present the results of agency analysis rather than primary data (i.e., summarized rather than original data). Not having access to the primary data limits watershed groups ability to incorporate additional data, ask new spatial questions not addressed in the river assessment, or analyze interrelated ecosystem processes (e.g., land use and water temperature).

Incorporating original agency data into a GIS-based tool would allow user groups to evaluate rehabilitation and land use scenarios, functioning as decision support systems to guide multi-level watershed planning, rehabilitation, and monitoring.

Ecosystem Analysis at the Watershed Scale (EAWS)

The third approach to watershed-scale planning is a guidance document that was developed by a multidisciplinary group of federal, tribal, and state partners in the western United States (*Ecosystem analysis at the watershed scale: the federal guide for watershed analysis*; RIEC 1995). This procedure is geared toward guiding interdisciplinary teams of resource specialists through a six step ecosystem scale process. Teams are encouraged to use the best available science and staff to complete the watershed analysis. The ecosystem analysis procedure assists teams in characterizing the human, aquatic, riparian, and terrestrial processes operating within a selected watershed by responding to core watershed-level questions on erosion processes, hydrology, vegetation, stream channel, water quality, and species.

This latter framework for watershed planning raises valuable questions regarding catchment-level processes and interactions. The EAWS process is designed to generate baseline information about the watershed and provide a platform for continued integration of new information. The EAWS encourages federal, tribal, state, local, and public involvement early in the planning process. It also provides an ideal platform to incorporate GIS analysis to enhance decision-making such as project planning, modeling, development, implementation, and monitoring. Lastly, it advocates a shift from species based and site specific management to an ecosystem based approach where project outcome becomes more predictable due to our understanding of watershed scale processes.

Although the three guidelines to watershed assessment and planning share a common goal of improving aquatic resources, they have different target audiences, uses, and technical (scientific) content. I will apply the *Ecosystem Analysis at the Watershed Scale: the Federal Guide for Watershed Analysis* to the Rifle River watershed for this study. Applying and evaluating this ecosystem-based approach to watershed analysis and planning is necessary for several reasons. First, it will determine if characterizing ecosystem processes operating within a watershed is necessary for taking a scientific approach to watershed rehabilitation and protection. Second, understanding the complex interactions between land cover, which has a biophysical role, and other ecosystem processes (e.g., water temperature, hydrology) can enhance watershed planning committees ability to protect and rehabilitate valuable fish and wildlife resources. Third, watershed assessment analysis conducted at multiple scales will provide useful information to watershed planners in similar physiographic areas. Lastly, it appears to be the most suitable protocol for accomplishing the goals of the National Fish Habitat Action Plan.

APPLICATION OF ECOSYSTEM ANALYSIS AT THE WATERSHED SCALE

Ecosystem Analysis at the Watershed Scale (EAWS) is designed to guide interdisciplinary, interagency teams through an ecosystem-based analysis rather than the traditional site or species-specific planning process. The six step process is intended to guide planning teams in: 1) characterizing a watershed, 2) identifying key watershed issues, 3) describing current conditions relevant to key watershed issues, 4) describing reference conditions relevant to key watershed issues, 5) exploring and interpreting changes between reference and current conditions, and 6) developing management recommendations for key watershed issues. By applying the six step process to core topics – erosion processes, hydrology, vegetation, stream channel, water quality, and species and habitats – an understanding of basic ecosystem processes, conditions, and interactions can facilitate sustainable watershed planning (Appendix A).

It is important to note that in a complete watershed analysis, the interdisciplinary expertise of partners and public involvement would be crucial to the development of an effective watershed plan. Due to time and personnel constraints, a partial watershed analysis was conducted for this study, but I consulted with professionals possessing essential interdisciplinary expertise. For the purposes of this study, application of EAWS entailed characterization of land cover (vegetation), hydrology, water temperature, and stream channel morphology to address specific research questions about the Rifle River watershed, as outlined below.

Land Use/ Land Cover

Land use/ land cover reflects the type and abundance of vegetation on the landscape that can influence hydrology, water temperature, and stream channel morphology. Research questions were focused on determining if land cover changes have occurred over time, how natural habitats have been impacted (e.g., changes in the type and abundance of vegetation, reduction of natural habitat), and the spatial extent of changes.

First, I evaluated how land cover changed at the watershed scale from historic (circa 1800) to recent conditions (1992). Then I examined more recent land use trends by comparing 1992 and 2001 vegetation data to determine if land use changes occurred and the spatial extent of those changes (watershed level, 90m, 60m, and/or 30m buffers). This information was used to address the following research hypothesis:

H1: Between 1992 and 2001, there is no significant difference in land use/ land cover at the watershed scale; however, there is a significant difference in land use at the riparian scale (90m, 60m, and 30m buffers) due to a decrease in natural habitats in the Rifle River watershed.

The rationale behind this research question is based on my expectation that land use has shifted from agriculture to forest at the watershed scale and that development within the riparian zone has increased.

Next, I evaluated if the 90m buffer was historically (circa 1800) an indicator of watershed scale land use and if it is currently an indicator of watershed scale land use. Previous research has produced incongruous results on this topic and further investigation may clarify the impact humans have on the landscape. Finally, the watershed was divided into sub-watersheds to determine if land use is significantly different in the upper, middle, and lower sections. Results will be useful for recommending where to focus rehabilitation efforts.

Hydrology

Historic and existing hydrologic conditions were characterized to determine if hydrology has changed over time. Dominant hydrologic trends were evaluated, along with other watershed characteristics, to address the following hypothesis:

H2: Watershed hydrology has changed over time, resulting in reduced storage capacity and an increase in runoff due to loss of natural habitat within the riparian zone.

The presence and abundance of vegetation on the landscape, climate, and geology influence watershed hydrology; therefore, these characteristics were examined to assist in interpreting the results of hydrologic analysis. These results will be useful for investigating natural and human influences on watershed hydrology and the implications of those changes such as altering water quality and stream geometry.

Water Temperature

Water temperature falls under the core topic of Water Quality and also under the core topic of Species and Habitats. Water temperature, a water quality and biophysical parameter, was also evaluated to determine if thermal conditions are limiting salmonid distribution in the Rifle River watershed. Salmonids have been the focus of previous rehabilitation efforts, but it is unclear if the Rifle River exceeds water temperature tolerance limits for salmonids. Water temperature data collected by the MDNR suggests tributaries to the Rifle River may be providing thermal refuge for salmonids in the summer (July) and winter (February) when water temperature extremes occur. Modeling heat transport will explain the current environment and aid in identifying where temperature extremes may be limiting salmonid distribution. It can also be used to classify habitat for early life history steelhead (*Oncorhynchus mykiss*), resident brown trout (*Salmo trutta*), and resident brook trout (*Salvelinus fontinalis*) based on temperature requirements established in the literature. Based on global temperature modeling presented in Bartholow (1989), the Rifle River has the potential to be impacted by increases in global air temperature, which could shift the range of salmonids north of the watershed. The temperature model can be used to predict the impacts of global warming on salmonid distribution and recommend priority areas for habitat rehabilitation and protection.

Stream Channel Morphology

This topic was qualitatively assessed by inventorying in-stream and riparian habitat conditions in the mainstream and tributaries. The results of this assessment will be used to identify potential concerns related to geomorphic attributes and the quality of habitat available to fish, specifically salmonids. .

Study Site

The Rifle River watershed (RRW) was selected as a prototype for this study for numerous reasons including its significant fish and wildlife resources, sociopolitical importance, and ecological integrity. The Rifle River is located in northeastern-lower Michigan (Figure 2) and drains an area of approximately 99,718 hectares (385 square miles; MDNR 2002). The mainstream is perennial, stretching 105 river kilometers (rkm) long (65 river miles) from Ogemaw to Arenac County where it empties into Lake Huron's Saginaw Bay (HPRC&D 2005).

Of the 298 rkm of perennial stream in the watershed (185 river miles), approximately 80 rkm (50 river miles) of the mainstream and 97 rkm (60 river miles) of tributaries are designated as wild-scenic river under Michigan's 1970 Natural River Act (MDNR 2002). The Natural River Act also provides zoning set-backs and restrictions to "preserve, protect and enhance the Rifle River environment in a natural state for the use and enjoyment by all generations" (MDNR 2002, p 19). Additionally, the mainstream and tributaries (above T19N, R4E, Section 5, except Richter and Wells Creek) are recognized by the state of Michigan as designated trout streams (MDNR 2000).

The RRW supports over 40 fish species (Table 2). The upper portion of the watershed is known for brook trout and brown trout fishing (MDNR 2002). A sucker run (*Catostomidae* spp.) occurs each spring and is celebrated locally during the Omer Sucker Festival located in Omer, Michigan. There are also numerous federal and state listed threatened, endangered, proposed, and candidate species of plants, reptiles, insects, and birds found in the watershed (Table 3). In addition to the quality fishing opportunities, the RRW offers hunting, wildlife viewing, boating, trapping, and biking opportunities within a few hours drive of major metropolitan areas (i.e., Detroit, Bay City, Saginaw, Midland, and Flint), making it easily accessible to large urban populations.

The historical significance of the RRW dates back to Michigan's earliest inhabitants, which were Native Americans (Knutilla et al. 1971). There are two sites near the mainstream that allegedly provided winter protection for Native Americans during the period AD 1100-1400 (MDNR 2002). During the logging era (1840-1900), Michigan dominated national lumber production from 1869 to 1900 (Cook 2006). As a result of this vast logging, lumbermen were attracted to the area and created the settlements of Rose City, Lupton, and Selkirk (Knutilla et al. 1971). Virgin white (*Pinus strobus*) and Norway pine (*Pinus resinosa*) were harvested and floated down the Rifle River to be milled in Saginaw (Knutilla et al. 1971). The long-term impacts of clear-cut logging are unknown for this watershed. However, a study in Wisconsin found hydrologic and geomorphic conditions such as the sediment loads and channel bed elevation were altered in historically clear-cut areas that were then put into agricultural production (Fitzpatrick et al. 1999).

Based on 1998 land use estimates, the watershed is approximately 55% forested, 21% agriculture, 11% wetland, 3% urban, and 10% other (open space, roads, and idle land; SBRC&D et al. 1999). Forested lands are predominantly second and third growth pine and hardwoods; agricultural land is primarily for dairy and cattle production (MDNR 2002). As a result of glaciation, the watershed has varied topography and relief. The northern portion rises above 400 meters elevation and has rolling hills (MDNR 2002). At the mouth, the elevation is significantly lower as the river drains into an outwash plain of low relief (USGS 1972).

The mainstream of the Rifle River is one of the few undammed, free-flowing rivers in the Lake Huron watershed. The lack of barriers allows fish movement to occur unimpeded. The basin receives an average of 29 inches of precipitation a year and the upper portion of the watershed is predominantly (~73%) groundwater-driven, which provides stable water temperatures and ensures summer base-flows are sufficient to support resident trout populations (Knutilla et al. 1971; SBRC&D et al. 1999). Although groundwater is primarily supplied from glacial deposits of sand, clay, and gravel (Knutilla et al. 1971), 33% of the input is derived from sub-surface interbasin flow from the adjacent AuSable River watershed (SBRC&D et al. 1999). Due to artificial drainage (e.g., county drains) and underlying clay soils, the middle and lower portions of the watershed experience flashier hydrography (i.e., rapid increase in stream flow; SBRC&D et al. 1999). In addition to the perennial stream system, approximately 435 rkm of intermittent stream exist throughout the watershed.

The Rifle River Watershed Restoration Committee (RRWRC) was officially formed in the mid-1990s to increase coordination and collaboration of public and private partners working to reduce NPS pollution within the watershed (SBRC&D et al. 1999). Prior to the council's formation, the Mershon Chapter of Trout Unlimited led habitat rehabilitation efforts aimed at improving the recreational trout fishery (SBRC&D et al. 1999). Concern over protecting the high water quality and recreational opportunities drove numerous rehabilitation efforts, guidance documents, and state initiatives within the watershed (e.g., road-stream crossing assessment, streambank erosion inventory, in-stream habitat projects). Currently, a storm water management study is being conducted to protect the watershed from sediment and pollutants associated with storm water discharges.

The RRWRC is composed of local citizens, non-governmental organizations (Saginaw Mershon and Ann Arbor chapters of Trout Unlimited, Saginaw Bay and Huron Pines Resource Conservation & Development Councils), the Saginaw Chippewa Indian Tribe, and state (MDNR, MDEQ, Michigan Department of Agriculture) and federal agencies (U.S. Department of Agriculture, USFWS). Although the RRWRC is not currently a nonprofit organization, members have been meeting since the 1990s and partners have raised nearly $1.5 million for habitat protection and rehabilitation (HPRC&D 2005). Members of the RRWRC are dedicated to the resource and share a common goal to HELP (Honor, Enjoy, Love, and Protect) the watershed (HPRC&D 2005). The Nature Conservancy has also identified this watershed as a conservation area but has had little involvement due to funding restrictions (Kline personal comm. 2004).

The RRW was selected as the nation's first watershed development program in the 1950s, functioning as a pilot for conducting watershed-level stream improvements (Tody 1950). The ultimate goal of this effort was to enhance trout production by treating fish and game production, stream pollution, soil erosion, and agriculture as components of stream degradation (MDC 1951). Although innovative for its time, this landscape approach to rehabilitation fell short of its goal because river and ecosystem processes were poorly understood during that era. The watershed was selected then, as it is now, due its natural and cultural importance, proximity to large urban populations, resilient community advocacy, and relatively intact ecological integrity. The decision to use the RRW today was also based on the existence of historical hydrological and fisheries information from the 1950s, when the upper portion of the watershed was used as a fish and wildlife field laboratory (MDNR 2006).

Starting in the 1950s, trout populations of the RRW have been the focus of many stream improvement projects (Gowing 1968); therefore, a thermal model was developed to evaluate water temperature trends and identify potential biological limitations within the watershed. Due to stakeholder interest, there has been a significant amount of site-specific rehabilitation work conducted within this watershed, but additional work remains as new areas become degraded and unplanned development threatens ecosystem health. An understanding of how watershed processes operate and interact is essential for long-term management and protection of the RRW. Currently, there is insufficient information regarding how the watershed functions as a system and whether rehabilitation efforts have been effective.

METHODS

GIS Land Cover Analysis

To answer research questions, the vegetation category of EAWS was expanded to reflect commonly used GIS land cover classification schemes. Plant communities (e.g., forests, wetlands, grasslands) with the potential to benefit wildlife are natural habitats and unnatural habitats include land use activities (e.g., commercial, residential, agriculture) that may be negatively impacting physical and biological watershed characteristics. Land cover data is commonly available in the GIS environment and existing data from circa 1800, 1992, and 2001 were used in this study to determine changes in land use patterns over time.

The circa 1800 dataset was selected to represent historic conditions because it is the oldest GIS vegetation layer available for the Michigan and the best representation of plant communities prior to human disturbance. The most recent GIS vegetation data available was collected in 2001, thus 2001 data will be used to represent current land use patterns. The 1992 dataset was selected because it will allow research questions to be addressed about recent land use changes in the watershed (from 1992 and 2001).

Circa 1800 vegetation data was obtained from the Michigan Natural Features Inventory (MNFI) and was used in this study because it represents Michigan's vegetation prior to logging and development. This GIS layer has a pixel resolution of 30 square meters (m^2) and is an interpretation of land surveyor notes recorded between 1816 and 1856. A limitation of this dataset is that surveyor transects were spaced approximately 1.6 kilometers (km) apart and land cover has been interpolated between transects based on factors such as soils, current wetlands, slope, elevation, and aspect (Schools 2007). As a result of the scale differences between the circa 1800 vegetation dataset and current land cover datasets, quantifying a direct change in land cover over time would be inappropriate (Schools 2007); thus, changes in land cover were compared as percentages. Spatial data for 1992 and 2001 was obtained from the U.S. Geological Survey's National Land Cover Database (NLCD) and is based on Landsat satellite imagery, which has a pixel resolution of 30 m^2. The 2001 dataset was chosen to reflect current conditions within the watershed. Due to the limited datasets in existence, the 1992 dataset was used as an intermediate dataset between circa 1800 and 2001.

GIS land cover analysis was conducted at the watershed level and within riparian buffers using ArcGIS 9.0. Due to the $30m^2$ resolution of the GIS layers, stream buffer widths of 30m (~100ft), 60m (~200ft), and 90m (~300ft) were used in analysis and buffers extended on both sides of the river. The 30m (60m lateral zone) buffer was of interest because it is the approximate width of the USDA Forest Service riparian buffer model (Welsch 1991), and provides benefits such as sediment removal, reduced erosion, and water temperature stabilization (USDA-USFS 2003; Schultz et al. 1994). The 60m (120m lateral zone) buffer was selected because it is an intermediate between the 30m and 90m buffer widths and is the optimal minimum width for effective flood control (USDA-USFS 2003). The 90m buffer (180m lateral zone) was used in this study to evaluate how buffer and whole catchment land use is influencing the RRW. In addition, the watershed was divided into upper, middle, and lower sections or sub-watersheds to assess if current (2001) land use is similar throughout the watershed. Sub-watershed delineation was based on rationale as outlined in the Qualitative Habitat Assessment methods of this thesis.

The buffer tool was used to generate riparian buffers of 30, 60, and 90m extending on both sides of the Rifle River polyline feature. Each of the buffers was then used as a mask to extract land use from the vegetation raster image datasets (1800, 1992, and 2001). The percentage of total area per land cover class was calculated for the entire watershed and riparian buffer areas within the watershed. For sub-watershed analysis, land use percentages were based on the proportion of land use in each class relative to the total area of the sub-watershed. For example, the percentage of deciduous forest in the upper portion of the watershed was calculated by dividing the amount of deciduous forest in the upper watershed by the total area of the upper watershed.

Fourteen land cover classes were identified in the MNFI circa 1800 layer and 15 land cover classes were identified in the 1992 and 2001 NLCD for the Rifle River watershed. For the purpose of analysis, MNFI and NLCD land cover classes were each reclassified into the following eleven categories: open water, deciduous forest, coniferous forest, mixed forest, woody wetlands, herbaceous wetlands, grasslands/ herbaceous/ savannah, scrub/shrub, developed, agriculture, and miscellaneous unnatural habitats (Table 5).

Summarized results of land cover were calculated and plotted to determine if land cover classes could be further combined. Miscellaneous unnatural habitats were not present in circa 1800 and represented only a small percentage (0.0% to 0.3%) of land cover during 1992 and 2001; therefore, this category was omitted from all graphs and values were combined with the developed class for statistical analysis. Woody and emergent herbaceous wetlands were originally calculated separately to determine the dominant type of wetland habitat present in the watershed. At all spatial and temporal scales analyzed, woody wetlands were the dominant wetland vegetation and emergent herbaceous wetland lands represented a small percentage of land use (<5%). Thus, woody wetlands and emergent herbaceous wetlands were combined into one class labeled wetlands for statistical analysis. The shrub/scrub land cover class was only present in 2001; it is defined as an area dominated by shrubs less than 5 meters tall and greater than 20% canopy. This class was not similar to any of the other land cover classes, thus it could not be combined nor omitted. Open water was not included in statistical tests because percentages were similar between all years and this land cover class was not directly related to hypothesis testing.

Statistically significant relationships were determined by a p-value of $p \leq 0.05$ and all calculations were computed in the statistical software SAS®. I used the chi-square test (X^2) of homogeneity to determine if overall land use was statistically different between vegetation datasets and/or spatial scales being evaluated. Where chi-square test results were significant, the chi-square test was repeated to determine if land use classes could be combined and identify which land use classes were different from each other (Snedecor and Cochran 1989). Land use categories were combined until no further categories could be combined due to significant chi-square results (Snedecor and Cochran 1989).

Land use differences were evaluated between circa 1800 and 1992 at the watershed scale, to establish if land cover changes had occurred over time.

Land use differences were evaluated between 1992 and 2001 at all four spatial scales (watershed, 90m, 60m, and 30m) to address my hypothesis that there is no significant difference in land use between 1992 and 2001 at the watershed scale, but a significant difference exists in land use at the riparian scale (90m, 60m, and 30m buffers). Land use differences were evaluated for both circa 1800 and 2001 between the watershed scale and the 90m riparian buffer to ascertain if the 90m buffer is reflective of watershed scale land use. Further analysis was conducted on the 2001 dataset to identify where watershed scale and riparian buffer land use is different. Finally, land use similarity was determined for sub-watersheds to identify areas where rehabilitation efforts should be focused. In summary, land use similarity was determined:

1. between circa 1800 and 1992 at the watershed scale,
2. between 1992 and 2001 at the watershed scale,
3. between 1992 and 2001 within each riparian buffer (90m, 60m, and 30m),
4. between circa 1800 watershed scale and 90m riparian buffer,
5. between 2001 watershed scale and each riparian buffer (90m, 60m, and 30m),
6. 2001 at the sub watershed scale.

Hydrologic Analysis

A 69-year (1938 – 2006) record of mean daily discharge data was evaluated to describe and quantify changes in the hydrologic regime of the RRW over time. United States Geological Survey (USGS) stream flow data was used to characterize current and historical hydrological conditions in the watershed. Currently, there is one functional USGS gage station operating in the watershed and it is located on the mainstream of the Rifle at Melita Road (M-70) near Sterling, Michigan. The gage is positioned 32 km upstream of the mouth and drains an area of approximately 830 km^2 (320 mi^2), which is approximately 80% of the watershed. Mean daily discharge data for water years (October 1 – September 30) in cubic feet per second (cfs) was used in hydrologic calculations.

Indicators of Hydrologic Alteration (IHA) software (The Nature Conservancy 2006; Richter et al. 1996, 1997, 1998) was used to conduct trend analysis. The 69-year record of data was analyzed as a single time period (i.e., trend analysis) because there have been no significant impacts to the system over time (e.g., dam, impoundment) that would warrant pre- and post-impact assessment. The IHA software calculates 67 statistical parameters, consisting of 33 IHA and 34 Environmental Flow Component (EFC) parameters, and generates associated significance values (Tables 6 and 7; The Nature Conservancy 2006).

Hydrologic datasets typically have non-normal (skewed) distributions; therefore, non-parametric statistics (i.e., median and percentiles) were selected for calculation in the IHA software because they provide more robust measures of central tendency and variability within the dataset and are less affected by extreme values. Parametric statistics (i.e., mean and standard deviation) were calculated for average monthly flows and flood frequency because this approach was recommended in the IHA literature. The use of parametric statistics removed some of the variability by using the average rather than median value, and therefore provided higher r^2 values by improving the fit of the trend line to the data. The IHA software uses least-squares fit regression lines to evaluate trends over time along with regression values and statistical test results (p-values). I determined statistically significant relationships by a p-value of ≤ 0.05. Rain events were assumed to be occurring uniformly within the watershed and modeling the influence of the location of precipitation events to the stream gage was not a component of this research.

In addition to IHA analysis, mean annual flow was calculated because it reflects the average river flow over the period of record, which provides a more stable measure of stream flow over time. Mean annual discharge was computed by dividing the sum of mean daily discharge values by the number of daily discharge values for the year. Stream flow values were plotted over time and visually examined for trends.

Water Temperature Model

I developed a mechanistic temperature model for the RRW to evaluate and quantify heat transport within the system. In particular, I was interested in modeling water temperatures under low flow conditions because they can limit fish distribution. During low flow conditions, stream depth decreases as flow decreases, potentially raising water temperatures (Gordon et al. 2004). I used the Stream Network TEMPerature model (SNTEMP), which was developed by the USFWS as a tool to predict daily mean water temperature in response to stream manipulation activities (e.g., rehabilitation, irrigation diversions, thermal loading). Input data required to build the SNTEMP mechanistic stream temperature model include stream geometry, time period, meteorology, and hydrology parameters (Table 8; Bartholow 2000). Data necessary to construct the temperature model was obtained from existing sources or gathered in the field, depending on availability.

The stream network was defined by assigning Melita Road (M-70) near Sterling, Michigan, as the starting reference point (rkm 0.0) and working upstream to the headwaters of the Rifle River near Lupton, Michigan (rkm 60.0). Melita Road was selected as the model reference point because coinciding water temperature and discharge data were available for this site and both are necessary for model development. The USFWS Sea Lamprey Control Program generously provided discharge data that was collected throughout the watershed during 1997 and 2000; this data was used to identify tributaries that have the ability to thermally alter the mainstream (contribute ≥ 10% of the mainstream flow) and should be represented in the SNTEMP stream network. This task was accomplished by plotting distance (rkm) against discharge (cfs) for the mainstream and tributaries. The following tributaries were identified and incorporated into the model through this process: Houghton Creek, Prior Creek, Klacking Creek, and the West Branch of the Rifle River (Figure 3).

Latitude, elevation, and distances (rkm) were measured using Terrain Navigator USGS topographic map software from Maptech®. Manning's *n* is a measure of channel roughness that typically changes during high and low flow conditions and as the stream bottom changes. SNTEMP, however, regards

Manning's *n* as a constant and an acceptable default value of 0.035 was used in the model.

Stream wetted width and percent shade data was collected in the field. Stream wetted width was estimated by measuring the width of the waters surface perpendicular to channel flow at 3 transects in each stream reach. Stream reach lengths were determined by multiplying wetted width at a representative channel cross-section by 7 (Bain and Stevenson 1999). Transects were evenly spaced along the reach and wetted width values were averaged. The amount the stream segment was shaded by vegetation at noon in July, also known as percent shade, was visually estimated for the SNTEMP model.

The SNTEMP model allows mean annual air temperature at the weather station to function as a surrogate for ground temperature. The streambed thermal gradient is an insensitive parameter and the suggested model default value based on Bartholow (2000) was used.

All meteorological data was obtained from the National Climate Data Center (NCDC). Saginaw MBS International Airport in Freeland, Michigan, was the closest weather station with comparable climate and topography to the Rifle River basin; therefore, mean daily air temperature, wind speed, dew point, and cloud cover data from this station were used to develop the SNTEMP model.

Missing air temperature values were derived by using the average daily temperature for the day before and after the missing data value. Quality control was conducted on all air temperature values (actual and derived) by plotting temperature over time to visually assess for outliers. No outliers were identified.

Relative humidity data was not available but could be approximated with a low error rate (0.6%) by using dew point and air temperature as outlined by Bartholow (1989) with the following equation:

$$Rh = [(112 - 0.1\ TA + Tdp) / (112 + 0.9\ TA)]^8$$

where Rh = relative humidity, TA = air temperature °C, Tdp = dew point temperature °C. Hourly cloud cover information was calculated to obtain daily average percentages. Percent sunshine was estimated by subtracting the percent of daily average cloud cover from 100%. Average daily dust coefficient and ground reflectivity values were estimated using equations presented in Theurer et al. (1984).

Average daily discharge data was obtained from the USGS. Water temperature data was collected by the MDNR using HOBO water temperature data loggers that were placed at 16 sites (11 tributaries and 5 mainstream sites) within the watershed. Average daily lateral inflow temperature was estimated to be 7.2°C (45°F) by using mean annual air temperature for the weather station as a surrogate.

Water temperature data was gathered in the field between 1997 and 2005; however, it was not continuously recorded during this time period and varied within and between sites. The HOBO temperature loggers measured water temperature 20 or more times a day, depending on how the unit was programmed. The four major contributing tributaries previously identified and incorporated into the stream network (Houghton, Prior, Klacking, and the West Branch) and four road-stream crossings on the mainstream (Ranch Bridge, State

Road, M-55, and M-70) were among the sites with existing temperature data. I determined that 1997 and 2000 calendar years had the most complete water temperature data sets. Hydrologic data for these two years was then further examined to determine if they were similar water years or represented different types of flow conditions.

Daily mean discharge data was visually evaluated for the period of 1995 to 2005 to determine annual discharge trends for 1997 and 2000 (Figure 4). Winter and spring discharge measurements for 1997 were above the 11 year average (1995-2005) and 2000 discharge measurements were below the 11 year average. The 1997 data set was used for model development and calibration. The 2000 data set was used for model validation and modeling low flow conditions.

Quality control was conducted on water temperature data by graphically plotting date against temperature to identify outliers. Only one site on the West Branch of the Rifle River had an extreme water temperature reading on the morning of June 10, 1997, and this temperature was removed from the dataset. This temperature appeared to be erroneous due to a large fluctuation in water temperature (± 10°F) within a two hour and twenty minute period.

Average water temperature values were calculated for each day. Missing daily water temperature values for stream network sites were estimated by chronologically ordering all daily air temperature and discharge values from January 1997 to December 2005 and running a multiple linear regression in SAS®. This approach allowed me to successfully derive a predictive relationship between daily average values for air temperature and discharge to fill missing water temperature values.

Water temperature data collected on the mainstream and tributaries was examined for existing trends and potential limitations to salmonids. The only continuous period of record where water temperature data existed for all mainstream data collection sites was from February 1997 to January 1998. Tributary data existed from late June 1997 to early June 1998 with the exception of Prior Creek where regression values were used. Mean daily water temperature was plotted over the corresponding period of record. Below zero water temperature values were changed to zero because the SNTEMP model produces error messages when negative values are present.

The model was calibrated by adjusting input parameters until predicted water temperatures matched measured temperatures closest. To determine if calibration adjustments improved model performance, predicted and measured temperatures were plotted over time and visually assessed. The calibration process was completed when no further model adjustments could be made to improve model performance and the model's output provided the "best fit" to measured water temperatures. Residuals (predicted - measured) were grouped into four categories to describe the model's predictive performance in terms of the percentage of time that predictions exceeded measured temperatures: 1) optimal (<1°C), acceptable (<2°C), marginal (2-4°C), and unacceptable (>4°C).

Stream width coefficient A, width exponent B, global air temperature, and humidity were adjusted as calibration parameters. Originally, stream width coefficient A had been set to stream wetted width measurements and width exponent B was set to zero, where width = (width coefficient A)*flow $^{(\text{width exponent B})}$ These were adjusted by developing a width-flow relationship and performing a standard linear regression for different portions of the watershed. The calculated coefficient A of 2.26 and exponent B of 0.25 was used for the upper section, coefficient A of 3.6 and exponent B of 0.86 was used for the middle section, and coefficient A of 4.8 and B exponent of 1.14 was used for the lower portion of the watershed. The global air temperature calibration coefficient was set to 1.1. Relative humidity values were decreased by 20-40% to reduce over-prediction during the winter. These adjustments were deemed appropriate because air temperature and relative humidity values used in the model were collected offsite (Saginaw International Airport) and under different conditions than those at the stream.

Originally, all headwater nodes (upstream boundaries of the mainstream and tributaries) were assigned zero discharge and allowed the model to estimate water temperature based on mean annual air temperature. However, using mean annual air temperature resulted in water temperature predictions that were uniform throughout the year, regardless of season (e.g., Houghton Creek at the mouth was 7.66°C all year) and this was not reflective of measured water temperature data. Thus, the model tended to over estimate mean daily water temperature in the winter and under estimate temperatures in the summer at all sites above Melita Road. As a result, all headwater nodes were moved closer to where actual temperature data had been collected and this improved model performance. Temperature data had been collected on tributaries near the mouth; therefore, using measured values in the model resulted in more accurate modeling of thermal contributions to the mainstream.

After the model was calibrated, a second independent dataset from 2000 was used for validation. Model validity was determined by graphically and statistically comparing measured data from 2000 to the models predicted temperatures. Graphically, the model was considered to be validated if predicted temperatures closely matched measured values. Statistically, the model was evaluated for goodness-of-fit by calculating the root mean square error (RMSE) using the following equation:

$$RMSE = [\sum (Pi - Oi)^2 / n]^{0.5}$$

where Pi = prediction at time/space i

Oi = observed value at time/space i

n = number of samples

The RMSE is a measure of the average error and will give an approximation of the difference between measured values and predicted. To check for systematic errors, residuals were plotted against observed water temperatures values and examined for trends. Finally, the process was ended when the error level was within an acceptable range (<10% of predicted values exceeded measured values by 4°C).

After calibration, the model was used to predict mean daily temperatures every 2 km along the stream network. Output results were used to calculate mean weekly temperatures and plotted seasonally over the length of the river to explain the current water temperature regime and identify where thermal limitations to salmonids may be occurring in the watershed. To determine the percentage of time watershed temperatures exceed optimal and lethal temperatures for salmonids, temperature duration curves were graphed. Temperature duration curves were constructed for the upper (above M-55), middle (above Maple Ridge Road), and lower watershed (above Melita Road) to determine the percent of time these sections of the watershed are suitable for salmonids. Global warming was modeled by increasing mean annual air temperature by 2.7°C. Daily model output values were then used to calculate mean weekly temperatures and plotted for the length of the river.

Lethal, optimal, and favorable water temperatures for brown trout, brook trout, and steelhead were used to interpret the biological implications of model output. Based on the literature and a synthesis of Michigan DNR temperature information, mean daily temperatures of 10-21°C are considered favorable for salmonid growth, 15-19°C is optimal, > 20°C is lethal for brook trout, and > 24°C is lethal for brown trout and steelhead (Wehrly et al. 1999; Eaton et al. 1995; Table 10).

Qualitative Habitat Assessment

A qualitative in-stream habitat assessment was conducted to characterize intermediate scale habitat features in the mainstream and tributaries. The mainstream was broken into three sections or sub-watersheds: upper (headwaters to M-55), middle (M-55 to Maple Ridge), and lower (Maple Ridge to Melita Road). Sub-watershed delineation was based on changes in geology, stream gradient, salmonid stocking boundaries, and a visual assessment of the river (Table 11). The mainstream from the headwaters (Rifle River Recreation Area) to Melita Road was visually assessed by kayaking the river and noting changes in field characteristics. Sample reaches were selected to accurately represent the proportion and variety of topographic features, riparian vegetation or land use, geomorphic features (i.e., pool, riffle, run), substrate, and streambank erosion represented within each sub watershed. Data was collected on 4.5 rkm within each sub watershed for a total of 13.5 rkm.

The tributaries sampled are those that the State of Michigan considers vital to the protection of the mainstream (Table 12). Three attempts were made to collect data on Silver Creek, but there was no satellite reception and the site was not surveyed. This resulted in each of the 16 tributaries being sampled 1 rkm for a total of 16 rkm. Data was collected by entering the channel near the mouth or tributary junction and walking upstream. This technique reduced turbidity and allowed stream bed features to be observed. A total of 29.5 rkm were sampled within the watershed (Figure 9). Approximately 700m of Mansfield Creek were surveyed, however, the GPS unit malfunctioned and this site was not revisited due to limited access.

The following habitat feature and feature characteristic information was recorded to describe riparian and in-stream habitat at the mesohabitat scale (pool, riffle, run): 1) reach name, 2) habitat feature – pool, riffle, run, 3) location – latitude/longitude recorded at the start of each habitat type 4) dominant substrate estimate based on three grab samples 5) primary vegetation within 9m (~30ft) of lotic habitat (right and left banks were independently assessed) 6) riparian density (right and left banks were independently assessed), 7) stream canopy, and 8) site quality (Tables 13 and 14). For the purposes of analysis, substrate classes were reclassified into five substrate categories: boulder (>256mm), cobble (64-256mm), gravel (2-64mm), sand (0.06-2.0mm), and silt (<0.06mm). This more general classification of substrate data facilitated visual interpretation of results.

Information on the location and associated habitat characteristics was recorded using a Trimble® GeoXM™ GPS (Global Positioning System) unit with 2-5m accuracy. After collection, data was downloaded, differentially corrected, converted into shapefiles, and appended to calculate summary statistics on sub-watershed, tributaries, and watershed-level mesohabitat data.

Collection of stream wetted width information is described under SNTEMP methods. Depth was measured at four evenly spaced locations along each of the three transects within the stream reach. All depth values for the reach were averaged to estimate average stream depth. The original 10 substrate groups used in data collection (boulder, cobble, pebbles, granules, very coarse, coarse, medium sand, fine sand, very fine sand, and silt) were reclassified into 5 groups (boulder, cobble, gravel, sand, and silt) to present results in a more concise manner.

RESULTS

GIS Land Cover Analysis

Results of the chi-square test showed overall land use is different ($p<0.01$) between circa 1800 and 1992 at the watershed scale (Figure 10). Further analysis of the chi-square suggests there is no difference ($p=0.17$) between evergreen forest and mixed forest land cover in the two years and these categories were combined; evergreen forest (41.8% to 6%) and mixed forest (30.4% to 9.5%) both decreased between 1800 and 1992. In addition, deciduous forest, grasslands, agriculture, and developed lands were not different ($p=0.63$) between the two years and these categories were combined; deciduous forest (2.4% to 35.2%), grasslands (0.2% to 4.3%), agriculture (0% to 25.4%), and developed (0% to 1.1%) all increased between circa 1800 and 1992. Wetlands were different ($p<0.01$) from all other land use categories; they decreased (24.1% to 16.7%) between circa 1800 and 1992. Overall, natural habitats declined from 100% in the 1800's to 73.5% of land use in 1992.

Results of the chi-square test showed overall land use at the watershed scale is different ($p=0.03$) between 1992 and 2001 (Figure 10). Further chi-square tests established deciduous forest, evergreen forest, mixed forest, wetlands, and agriculture land use classes were not different ($p=0.49$) from each other in the two years and these categories were combined; deciduous forest (35.2% to 29.6%), mixed forest (9.5% to 5%), and agriculture (25.4% to 15.2%) all decreased while evergreen forest (6% to 7.8%) wetlands (16.7% to 19.4%) slightly increased between 1992 and 2001. There was no difference ($p=0.42$)

between grasslands, developed, and shrub land for the two time periods and these categories were combined; grasslands (4.3% to 10.5%), developed (1.1% to 9.3%), and shrub (0% to 1.7%) land use practices all increased from 1992 to 2001. The percentage of natural habitat stayed relatively stable between 1992 and 2001 (73.5% to 73.9%), however, changes occurred in the type of unnatural land use occurring. There was a reduction in agriculture and an increase in developed areas from 1992 to 2001.

Results of the chi-square test showed overall land use within the 90m buffer is different ($p<0.01$) between 1992 and 2001 (Figure 11). Further chi-square tests were conducted and there was no difference ($p=0.98$) in evergreen forests and wetlands in the two years within the 90m buffer and these categories were combined; evergreen forest (8% to 10.7%) and wetlands (26.4% to 34.9%) increased within the 90m buffer between 1992 and 2001. There was no difference ($p=0.67$) in deciduous forests, mixed forests, and agriculture within the 90m buffer in the two years and these categories were combined; deciduous forest (26.5% to 18.5%), mixed forest (10.4% to 4.5%), and agriculture (21.7% to 10.9%) all decreased within the 90m buffer between 1992 and 2001. There was no difference ($p=0.59$) in grasslands, developed, and shrub land within the 90m buffer in the two years and these categories were combined; grasslands (2.9% to 8.7%) developed (0.9% to 8%), and shrub (0% to 1.2%) land all increased within the 90m buffer between 1992 and 2001. There was a slight increase in natural habitats from 77.3% to 79.9% within the 90m buffer between the two years.

There was a significant difference (p=0.01) in 60m buffer land use in 1992 and 2001 based on chi-square test results (Figure 12). Further chi-square tests were conducted and there was no difference (p=0.85) evergreen forests and wetland land use in the two years within the 60m buffer and these categories were combined; evergreen forests (8.5% to 10.4%), wetlands (28.7% to 38.8%) increased within the 60m buffer between 1992 and 2001. There was no difference (p=0.61) in deciduous forests, mixed forests, and agricultural land use within the 60m buffer in the two years and these categories were combined; from 1992 to 2001 there was a decrease in deciduous forests (25% to 17.4%), mixed forests (11% to 4.3%), and agriculture (19.9% to 10%) within the 60m riparian buffer. There was no difference (p=0.64) between grasslands, developed, and shrub land use within the 30m buffer in the two years and these categories were combined; grasslands (2.5% to 7.8%), developed (0.8% to 7.3%), and shrub (0% to 1.1%) all increased within the 60m buffer between 1992 and 2001. Natural habitats within the 60m buffer showed a small increase from 77.3% to 79.9%.

Overall, land use within the 30m buffer in 1992 and 2001 was different (p=0.01; Figure 13). Further chi-square test results showed there was no difference (p=0.31) between deciduous forests, evergreen forests, and wetlands in the two years within the 30m buffer and these categories were combined; there was a decrease in deciduous forests (22.7% to 16.6%) and wetlands (31.7% to 42.5%) while evergreen forest (9.1% to 9.7%) slightly increased within the 30m buffer between 1992 and 2001. There was no difference (p=0.62) between mixed forests and agricultural land use between the two years within the

30m buffer and these categories were combined; mixed forests (11.2% to 4%) and agriculture (18.4% to 9.3%) land use decreased within the 30m buffer between 1992 and 2001. There was no difference (p=0.69) in grasslands, developed, and shrub land use in the two years within the 30m buffer; grasslands (2.1% to 7.1%), developed (0.7% to 6.7%) and shrub (0% to 1.0%) land use all increased within the 30m buffer between 1992 and 2001. There was an overall increase from 79.2% to 81.6% in natural habitats within the 30m buffer.

Results of the chi-square test determined that overall land use was different (p<0.01) between the watershed scale and within the 90m buffer in circa 1800 (Figure 14). There was no difference (p=0.30) between deciduous forest, evergreen forest, mixed forest, and grasslands deciduous forest between the watershed scale and 90m buffer based on chi-square tests; thus, these classes were combined into one; there was a decrease in deciduous forest (2.4 to 2.2%), evergreen forest (41.8% to 19.7%), mixed forest (30.4% to 28.6%), and grasslands (0.2% to 0%) between the watershed scale and the 90m buffer. This combined class was different from wetlands (p<0.01); there was a smaller percent of wetlands at the watershed scale than within the 90m riparian buffer (24.1% and 47.1%). Since this dataset was based on pre-settlement information, natural habitats comprised 100% of land cover.

Overall, land cover in 2001 at the watershed scale was similar to the 90m (p=0.29) and 60m (p=0.10) buffers (Figure 15). The 30m buffer was different (p=0.03) from watershed scale land use in 2001. As a result, additional chi-square tests were computed and there was no difference (p=90) between deciduous forest, evergreen forest, mixed forest, grasslands, developed, agriculture and shrub land use in 2001 between the watershed scale and within the 30m buffer; thus, these categories were combined. There was a decrease in deciduous forest (29.6% and 16.6%), mixed forest (5% and 4%), grassland (10.5% and 7.1%), developed (9.3% and 6.7%), agriculture (15.2% and 9.3%), and shrub (1.7% and 1%) while there was a slight increase in evergreen forest (7.8% and 9.7%). There was a difference ($p<0.01$) between wetlands and all other classes combined. The percentage of wetlands was higher within the 30m riparian buffer (42.5%) than at the watershed scale (19.4%).

Based on sub-watershed delineation, the upper, middle, and lower portions of the watershed represented 31%, 30%, and 39% of the total area respectively (Figure 16 and 17). The chi-square test determined that there was no difference between land use in the sub-watersheds during 2001 ($p=0.99$). There was also no difference ($p=0.17$) between land use within 30m of the river in the sub-watersheds.

Hydrologic Analysis

The Rifle River is a fourth-order stream with a mean annual discharge 317 cfs for the period of record (1937 to 2006). The average high flow was 2105 cfs and the average low flow was 131 cfs for the period of record.

Mean/Standard Deviation

Analysis of mean monthly stream flow (IHA Group 1) indicated an upward trend for the month of August ($p=0.05$; Figure 18). Although not statistically significant, all other months showed an increasing trend (Figure 19), with the exceptions of March, April, and June, which showed decreasing trends. An analysis of flood frequency (EFCs Group 5) revealed the frequency of large floods to be decreasing ($p=0.05$) over the period of record (Figure 20).

Median/Percentiles

Analyses of the magnitude and duration of annual extreme water conditions (IHA Group 2) revealed upward trends for 1-day ($p<0.01$), 3-day ($p=0.025$), 7-day ($p=0.025$), 30-day ($p=0.01$), and 90-day ($p=0.05$) minimum flows (Figures 21-25). However, no significant trends were detected for maximum flows. The timing of annual extreme water conditions (IHA Group 3) indicate a downward trend ($p=0.025$) in the timing of minimum flows, which suggests minimum flows are occurring at an earlier Julian date (Figure 26). The rate and frequency of water condition changes (IHA Group 5) indicate the number of hydrologic reversals, which is the number of times per year mean daily discharge shifts from a rising stage to a falling stage or vice-versa, has decreased ($p<0.01$) over time (Figure 27). The EFC results suggest the frequency of extreme low flows has also decreased ($p<0.01$) over time (Figure 28). Mean annual flow data were graphed and visually assessed; however, no obvious trends or changes in hydrology were observed (Figure 29).

Water Temperature Model

Adjusted r^2 values indicated that 86 to 93% of the variation in water temperature values was explained by the fitted model for all six sites ($p<0.001$ for each; Table 9). Plots of the residuals showed no apparent trend, which indicated that the linear model was appropriate. A scatterplot of the data (predicted vs.

known) showed a linear relationship because the data points fell around a straight line and there were no evident outliers. This suggests that regression assumptions were met and the data are linearly related. Residual plot and scatterplot results from the Rifle River at Melita Road, which had one of the lower adjusted r^2 values (0.89), are shown in Figures 5 and 6.

Based on actual water temperature data, the months of July and August were found to be exceeding temperatures optimal for growth and survival of salmonids (20.6°C; Dexter and O'Neal 2004) on all mainstream sites and the West Branch (Figures 7 and 8). Predicted mean daily water temperature values for Prior Creek appeared irregular and deviated from the overall trend of the other tributaries. After the model was run, Prior Creek values appeared to be hindering the models predictive ability on the mainstream and this node was eliminated, which improved the model's precision.

Graphical display of predicted and measured water temperatures over time illustrate that predicted temperatures from the calibrated model follow the general pattern of real-world measurements for 1997 (Figure 30). The model tends to over-predict in late winter and early spring, under-predict in the summer, and is best in late fall and early winter. Based on residuals of the calibrated model, performance was optimal (<1°C) 60.5% of the time, acceptable (<2°C) 21.4% of the time, marginal (2-4°C) 15.1%, and unacceptable (>4°C) 3% of the year (Figure 31).

Graphical results of the 2000 dataset used in model validation suggest that predicted temperatures follow the general trend of measured temperatures over the year (Figure 30). The model tends to under-predict from late spring until early fall, but appears to follow the trend closely the rest of the year. Goodness-of-fit results using the RMSE approximated the average model error to be 1.59°C for 1997 and 1.64°C for 2000. Results from residuals plotted against observed temperatures for the 1997 calibration dataset show that residuals increase as temperature increases (Figure 31). This suggests that there is a linear bias to the model ($p<0.01$). Based on residuals of the validated model, performance was optimal (<1°C) 53.4% of the time, acceptable (<2°C) 27.1% of the time, marginal (2-4°C) 15.2%, and unacceptable (>4°C) 3.3% of the year (Figure 31).

When divided seasonally, the spatiotemporal variability in the Rifle River's thermal regime becomes apparent. During winter, the river is slightly warmer in the headwaters (rkm 59) and becomes cooler as it moves downstream (rkm 0; Figure 32). This pattern continues on through early spring and then the regime gradually shifts to being cooler in the headwaters and warmer downstream by late spring (Figure 32). In both winter and spring, temperatures remain below optimal recommendations for salmonids, but by late May the river has warmed and favorable conditions exist throughout the system. In summer, optimal temperatures are exceeded downstream of rkm 33 in late June through July, but the entire mainstream remains within favorable range until early fall (Figure 33). The river gradually shifts from being warmer downstream to being cooler and drops below favorable conditions by mid-October (Figure 33). Overall, seasonal changes in temperature are more dramatic downstream of rkm 33 than at upstream sites.

Based on temperature duration curves, the upper portion of the watershed never exceeded optimal temperatures (Figure 34). In the middle and lower sections, temperatures were exceeded approximately 9% of the time. Temperatures were within optimal range for salmonid growth 13%, 17%, and 19% of the time for the upper, middle, and lower sections of the watershed, respectively.

Under the global warming scenario, temperature patterns were similar to the original simulation where warmer temperatures are upstream (rkm 59) and cooler temperatures exist downstream (rkm 0; Figure 35). Again, the temperature pattern gradually turns over through the spring and the river becomes warmer downstream than upstream (Figure 35). In both winter and spring, temperatures remain below optimal recommendations for salmonids until late spring when favorable temperatures occur. In the summer, temperatures are within optimal and preferred range above rkm 33 except for late June when they are exceeded downstream (Figure 36). In the early fall, temperatures are beneficial to salmonids throughout the mainstream. The river gradually turns over throughout the fall, shifting from cooler to warmer conditions in the headwaters relative to downstream sites. By mid-October, temperatures drop below favorable range. Overall, seasonal temperature changes are more dramatic downstream of rkm 33 than at upstream sites.

Qualitative Habitat Assessment

Stream geometry measurements established that the upper sub-watershed had a reach average wetted width of 13.41m and an average depth of

0.46m (Table 15). The middle portion average wetted width was 19.46m and 0.41 was the average depth. The lower section of the watershed had a mean wetted width of 27.51m and depth of 0.62m. Average stream wetted width in the tributaries ranged between 1.6m and 7.6m. Average stream depth ranged from 0.07m to 0.42m. Wetted width and depth values coincide with an average daily discharge of 142 cfs at the gage on Melita Road.

Results suggest that the sub-watersheds vary in the type of mesohabitat available to aquatic organisms. The upper portion of the watershed is dominated by the frequency of pool habitat with 49% of the habitat features assessed being pools (Figure 37). In the middle portion of the watershed pool habitat (48%) also occurred with higher frequency than other habitat features assessed. However, in the middle section there are fewer riffles and more run habitat than the upper section of the watershed. Lastly, the lower portion of the watershed had less than the recommended 40% pool frequency (North Coast Regional Water Quality Control Board 1999). The lower portion had relatively similar proportions of the number of pool, riffle, and run habitat with 29%, 31%, 40% respectively, although run habitat occurred slightly more frequently.

Inventory results for the tributaries determined that pools were the dominant mesohabitat (Figure 37). However, Little Klacking, South Eddy, Fritz, and Townline creeks had less than 55% pool habitat, which is recommended for streams <15m wide and <2% gradient (Washington Fish and Game Commission 1997; Table 15). There was no riffle habitat present in sample reaches of Mayhue, Oyster, and Klacking creeks. Mayhue Creek appears to be channelized and runs parallel to Rose City Road for about 1km. Oyster Creek (downstream of Rose City Road) has an abundance of large woody debris, creating deep pool habitat and making it difficult to walk. Klacking Creek appeared to be impacted by the triple culvert on Peters Road, the placement of in-stream rock weirs by landowners, and areas where land owners had mowed vegetation up to the rivers edge.

Site quality results, which represents the amount of streambank erosion observed, identified that the majority of the upper watershed was good quality (66%; Figure 38; Table 16). In the middle watershed, both good (43%) and poor (40%) site quality were observed most frequently. Conversely, the lower portion of the mainstream was dominated by poor (58%) site quality. Results for the tributaries determined that Klacking, Fritz, and Townline creeks had the greatest amount of streambank erosion.

Fritz Creek had a claypan bottom and highly eroded banks. Townline Creek also had a bedrock bottom with eroded banks and Townline Road where it crosses Townline Creek had collapsed.

Results of the stream canopy assessment determined that all mainstream sites had either a moderate or sparse canopy (Figure 39; Table 16). The majority of the upper portion of the watershed inventoried had moderate (78%) shading. In both the middle and lower portions of the watershed, there were similar amounts of moderate (48% and 58% respectively) and sparse shading (52% and 42% respectively). The majority of the tributaries had moderate stream canopy (25-75% shading).

Substrate results established that the sites sampled in the upper watershed consisted of 1% boulder, 40% cobbles, 35% gravel, and 24% sand (Figure 40; Table 16). In the middle portion of the watershed there was 6% boulder, 22% cobbles, 30% gravel, and 42% sand. The lower portion of the watershed had 2% boulder, 35% cobbles, 25% gravel, and 38% sand. Overall, the three portions of the mainstream had a small percent of boulder substrate and there was no silt substrate present at any of the sites. The tributaries were primarily sand and gravel bottomed. Dedrich Creek had a cobble bottom overlain with silt and there were several old beaver dams upstream of Gerald Miller Road.

DISCUSSION

GIS Land Cover Analysis

It is important to note that circa 1800 and 1992 datasets were not collected in the same manner or with the same accuracy; thus, percentage of land cover and chi-square results may be imprecise (Table 4). Additionally, differences in methodology used to derive 1992 and 2001 makes a direct change analysis inappropriate (Homer et al. 2007). In late 2007, a product that will facilitate direct change analysis will be available. At the current time, uncertainty surrounds the total error when comparing the 1992 and 2001 NLCD.

As expected, results show that there is a difference in land use at the watershed scale between circa 1800 and 1992 vegetation datasets. Anthropogenic influences have been changing the landscape over the past 150 years by increasing deciduous forest, developed, and agricultural lands.

Meanwhile evergreen forest, mixed forest, and wetland habitats have declined over the same period of time.

Surprisingly, land cover changed at the watershed scale between 1992 and 2001. During this relatively short period (~10 years), grassland, developed, and shrub lands have increased while other land use classes stayed relatively stable or slightly decreased. It appears that the watershed experienced a surge in human development during this time period, with developed land use increasing from 0.8% to 9.2%. This is important because previous research has documented negative biological impacts when urban land use is in excess of 10% of the catchment area (Wang et al. 1997). If watershed land use continues on this trajectory over the next 10 years, it is predictable that there will be a decline in aquatic habitats and shifts in fish community composition unless sustainable development is fostered (both economic and ecological). In general, the town of West Branch, which is adjacent to a major highway (I-75), has been expanding and is an area of concern due to future development potential. As a result, partners have been working on the Ogemaw County Stormwater Project to address and mitigate stormwater runoff problems before the West Branch and subsequently the mainstream of the Rifle River are further impacted.

Results were also significant in 1992 and 2001 at the 90m, 60m, and 30m riparian buffer scales. Grassland, developed, and shrub land use was not different in the two years at all three spatial scales, which paralleled watershed scale results. Evergreen forest and wetland land uses were similar to each other in 1992 and 2001; deciduous forest, mixed forest, and agriculture were similar to each other at both the 90m and 60m buffer scale. These findings were contrary to the watershed scale where there was no difference between these five land use classes. At the 30m scale, the main distinction was that deciduous land use was similar to evergreen forest and wetlands, rather than mixed forest and agricultural land use observed at the other spatial scales. Overall, these results suggest that the impacts of development can be observed at all spatial scales, including the 30m buffer. Additionally, different land use patterns emerged at different spatial scales with the exception of the 90m and 60m buffers. These results refuted my hypothesis that there is no significant difference in land use at the watershed scale; however, there is a significant difference in land use at the riparian scale (90m, 60m, and 30m buffers) due to a decrease in natural habitats.

Results from land use at the watershed scale versus the 90m riparian buffer indicated that in circa 1800 there was a difference in land cover at these two spatial scales. The primary distinction is that almost half (46%) of the riparian zone is comprised of wetland habitat, which is approximately twice the amount present at the watershed scale (23.6%). Conversely, watershed scale land use in 2001 is not different from the 90m or the 60m riparian zone; therefore, land use within the 90m riparian zone is reflective of watershed scale land cover. It is not until the 30m buffer that there is a difference in land use, again between wetlands and all other land use classes. Although the percentage of wetlands has decreased over time, they comprise nearly twice the amount of land in the 30m riparian zone (38%) compared to the watershed scale (17.5%). The circa 1800 dataset is a useful guide for comparing current land use patterns to historic conditions, facilitating our understanding of how and where human activities are changing the landscape. These results suggests that land use similarities between the watershed scale, 90m buffer, and 60m buffer may be the result of human encroachment upon the riparian zone and our ability to homogenize the landscape. However, it appears that the 30m riparian buffer is still relatively intact either as a byproduct of the protections afforded under Michigan Natural River Program's zoning ordinances or simply because it is the last portion of the watershed to reflect larger scale changes.

The outcome of the sub-watershed analysis determined that, based on 2001 data, there is not a significant difference in land use in the upper, middle, and lower portions of the watershed. This was an unexpected, but a valuable finding as the purpose of this analysis was to identify priority areas for rehabilitation and protection. Based on land cover analysis, future protection and rehabilitation efforts can be implemented throughout the watershed rather than having a narrow geographic focus. Most importantly, efforts should be focused on preserving the integrity of the 30m riparian zone.

Hydrologic Analysis

Of the 67 measures of hydrologic regime trend analysis, 11 were found to have changed over time. Mean monthly flows for August have increased over time from approximately 165 to 190 cfs. August flows typically represent annual low flows (i.e., base-flows), thus a rising trend suggests that base-flow has increased over time. Annual minimum flows (1, 3, 7, 30, and 90-day means) also indicated an upward trend while high flows have remained stable, suggesting that the hydrologic regime has actually become more stable over time. The frequency of extreme low flows is declining, which also maintains that there has been an increase in base-flows as the result of more ground water entering the system.

Results show that the date of minimum flow is occurring earlier in the season, shifting the timing of annual minimum flow from early September to early August. Based on discharge data, the winter of 2003 was very dry and the annual minimum flow took place in March. Even with the 2003 data omitted from analysis, the trend is still significant. The number of hydrologic reversals has decreased over the period of record, falling from approximately 120 to 88 reversals per year. This number represents how frequently mean daily discharge shifts from a rising stage to a falling stage or vice-versa. Based on these results, there is less year-to-year variability, which may be the result of changes in the frequency and duration of precipitation events occurring within the basin.

The frequency of large floods (>3330 cfs) has been decreasing over the last 69 years with the most recent large flood in 1989 at 3719 cfs. Based on these results, it is difficult to determine if this trend is important in ecological terms as it may simply be a 50-year flood event. Large flood events are important for transporting sediment, flushing fine particles, and shaping the stream channel. Large flood frequency information is mainly used for the design of road-stream crossings such as bridges, culverts, and spillways (Gordon et al. 2004). This information is important for the future design of fish-friendly culverts that do not interfere with the watershed's natural hydrologic regime.

I had hypothesized that dominant watershed hydrologic processes have changed over time, resulting in reduced storage capacity and increased runoff due to loss of natural habitats, particularly in the riparian zone. The rationale behind this hypothesis was that the type and abundance of vegetation on the landscape can alter the storage capacity and ultimately the base-flow conditions of a groundwater driven system like the Rifle River. However, the results of my hydrologic analysis discussed above do not support this hypothesis.

Overall, the results of this study indicate that the Rifle River has become hydrologically more stable over time. Large-scale drivers and processes, such as land use and climate, may be associated with the observed hydrologic changes. Based on the results of the GIS analysis, vegetation within the watershed has also changed over time; however, the percentage of natural habitats has stayed relatively stable between 1992 and 2001 at all spatial scales and the 30m riparian buffer has retained the highest percentage of natural land cover. In addition to land cover, an increase in precipitation has been documented over the last century (Allan et al. 2004; USEPA 2000). If the storage capacity or amount of available ground-water is fairly stable, an increase in precipitation also has the ability to increase base-flows because the amount of water recharging the ground-water is greater. Another factor that may be influencing higher base-flow conditions is the reduction in agricultural land use, which historically used tiles to drain wetlands for food production. Drain tiles are designed to move water away from the land and into artificial ditches, resulting in flashier hydrography. However, as old drain tiles are removed, become clogged, or structurally fail due to aging, rainfall can infiltrate and percolate through the ground rather than entering the system as surface water and the hydrologic regime becomes more stable. In conclusion, stable base-flow conditions in this basin suggest that groundwater recharge has not been altered by land use changes and/or groundwater withdraws.

Water Temperature Model

The SNTEMP model is a useful tool for predicting stream temperatures. The model can be used to identify spatial and temporal boundaries to salmonid distribution, classify potential fish habitat, predict the impacts of climate change, and model changes in stream morphology and riparian shading. Additionally, the SNTEMP model is a tool that can be used to communicating with stakeholders to understand the potential biological implications of management and landowner actions.

Model calibration involves adjusting parameters that are estimated or not representative of on-site conditions. The model was sensitive to changes in air temperature, and humidity. Measuring climate information on-site may improve model performance. SNTEMP does not perform well near freezing and does not allow negative water temperature values to be run. Negative values were recorded in the field and were used in calculating regression values to fill missing air temperature. It may improve model performance if all negative water temperature values are changed to zero prior to calculating regression values. Additionally, discharge measurements could be measured in the field for the mainstream above Melita Road and tributary contribution as these values were estimated and could be a source of model error.

The SNTEMP model had poor predictive ability in the summer months and estimated below actual measured temperatures. The model did not respond well to large fluctuations in daily temperature. As a result, it tended to over- and under-estimate these values. The influence of air temperature on water temperature increases as a river widens due to reduced canopy or other vegetative cover (Gordon et al. 2004); thus, daily air temperature fluctuations likely influence water temperatures in the lower portion of the watershed more strongly than the headwaters. Collecting and incorporating additional stream geometry data may improve the model's predictive ability.

The SNTEMP model predicted that the mainstream of the Rifle River did not exceed lethal limits to salmonids; however, average model error for 1997 and 200 is 1.59°C and 1.64°C. Interpretation of model output, particularly in summer, should consider this limitation. For example, when the average model error (1.59°C) is added to mean weekly temperature predictions under normal climate conditions, the stream below rkm 13 exceeds lethal temperature for Brook trout (22.8°C) approximately 2% of the time. In addition, temperature predictions that are presented as mean weekly temperature values may be moderating extreme thermal conditions. Overall, more than 80% of predicted values in both 1997 and 2000 were within 2°C of measured values.

The longitudinal distribution of mean weekly temperature predictions for the Rifle River indicate warmer winter and cooler summer temperatures in the headwaters above rkm 33. This reflected the influence of groundwater in the upper portion of the watershed. Small tributaries and groundwater can provide cold-water refuge for salmonids when recommended temperatures are exceeded on the mainstream (Dexter and O'Neal 2004). Based on MDNR data, the tributaries are within favorable temperature range for salmonids, except a few days in summer when the West Branch exceeded recommended values.

Qualitative Habitat Assessment

The process of collecting in-stream habitat data was essential for understanding the physical and biological characteristics of the watershed. In addition, it provided the opportunity to gain in-depth knowledge about the watershed that could not be gleaned from written documents; however, there were some limitations to the data collection techniques employed. One limitation was that riffle and run habitat units tended to be very short in the small tributaries and I was unable to record all of these units due to the accuracy of the GPS unit (2-5m). Additionally, there were often two different types of habitat units within the same cross section of the creek (e.g., pool and run) due to LWD that created pool habitat within or adjacent to other habitat units. Only the dominant habitat unit was recorded and I was not able to capture the complexity of this mesohabitat. The complexity of mesohabitat also made it difficult to clearly define the type of habitat to record and other field personnel may record mesohabitat differently. Finally, it was difficult to quantify and summarize overall site quality using this mixture of qualitative assessment methods as they collectively have not been implemented, tested, and established in the literature.

There are a variety of techniques established in the literature to inventory the abundance, type, distribution, and quality of habitat. One example is the Basinwide Visual Estimation Technique (BVET), which is used by the U.S. Forest Service (Dolloff et al. 1993). This approach involves a visual or qualitative assessment of habitat and includes taking quantitative measurements at pre-selected intervals to calibrate and correct for estimation bias. However, this technique requires more time and personnel to accomplish. The approach used in this study allowed me to assess a much larger portion of the watershed with minimal assistance.

Two problematic culverts (perched and sediment loading) were identified and photographed in the process of collecting data (Appendix B). This information was passed along to agency personnel who are working to remove barriers to fish migration in the watershed. The double culvert on Prior Creek at Peters Road is not a high priority culvert for future replacement. The creek appears of good quality at the road; however, there is a beaver pond not far upstream. There is a road on Mansfield Creek located just upstream from the mouth that appears to be on private property. This road has a poorly placed culvert that has carving out a huge hole and cut away the banks.

Results of the qualitative habitat assessment suggest that the lower portion of the mainstream has less than the recommended pool frequency and streambank erosion increases as the mainstream flows from the headwaters to the mouth. The mainstream has sparse to moderate shading, which appears to be a function of stream width. None of the sites assessed on the mainstream were densely vegetated or devoid of vegetation. The middle portion of the watershed has the greatest stream width due to a bedrock outcropping. Substrate in the mainstream was primarily sand, gravel, and cobble. The absence of silt substrate in mainstream samples suggests that substrate is not limiting salmonid presence.

The tributaries assessed in this study were generally very cold, had abundant large woody debris (LWD), and complex mesohabitat. Large woody debris appears to have a strong influence on the smaller streams and creates an abundance of pool habitat by scouring adjacent to the LWD. This resulted in complex mesohabitat because pools were often adjacent to riffle or run habitat at the same cross section of river. Results of the qualitative assessment identified a few tributaries with problems (e.g., abundance of pool habitat, silt substrate) and potential causes of those problems. Some of the potential causes include channelization, bedrock outcroppings, land owner activities, culverts, and beaver dams.

CONCLUSION

Evaluation of Ecosystem Analysis and Management Recommendations

I conducted a science-based study of the Rifle River watershed using the EAWS approach to characterize ecosystem processes and identify where rehabilitation and protection efforts should be focused. To accomplish this investigation I used documented and repeatable methods that produced verifiable results and conclusions. Through this analysis I was able to describe the watershed's hydrologic characteristics, land use changes over time, predict the thermal limits to salmonid distribution, and inventory in-stream habitat features of the Rifle River watershed.

The study was conducted on multiple spatial scales because spatial and temporal patterns of ecosystem processes emerge at different scales and these interactions can be overlooked when only one scale is used. For example, results of this study suggest base-flow has increased over the period of record and land use changes have occurred over time. If only land use had been examined, I may have speculated that hydrology was being negatively impacted (e.g., decrease in base-flow conditions) due to an increase in developed land use and a decrease in natural habitats. Conversely, if only hydrology had been examined, I may have speculated that significant land use changes had not occurred; therefore, three spatial scales were used in this study. Characterization and analysis of land use, hydrology, and the thermal regime were conducted at the watershed level. The river scale was used to characterize land use adjacent within 30m, 60m, and 90m of the river. The qualitative in-stream habitat assessment was conducted at the reach scale.

Analyzing land use at multiple spatial scales provided useful information that can be passed along to watershed planners in similar physiographic regions. The characterization process identified that there has been an increase in developed land, grassland, and shrub land over the last 10 years (1992-2001) at the watershed scale and river scale (90m, 60m, and 30m buffers). Currently, only the 30m buffer has different land use from the watershed scale and it is characterized by a decrease in mixed forest and agriculture and an increase in developed land, grassland, and shrub land. Because land use appeared to be different in the upper, middle, and lower sections of the river, another spatial scale, the sub-watershed, was employed to determine if rehabilitation activities should be focused in a specific region of the watershed. Surprisingly, there was no difference in land use within these sub regions or within 30m of the river in these sub regions. However, results did identify that within 30m of the river the upper portion of the watershed has the greatest percent of wetlands, the middle portion has the greatest percent of developed lands, and the lower portion has the greatest percent of deciduous lands. This information is important since rehabilitation activities typically occur within 30m of the river and developed lands are known to impact stream health. Completion of the Ogemaw County Stormwater Project in the middle portion of the watershed is important for minimizing the impacts of development on the West Branch and mainstream. Additionally, local land planning efforts should focus on ensuring sustainable development occurs in the watershed, particularly in the West Branch area.

Hydrologic analysis was conducted at the watershed level, using data collected at a single location. Results from this analysis were very informative because it suggests base flow has increased and the river has actually become more stable over time. This is useful information because anecdotally the Rifle River has a reputation for being a flashy system where water levels rise rapidly during rain events. Flashy systems are often associated with increased development on the landscape because impervious surfaces increase runoff and reduce infiltration; however, some rivers are naturally flashy. Evaluation of both hydrologic and land use data suggests that the Rifle River is not a flashy system. County road commission personnel who engineer and design road-stream crossings should be informed of an increase in base-flow to ensure that appropriate culvert size is selected to ensure fish passage.

Water temperature modeling was conducted at the watershed scale, using data collected at multiple sites throughout the watershed. The thermal regime of the Rifle River does not appear to be limiting salmonid distribution. Water temperatures above 20°C occur less than 5% of the time at Melita Road (rkm 0); however, the model tended to under-predict in the summer when lethal temperatures typically occur. The upper portion of the mainstream (above rkm 33) provides cooler summer temperatures and warmer winter temperatures that are not optimal for growth, but may function as thermal refuge. Under the global warming scenario, maximum temperatures would stay relatively stable and minimum temperature would increase. To improve model performance, I would recommend collecting water temperature data throughout the year. Winter data was typically lacking and regression values had to be used in model development. A study on local climate data would also be useful, as the nearest weather station did not reflect local conditions and impacted model performance. Otherwise, current temperatures do not appear to be limiting fish distribution; however, the type of in-stream habitat may be as stream morphology may be.

The in-stream qualitative habitat inventory was conducted at the reach scale. Although it was a general inventory, it provided useful information regarding the quality of potential fish habitat in the mainstream and tributaries.

The information was also useful for understanding the impacts of riparian vegetation removal, beaver dams, and large woody debris. Due to the coarse scale of this approach, it is not recommended as a monitoring tool. Future habitat monitoring should include depth measurements of pool, riffle and run features as individuals who conduct surveys may classify habitat units differently. By collecting depth measurements this would provide sufficient information to detect changes over time. In addition, characteristics such as pool depth are more informative when evaluating the quality and quantity of habitat available to fish and life stage of interest.

As a result of studying these processes at multiple spatial scales, more useful information emerged that can be used to guide land use planning and rehabilitation efforts designed to protect valuable fish and wildlife resources. For example, changes in hydrology may be increasing bank erosion as the stream channel adjusts to new base-flow conditions. The streams ability to transport sediment should be further studied and the results used to set quantitative objectives. Understanding watershed processes lays the foundation for a science-based rather than opportunistic approach to fisheries and aquatic habitat protection and rehabilitation. It is important that the RRWRC set clear and quantitative objectives based on scientific findings rather than prioritizing projects based on local interests or land owner need since this type of opportunistic project selection may results in short-term fixes that fail to meet long term fisheries objectives. As a byproduct of gathering and interpreting ecosystem information, management actions become more predictable because decisions are based on an understanding of watershed interactions. Correspondingly, this improves accountability through quantifiable results that can be easily communicated to partners.

The EAWS approach can be used to accomplish the goals of the National Fish Habitat Action Plan because it is landscape focused, science-based, and is focused on habitat rather than species. It is not intended to produce a final watershed management plan, but rather it is intended to function as an adaptive approach to understanding complex watershed processes. Finally, this process can be easily incorporated into existing approaches such as the Michigan DNR river assessments.

The current rehabilitation strategy or goal of the Rifle River Watershed Restoration Committee (RRWRC) is to preserve the natural condition of the river. The primary way it has accomplished this goal is by reducing sediment delivery into the river to protect water quality, fish habitat, and aesthetic attributes of the system. There is limited information on historic rehabilitation efforts in the Rifle River watershed due to a lack of documentation by past watershed restoration committee members. To address this need, I worked with Jim Hergott (Saginaw Bay RC&D) during the summer of 2005 to inventory the committee's most recent rehabilitation efforts (1998-2005) and provide a historical record for future resource managers. Starting in 1995, a total of 370 eroding streambanks were identified on the mainstream and West Branch. Of those sites, 134 projects had been completed and they were all located on the mainstream (Figure 41). Treatments used to rehabilitate the river are focused on the riparian zone and have consisted of tree revetments (68%), rock rip-rap (22%), and other structures such as lunkers, log jams, shaping and seeding (10%). In general, projects appear to be opportunistically chosen based on land owner needs and to control streambank erosion.

In addition to the above mentioned recommendations, the RRWRC should continue to focus rehabilitation efforts within the 30m riparian buffer, specifically in middle and lower portions of the watershed where development and streambank erosion, respectively, are greatest. Public education aimed at ensuring Natural Rivers ordinances are not being violated through the removal of riparian vegetation and discouragement of the placement of in-stream rock weirs would also benefit fish habitat. Although there are drawbacks to taking an opportunistic approach to rehabilitation, some project will need to be selected based on land owner need in order to keep local public support and advocacy. To ensure the hydrologic regime of the Rifle River remains unaltered, no dams or barriers should be placed on the system that would alter the natural flow regime or fish passage as these are both vital for the ecological health of the watershed. Based on temperature modeling results under normal conditions, salmonid habitat improvement projects should be focus on the area above rkm 33. Other factors that may be limiting salmonid distribution, such as the quality and quantity of in-stream habitat, should be further investigated. Monitoring of future rehabilitation projects, especially tree revetments, is strongly encouraged to evaluate treatment efficacy. The extensive use of tree revetments in this system is unique and the effects of this type of bank stabilization are not well documented in the scientific community.

In conclusion, EAWS appears to work best as an interagency approach, rather than as a public approach. It is intended to guide teams of interagency professionals in establishing baseline conditions to address management questions specific to the watershed of interest. Using this existing knowledge, future changes can be detected and baseline data can be built upon to address management objectives over time. It can also be incorporated into an existing watershed management approach due to the flexible framework. The results of the interagency team, whether positive or negative, should also be communicated to the general public and other relevant stakeholders by an appointed or selected individual.

Table 1. Comparison of watershed analysis and planning frameworks: Michigan Department of Environmental Quality (MDEQ), Michigan Department of Natural Resources (MDNR), and Ecosystem Analysis at the Watershed Scale (EAWS).

	MDEQ	*MDNR*	EAWS
Approach	Clean Water Act, Section 319	River assessment	Ecosystem analysis
Organization	Grassroots	Agency	Multidisciplinary teams
Focus	Site specific; Water quality	Agency findings	Watershed processes
Information Transfer	Yes	Uncertain	Yes
Science-based	Opportunistic	Yes	Yes
Decision Support System Platform	No	Yes	Yes
Limitations	Site specific; Opportunistic	Citizen involvement; Summarized results	Time and labor intensive

Table 2. Rifle River Watershed fish community. Information based on MDNR fish surveys for the lower Rifle River (Omer), and Michigan's Wildlife Action Plan (Eagle et al. 2005).

Family	Common Name	Scientific Name
Catostomidae	white sucker	*Catostomus commersonii*
	northern hog sucker	*Hypentelium nigricans*
	black redhorse	*Moxostoma duquesnei*
	golden redhorse	*Moxostoma erythrurum*
	shorthead redhorse	*Moxostoma macrolepidotum*
Centrarchidae	rock bass	*Ambloplites rupestris*
	green sunfish	*Lepomis cyanellus*
	pumpkinseed	*Lepomis gibbosus*
	bluegill	*Lepomis macrochirus*
	smallmouth bass	*Micropterus dolomieu*
	largemouth bass	*Micropterus salmoides*
	black crappie	*Poxomis nigromaculatus*
Cottidae	mottled sculpin	*Cottus bairdii*
	slimy sculpin	*Cottus cognatus*
Cyprinidae	common carp	*Cyprinus carpio**
	spotfin shiner	*Cyprinella spiloptera*
	common shiner	*Luxilus cornutus*
	northern pearl dace	*Margariscus nachtriebi*
	hornyhead chub	*Nocomis biguttatus*
	blacknose shiner	*Notropis heterolepis*
	sand shiner	*Notropis stramineus*
	bluntnose minnow	*Pimephales notatus*
	longnose dace	*Rhinichthys cataractae*
	western blacknose dace	*Rhinichthys obtusus*
	creek chub	*Semotilus atromaculatus*
	brassy minnow	*Hybognathus hankinsoni*
	finescale dace	*Phoxinus neogaeus*
Esocidae	northern pike	*Esox lucius*
Gasterosteidae	Brook (five-spined) stickleback	*Culaea inconstans*
Ictaluridae	black bullhead	*Ameiurus melas*
	brown bullhead	*Ameiurus nebulosus*
	stonecat	*Noturus flavus*
Percidae	rainbow darter	*Etheostoma caeruleum*
	johnny darter	*Etheostoma nigrum*
	channel darter	*Percina copelandi*
	least darter	*Etheostoma microperca*
	yellow perch	*Perca flavescens*
	northern log perch	*Percina caprodes semifasciata*
	blackside darter	*Percina maculate*
	walleye	*Sander vitreus*
Petromyzontidae	sea lamprey	*Petromyzon marinus**
Salmonidae	rainbow trout	*Oncorhynchus mykiss**
	brown trout	*Salmo trutta**
	brook trout	*Salvelinus fontinalis*
	cisco	*Coregonus artedi*
Umbridae	central mudminnow	*Umbra limi*

*non-native

Table 3. Federal and state listed threatened, endangered, proposed, and candidate species in the Rifle River Watershed ID 4080101 30 1-18 (Michigan Natural Features Inventory 2006).

Scientific Name	Common Name	Federal Status	State Status
Clemmys insculpta	Wood Turtle		SC
Gavia immer	Common Loon		T
Haliaeetus leucocephalus	Bald Eagle	LT,PDL	T
Alasmidonta viridis	Slippershell Mussel		SC
Buteo lineatus	Red-shouldered Hawk		T
Dalibarda repens	False-violet		T
Pandion haliaetus	Osprey		T
Appalachina sayanus	Spike-lip Crater		SC
Emys blandingii	Blanding's Turtle		SC
Northern fen	Alkaline Shrub/herb Fen, Upper Midwest Type		
Dendroica kirtlandii	Kirtland's Warbler	LE	E
Opuntia fragilis	Fragile Prickly-pear		E
Percina copelandi	Channel Darter		E
Great Blue Heron Rookery	Great Blue Heron Rookery		
Merolonche dolli	Doll's Merolonche		SC
Dentaria maxima	Large Toothwort		T

State Status
E = Endangered
SC = Special Concern
T = Threatened

Federal Status
LE = Listed Endangered
LT = Listed Threatened
PDL = Proposed Delisted

Table 4. Side-by-side comparison of data layers used in this study: Michigan Natural Feature's Inventory (MNFI) Circa 1800 data and U.S. Geological Survey's National Land Cover Dataset (NLCD).

Dataset	Classification Schemes	Classification Methodologies	Spatial Resolution	Accuracy	Source
MNFI Circa 1800	11 classes (based on MNFI reclassification of original classes)	Originally digitized and cleaned with a 40ft tolerance.	30-meter pixels	Errors due to interpretation and data input. Direct comparison is not recommended.	Michigan's native landscape based on original land surveyor data and descriptions of vegetation from 1816-1856. Transects were spaced 1 mile apart and vegetation was interpreted between transects. Maps delineated by local scientists.
NLCD 1992	21 classes	Mapped using unsupervised clustering algorithm and GIS modeling with ancillary data	30-meter pixels	Scientifically rigorous accuracy assessment conducted by region. Direct comparison is not recommended. Classification accuracies range from 0.6 to 0.79	Based on Landsat 5 (Thematic Mapper) satellite imagery and land cover data of the conterminous U.S. from 1992-1995.
NLCD 2001	16 classes, % tree canopy, and % urban imperviousness	Mapped using decision-tree (regression tree) algorithms	30-meter pixels	Direct comparison is not recommended. Accuracy assessment to be completed in 2008.	Based on Landsat 7 (Enhanced Thematic Mapper Plus) and 5 (Thematic Mapper) satellite imagery and land cover data of the conterminous U.S., Alaska, and Hawaii from 1999-2003.

Source: MNFI circa 1800 (http://www.dnr.state.mi.us/spatialdatalibrary/metadata/lu1800.htm)
NLCD 1992 and 2001 (http://www.epa.gov/mrlc/nlcd.html)

Table 5. Land cover classes present in circa 1800, 1992, and 2001 datasets for the Rifle River watershed and simplified land cover classification schemes used in land cover analysis.

Land Cover Classes	Simplified Land Cover Classes
*Circa 1800 MiGDL**	
1. Lake/River	Open Water
2. Aspen-Birch Forest	Deciduous Forest
3. Hemlock-White Pine Forest	Coniferous Forest
4. Jack-Pine Forest	Coniferous Forest
5. White Pine-Red Pine Forest	Coniferous Forest
6. Beech-Sugar Maple-Hemlock Forest	Mixed Forest
7. Black Ash	Woody Wetlands
8. Cedar Swamp	Woody Wetlands
9. Mixed Conifer Swamp	Woody Wetlands
10. Mixed Hardwood Swamp	Woody Wetlands
11. Muskeg/Bog	Woody Wetlands
12. Shrub Swamp/Emergent Marsh	Emergent Herbaceous Wetlands
13. Oak Barrens	Grasslands/Herbaceous/Savannah
14. Pine Barrens	Grasslands/Herbaceous/Savannah
*1992 NLCD***	
1. Open Water	Open Water
2. Deciduous Forest	Deciduous Forest
3. Evergreen Forest	Evergreen Forest
4. Mixed Forest	Mixed Forest
5. Woody Wetlands	Woody Wetlands
6. Emergent Herbaceous Wetlands	Emergent Herbaceous Wetlands
7. Grasslands/Herbaceous	Grasslands/Herbaceous/Savannah
8. Low Intensity Residential	Developed
9. High Intensity Residential	Developed

Table 5 (Continued).

Land Cover Classes	Simplified Land Cover Classes
1992 NLCD (Continued)	
10. Commercial/Industrial/Transportation	Developed
11. Quarries/Strip Mines/Gravel Pits	Miscellaneous Unnatural
12. Transitional	Miscellaneous Unnatural
13. Pasture/Hay	Agriculture
14. Row Crops	Agriculture
15. Urban/Recreational Grasses	Miscellaneous Unnatural
*2001 NLCD***	
1. Open Water	Open Water
2. Deciduous Forest	Deciduous Forest
3. Evergreen Forest	Evergreen Forest
4. Mixed Forest	Mixed Forest
5. Woody Wetlands	Woody Wetlands
6. Emergent Herbaceous Wetlands	Emergent Herbaceous Wetlands
7. Grasslands/Herbaceous	Grasslands/Herbaceous/Savannah
8. Developed-Open Space	Developed
9. Developed-Low Intensity	Developed
10. Developed-Medium Intensity	Developed
11. Developed-High Intensity	Developed
12. Barren Land	Miscellaneous Unnatural
13. Pasture/Hay	Agriculture
14. Cultivated Crops	Agriculture
15. Shrub/Scrub	Shrub/Scrub

*MiGDL = Michigan Geographic Data Library; **NLCD = National Land Cover Dataset

Table 6. Summary of hydrologic parameters used in Indicators of Hydrologic Alteration (IHA) statistics (modified from The Nature Conservancy 2006).

IHA Statistics	Hydrologic Parameters
Group 1: Magnitude of monthly water conditions	Mean value for each calendar month *(Subtotal 12 parameters)*
Group 2: Magnitude and duration of annual extreme water conditions	Annual minima and maxima for 1-day, 3-day, 7-day, 30-day, 90-day means; No. of zero-flow days; Base flow index: 7-day minimum flow/mean flow for year *(Subtotal 12 parameters)*
Group 3: Timing of annual extreme water conditions	Julian date of each annual 1-day maximum and 1-day minimum *(Subtotal 2 parameters)*
Group 4: Frequency and duration of high and low pulses	No. of low and high pulses within each water year; Median duration of low and high pulses (days) *(Subtotal 4 parameters)*
Group 5: Rate and frequency of water condition changes	Rise rates: median of all positive differences between consecutive daily values; Fall rates: median of all negative differences between consecutive daily values; No. of hydrologic reversals *(Subtotal 3 parameters)*
	Total 33 IHA Parameters

Table 7. Summary of hydrologic parameters used in Environmental Flow Components (EFCs) statistics (modified from The Nature Conservancy 2006).

EFC Statistics	Hydrologic Parameters
Group 1: Monthly low flows	Median values of low flows during each calendar month *(Subtotal 12 parameters)*
Group 2: Extreme low flows	Frequency of extreme low flows during each water year; Median values of extreme low flow event: duration, peak flow*, and timing *(Subtotal 4 parameters)*
Group 3: High flow pulses	Frequency of extreme high flows during each water year; Median values of high flow pulse event: duration, peak flow, timing, and rise and fall rates *(Subtotal 6 parameters)*
Group 4: Small floods	Frequency of small floods during each water year; Median values of small flood event: duration, peak flow, timing, and rise and fall rates *(Subtotal 6 parameters)*
Group 5: Large floods	Frequency of large floods during each water year; Median values of large flood event: duration, peak flow, timing, and rise and fall rates *(Subtotal 6 parameters)*
	Total 34 EFC Parameters

* minimum flow during event

Table 8. Data inputs required to build Stream Network TEMPerature model.

SNTEMP Data Input Requirements
Stream Geometry
Stream network definition
Latitude
Elevation
Distance from system reference point
Stream wetted width
Manning's n
Stream shading
Ground temperature
Streambed thermal gradient
Meteorology
Weather station latitude, elevation, and mean annual air temperature
Mean daily air temperature
Mean daily wind speed
Mean daily relative humidity
Mean daily percent sunshine
Daily dust coefficient
Daily ground reflectivity
Hydrology and Time Period
Average daily discharge
Average daily stream temperature
Average daily lateral inflow temperature
First and last day of simulation time period

Source: (Bartholow 2000)

Table 9. Results from multiple linear regression, which was used to estimate missing water temperature values for the mainstream and tributaries of the Rifle River watershed.

Location	Adjusted r^2
Rifle River at Melita Rd ($F_{2, 852}$= 3531; p≤0.001)	0.8921
West Branch ($F_{2, 1090}$= 4892; p≤0.001)	0.8996
Prior Creek ($F_{2, 295}$= 935; p≤0.001)	0.8628
Klacking Creek ($F_{2, 994}$= 6747; p≤0.001)	0.9313
Houghton Creek ($F_{2, 1241}$= 6266; p≤0.001)	0.9098
Gamble Creek ($F_{2, 909}$= 5590; p≤0.001)	0.9246

Table 10. Lethal, optimal, and favorable water temperatures for brown trout, brook trout, and steelhead based on the literature. Cold water guild values were used to interpret the biological implications of SNTEMP model predictions.

Species	Favorable Growth	Optimal Growth	Lethal
Steelhead	13 – 19 °C [a]	17 – 19 °C [b]	>24 °C [a,b]
Brown Trout	10 – 21 °C [c]	16 – 21 °C [d]	> 22.5 – 24.8 °C [c]
Brook Trout	7 – 18 °C [c]	14 – 19 °C [c]	> 21 – 26 °C [c]
Cold Water Guild (Brook, Brown, and Rainbow)	10 – 22 °C [e]	15 – 19 °C [e]	> 22 °C – Brook Trout [f] > 24 °C – Brown and Rainbow Trout

[a] Wismer and Christie 1987, [b] Hokanson et al. 1977, [c] Carlander 1969, [d] Brown 1971, [e] Wehrly et al. 1999, [f] Eaton et al. 1995

Table 11. Factors considered in sub-watershed delineation of the Rifle River.

Sub Watershed	Geology of Uplands [a]	Trout Stocking	Stream Gradient (ft/mile)	Drainage Area (Km2)
Upper	Loamy soils; moderately steep	Yes	2.4	300
Middle	Sandy soils underlain by silt loam to clay	No	6.5	558
Lower	Sandy soils; nearly level	No	9.9	957

[a] Modified from MDNR 2002

Table 12. Tributaries the State of Michigan considers vital to the protection of the Rifle River and were evaluated during the qualitative habitat assessment.

Tributary Name	Total Length Km
1. Vaughn Creek (source to Gamble Creek)	5.0
2. Gamble Creek (source to Mallard Pond)	4.3
3. Oyster Creek (Oyster Road to Mallard Pond)	6.4
4. Mayhue Creek (source to Oyster Creek)	4.8
5. Houghton Creek (source to Rifle River)	12.6
6. Wilkins Creek (source to Houghton Creek)	10.5
7. Prior Creek (source to Rifle River)	10.5
8. Little Klacking Creek (source to Klacking Creek)	4.5
9. Klacking Creek (source in Foose Swamp to Rifle River)	8.4
10. Fritz Creek (Fritz Road to Rifle River)	1.0
11. Dedrich Creek (source in Dedrich Swamp to Rifle River)	3.5
12. West Branch (outfall of Flowage Lake to Rifle River)	16.3
13. North Eddy Creek (source to South Eddy Creek)	5.8
14. South Eddy Creek (source to North Eddy Creek)	8.0
15. Mansfield Creek (source to Rifle River)	9.3
16. Townline Creek (source to Rifle River)	3.2

Source: (MDNR 2002)

Note: Silver Creek was also listed, but was not evaluated due to poor GPS satellite reception that resulted from topography.

Table 13. Mesohabitat data collected at each site during the qualitative habitat assessment of the Rifle River watershed.

Parameter	Description
1) Reach name	Rifle River or tributary name
2) Habitat feature	Pool, riffle, or run
3) Location	Latitude/Longitude
<u>Feature Characteristics</u>	<u>Indicator</u>
4) Substrate	In-stream habitat structure, upstream conditions, hydrology
5) Primary riparian vegetation	Hydrology, in-stream habitat, land use
6) Riparian vegetation density	Hydrology, in-stream habitat, land use
7) Stream canopy	Water temperature and quality
8) Site quality	Bank erosion (hydrology, land use, soils)

Table 14. Feature characteristic categories used for qualitative habitat assessment of the Rifle River watershed.

Feature Characteristics	Categories
1) *Substrate* [a]	Boulders: >256mm
	Cobble: 64-256mm
	Pebbles: 4-64mm
	Granules: 2-4mm
	Very coarse: 1.0-2.0mm
	Coarse: 1/2 – 1.0mm
	Medium sand: 1/4-1/2mm
	Fine sand: 1/8-1/4mm
	Very fine sand: 1/16-1/8mm
	Silt: <1/16mm
2) *Primary riparian vegetation* [b]	Herb-Low (≤30cm)
	Herb-Mixed
	Herb-Tall (>30cm)
	Shrubs-Low (≤1m)
	Shrubs-Mixed
	Shrubs-Tall (>1m)
	Trees-Deciduous
	Trees-Evergreen
	Trees-Mixed
3) *Riparian vegetation density*	Dense: >75%
	Moderate: 25-75%
	Sparse: <25%
	None
4) *Stream canopy* [c]	Dense: >75% shade
	Moderate: 25-75% shade
	Sparse: <25% shade
	None
5) *Site quality* [d]	Good: <25% bank erosion
	Fair: 25-50% bank erosion
	Poor: >50% erosion

[a] Sand-gage © 1984 by W.F. McCollough
[b] Modified from Bain and Stevenson 1999
[c] Modified from USDA Stream Visual Assessment Protocol (USDA-NRCS 1998)
[d] Modified from Qualitative Habitat Evaluation Index (Ohio State University 2007)

Table 15. Selected habitat variables for sub-watersheds (n=9) and tributaries (n=3) of the Rifle River.

Site	Wetted Width (m) Average	Depth (m) Average	Percent Habitat Area Pool	Riffle	Run
Upper	13.4	0.46	49%	23%	28%
Mayhue Creek	2.3	0.30	97%	0%	3%
Oyster Creek	2.3	0.24	71%	0%	29%
Gamble Creek	4.9	0.29	57%	4%	39%
Vaughn Creek	2.7	0.30	74%	2%	24%
Wilkins Creek	5.7	0.41	83%	13%	4%
Houghton Creek	6.6	0.35	79%	10%	12%
Prior Creek	6.2	0.12	71%	9%	21%
Little Klacking Creek	2.8	0.20	50%	18%	32%
Klacking Creek	3.7	0.39	74%	0%	26%
Dedrich Creek	1.6	0.07	56%	32%	12%
Middle	19.5	0.41	48%	15%	37%
West Branch	7.6	0.42	65%	15%	21%
North Eddy Creek	2.8	0.11	67%	2%	32%
South Eddy Creek	3.1	0.18	46%	7%	47%
Lower	27.5	0.62	29%	31%	40%
Fritz Creek	2.3	0.08	47%	20%	33%
Townline Creek	1.9	0.11	50%	9%	41%

Table 16. Results of qualitative habitat assessment for sub-watersheds of the Rifle River.

Variable	Upper	Middle	Lower
Riparian Canopy			
>75%			
25–75%	78%	48%	58%
<25%	22%	52%	42%
0%			
Riparian Vegetation			
Herb – Low (<=30cm)	4%	14%	3%
Herb – Mixed	1%	2%	
Herb – Tall (>30cm)	5%	33%	15%
Shrubs – Low (<=1m)			
Shrubs – Mixed			
Shrubs – Tall (>1m)	18%	2%	3%
Trees – Deciduous	38%	34%	41%
Trees – Evergreen	2%	2%	6%
Trees – Mixed	32%	15%	32%
Riparian Density			
Dense (>75% native)	40%	30%	49%
Moderate (25-75%)	54%	61%	41%
Sparse (<25%)	6%	8%	10%
None (0%)			
Substrate			
Boulders (>256mm)	1%	6%	2%
Coarse: (1/2-1.0mm)	3%	15%	2%
Cobbles (64-256mm)	40%	22%	35%
Fine sand (1/8-1/4mm)			
Granules (2-4mm)	1%	6%	2%
Med Sand (1/4-1/2mm)	1%	24%	
Pebbles (4-64mm)	34%	27%	25%
Silt (<1/16mm)			
Vcoarse (1-2mm)	19%	27%	33%
Vf sand (1/16-1/8mm)			
Site Quality			
Fair (10-25% bank erosion)	22%	16%	27%
Good (<10% bank erosion)	66%	43%	15%
Poor (>25% bank erosion)	12%	40%	58%

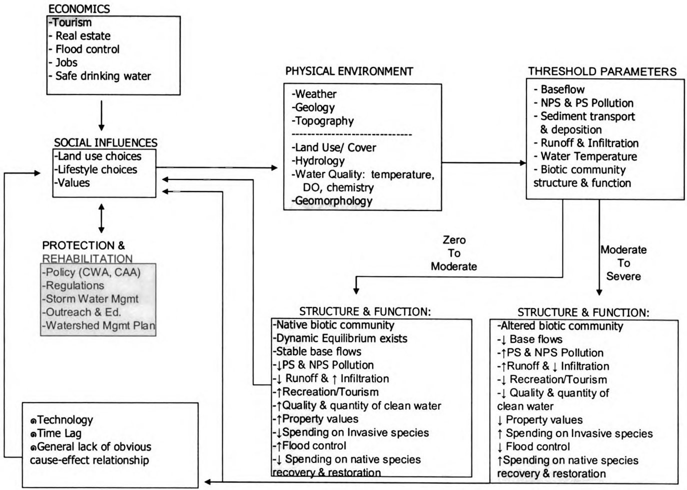


Figure 1. Conceptual model of watershed processes, interactions, and rehabilitation.

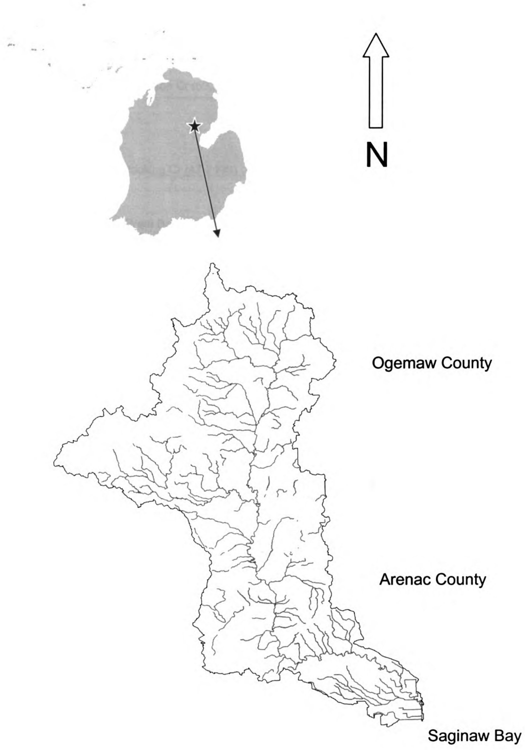


Figure 2. Location and map of the Rifle River watershed in northeastern-lower Michigan.

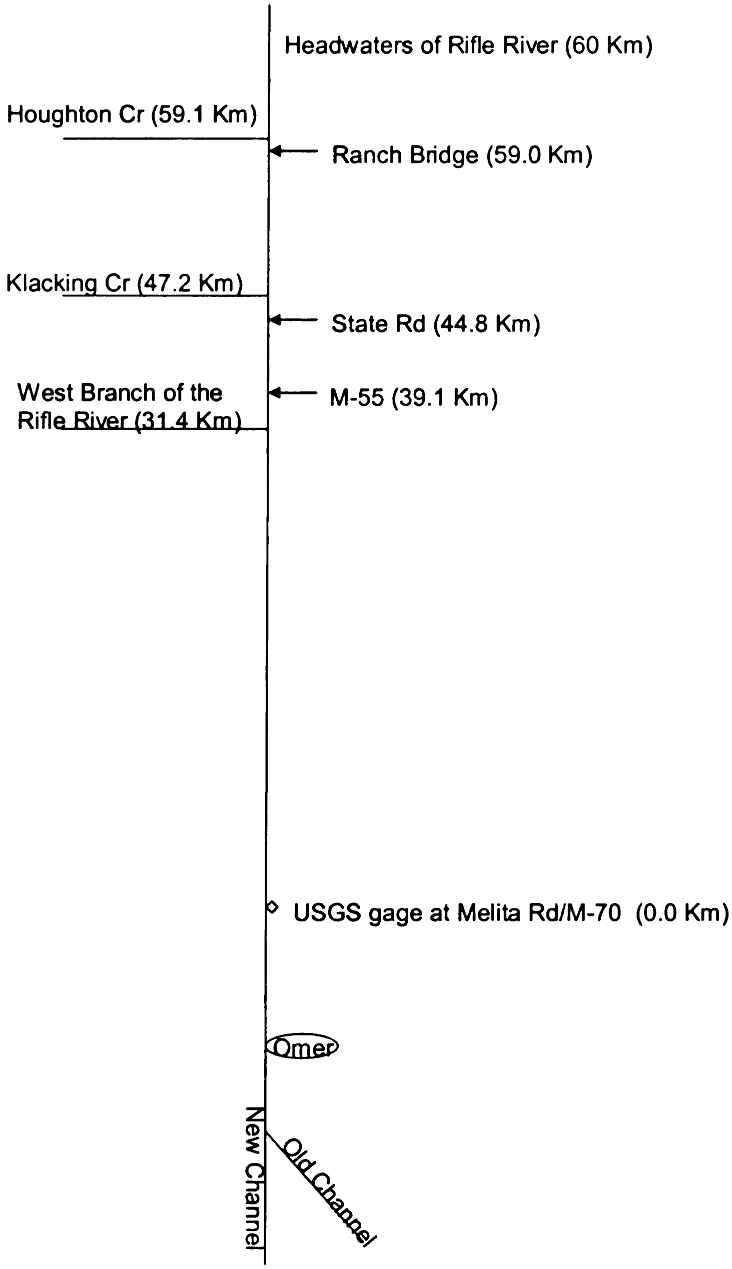


Figure 3. Composite stream network of Rifle River watershed from the headwaters to the mouth.

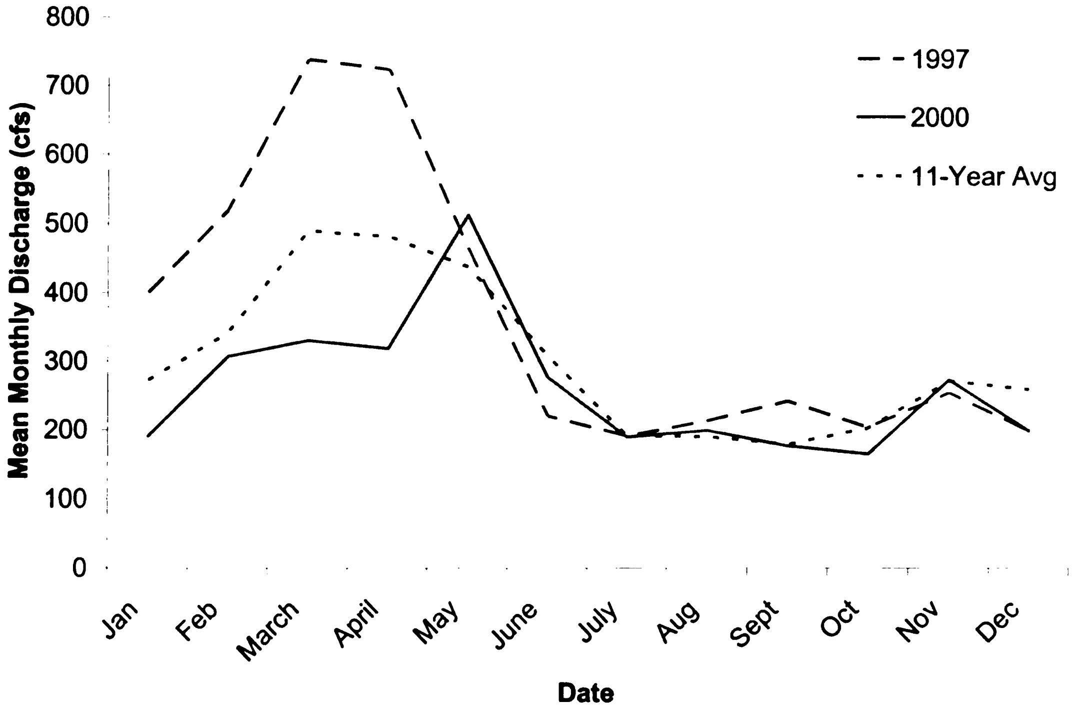


Figure 4. Mean monthly discharge at Melita Road (M-70) for calendar years 1997, 2000, and the 11 year average (1995-2005) in the Rifle River Watershed, Michigan.

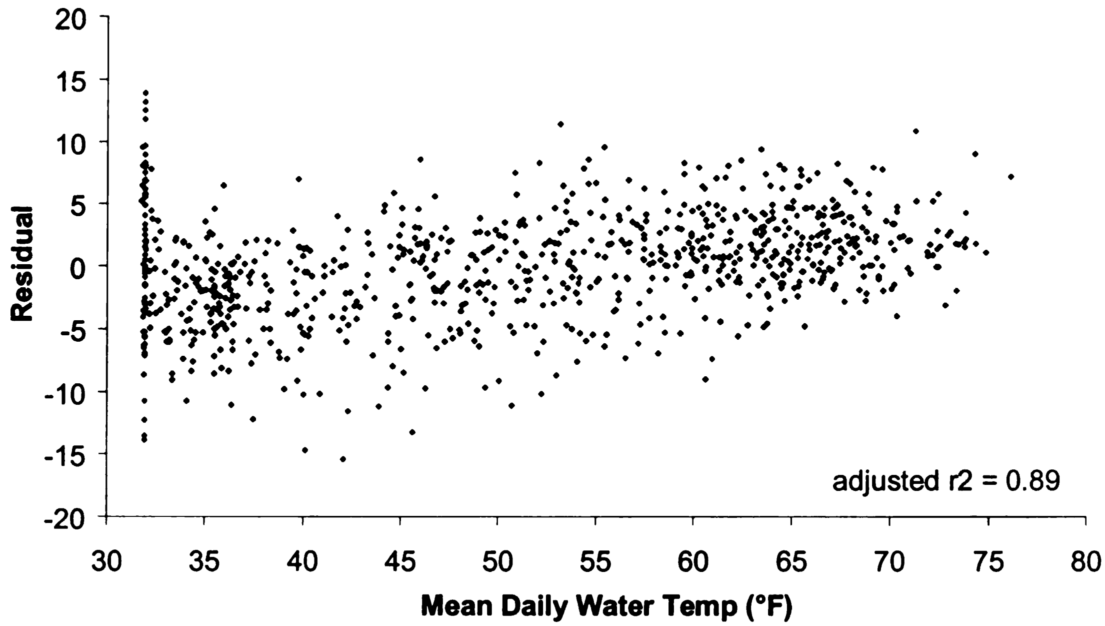


Figure 5. Residual plot from multiple linear regression for Rifle River at Melita Road.

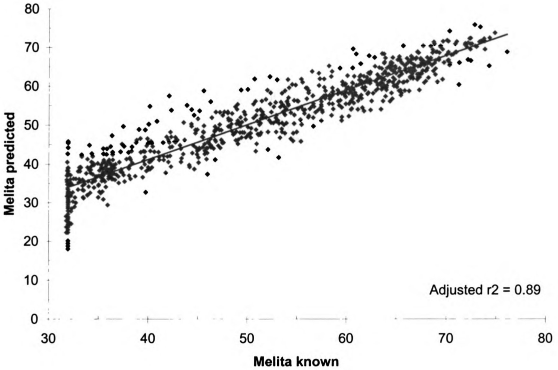


Figure 6. Scatterplot of predicted value from multiple linear regression vs. known values for Rifle River at Melita Road.

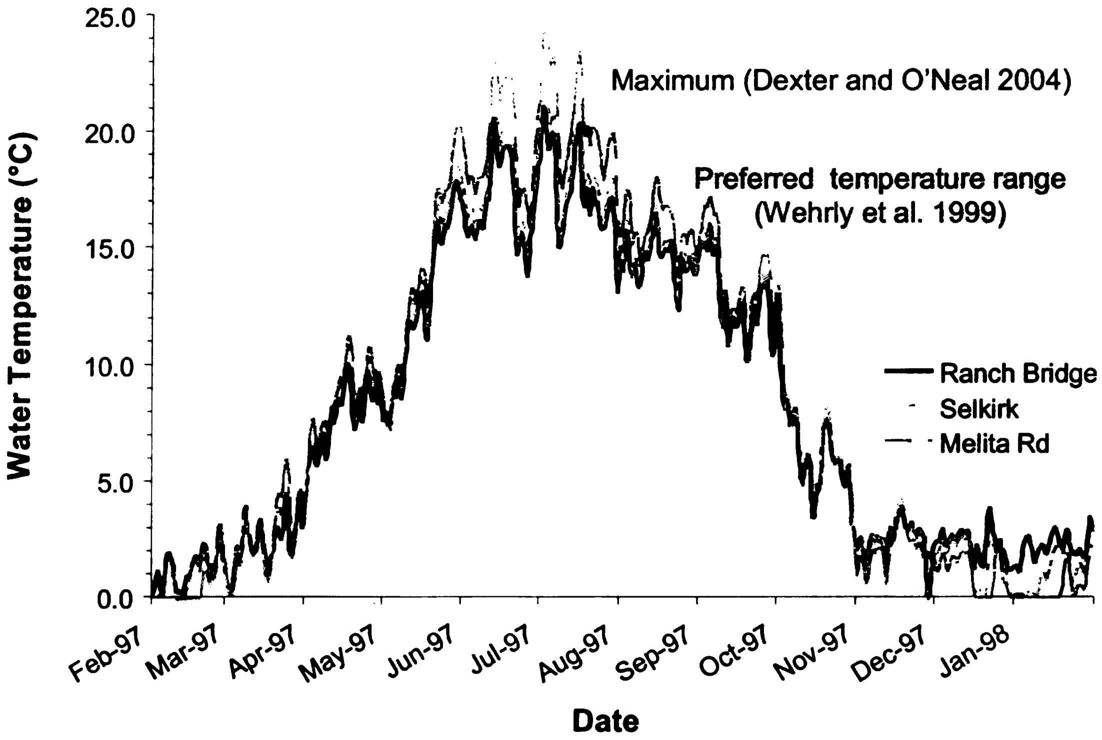


Figure 7. Mean daily water temperature collected by the Michigan DNR from February 1997 to January 1998 at the upper (Ranch Bridge, rkm 58.7), middle (State Road, rkm 44.8) and lower (Melita Road, rkm 0.0) sections of the Rifle River watershed, Michigan. The preferred temperature range (15-19°C) is based on the mean temperature measured at sites where Wehrly et al. (1999) found peak densities of brook, brown, and rainbow trout. Maximum is the temperature (20.6°C) that should not be exceeded for optimal growth and survival of trout (Dexter and O'Neal 2004).

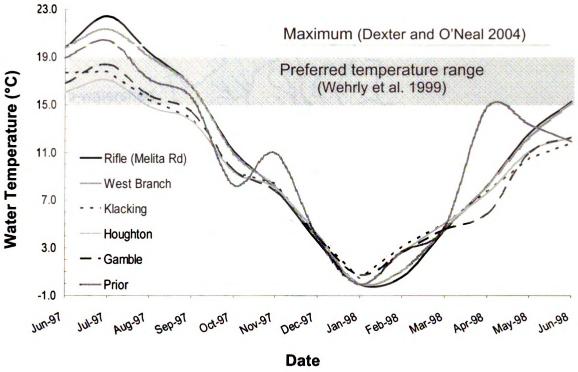


Figure 8. Mean daily water temperature collected by the Michigan DNR from late June 1997 to early June 1998 for the West Branch Rifle River, Klacking Creek, Houghton Creek, Gamble Creek, and the lower section of the mainstream (Melita Road). The preferred temperature range (15-19°C) is based on the mean temperature measured at sites where Wehrly et al. (1999) found peak densities of brook, brown, and rainbow trout. Maximum is the temperature (20.6°C) that should not be exceeded for optimal growth and survival of trout (Dexter and O'Neal 2004).

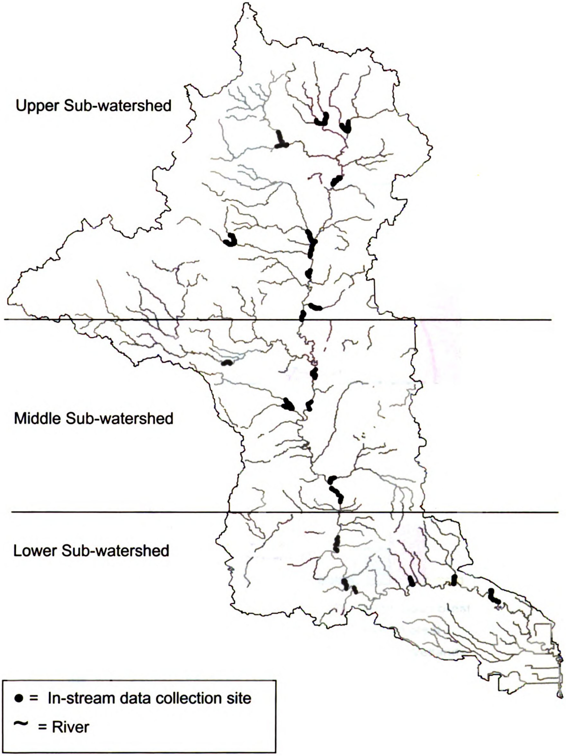


Figure 9. In-stream data collection sites within the Rifle River watershed, Michigan.

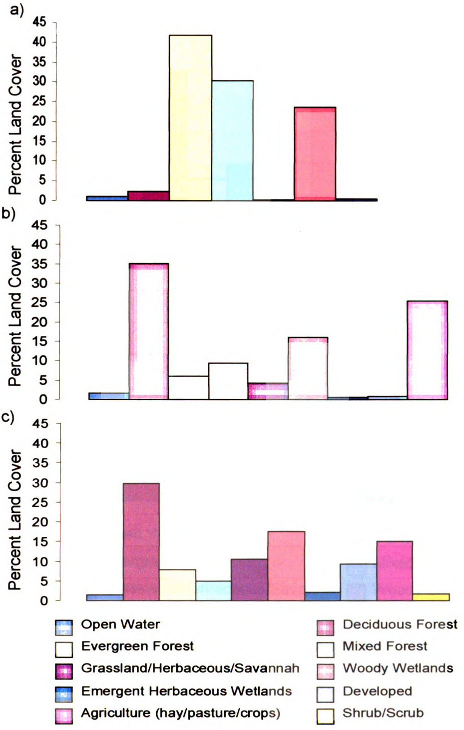


Figure 10. Land use results from GIS watershed scale analysis for a) circa 1800, b) 1992, and c) 2001 for the Rifle River watershed, Michigan.

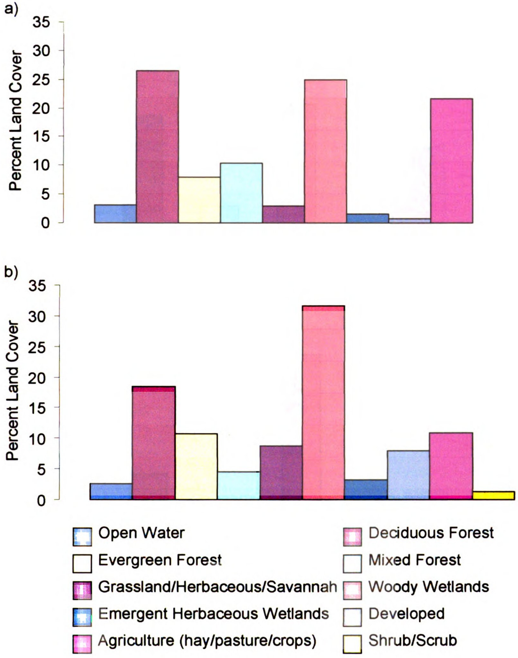


Figure 11. Results from GIS land use analysis within the 90m buffer for a) 1992 and b) 2001 for the Rifle River watershed, Michigan.

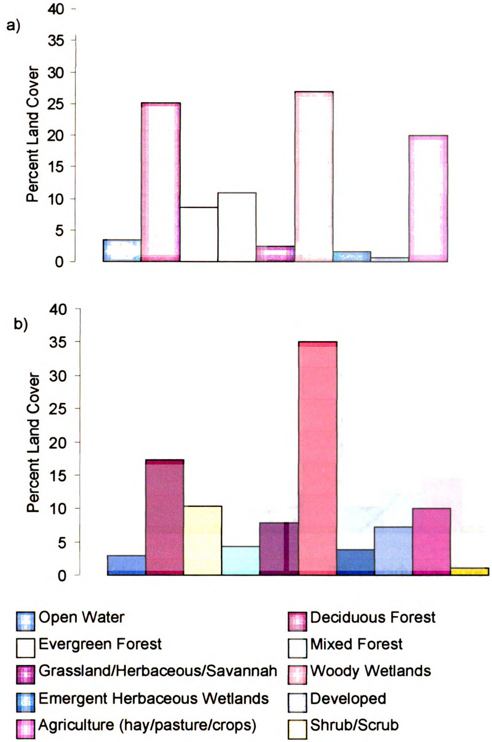


Figure 12. Results from GIS land use analysis within the 60m buffer for a) 1992 and b) 2001 for the Rifle River watershed, Michigan.

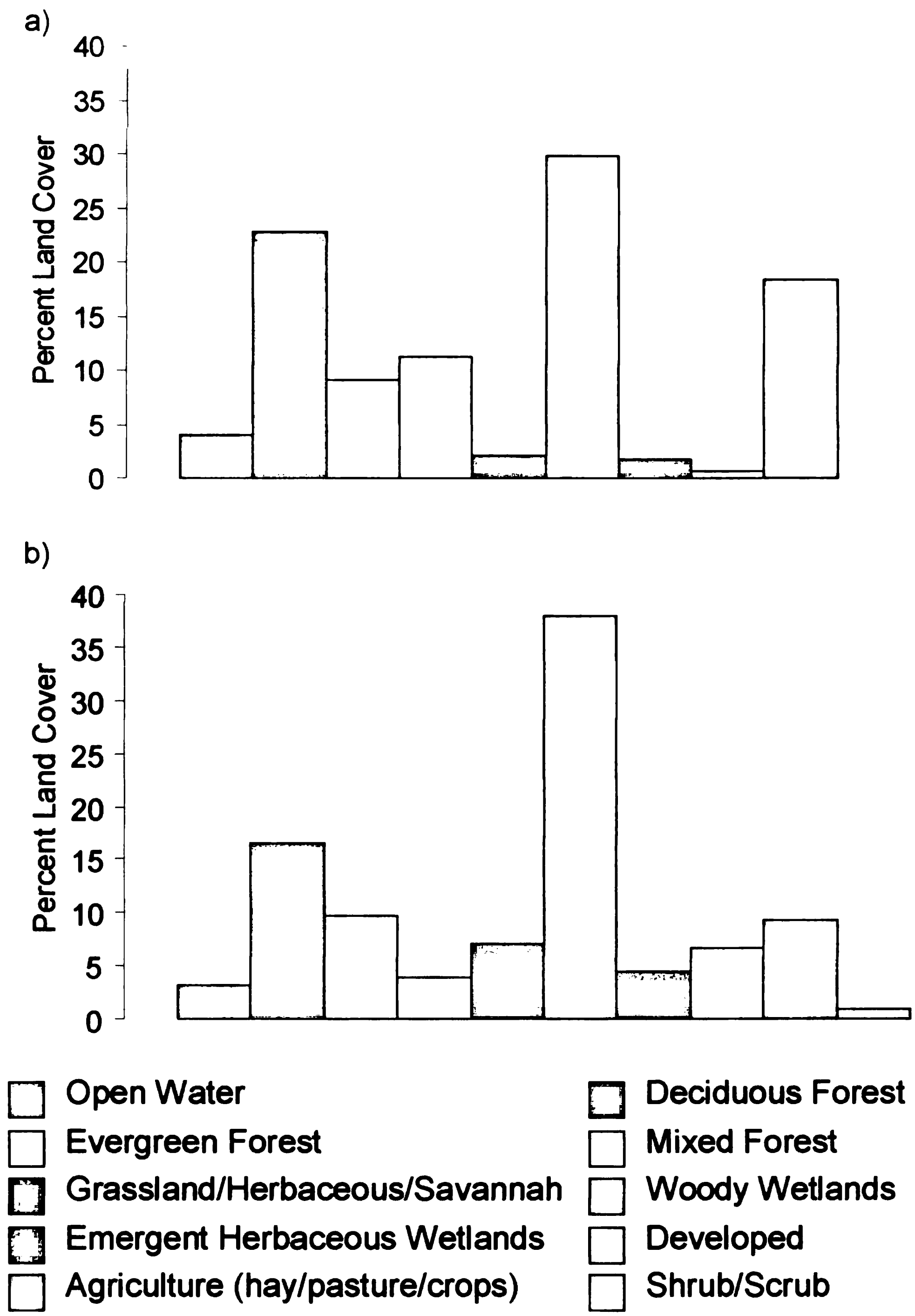


Figure 13. Results from GIS land use analysis within the 30m buffer for a) 1992 and b) 2001 for the Rifle River watershed, Michigan.

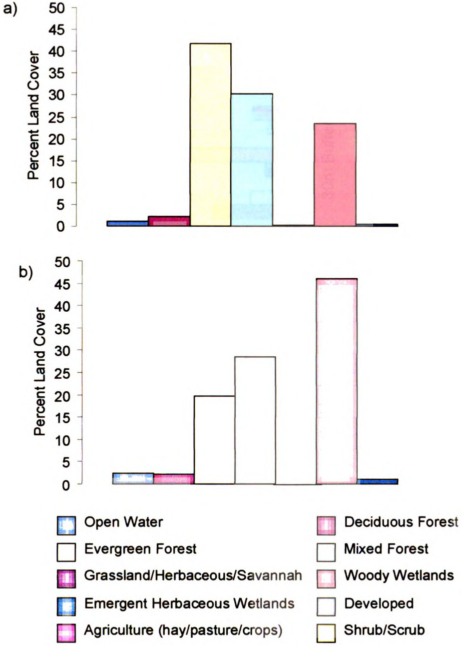


Figure 14. Results from GIS land use analysis for circa 1800 at the a) watershed scale and b) 90m buffer scale for the Rifle River watershed, Michigan.

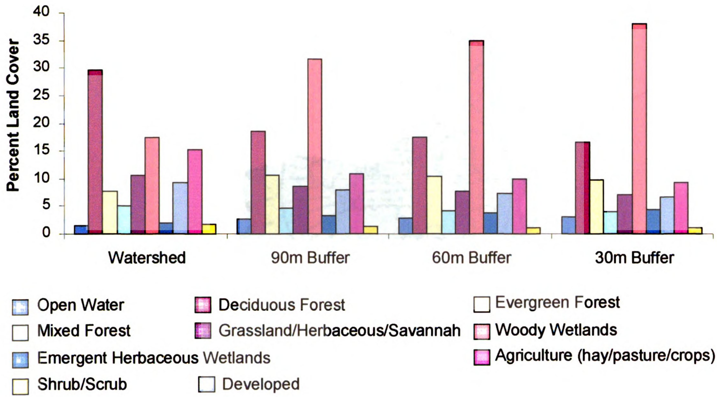


Figure 15. Results from GIS land use analysis for 2001 at the watershed scale and within 90m, 60m, and 30m buffers for the Rifle River watershed, Michigan.

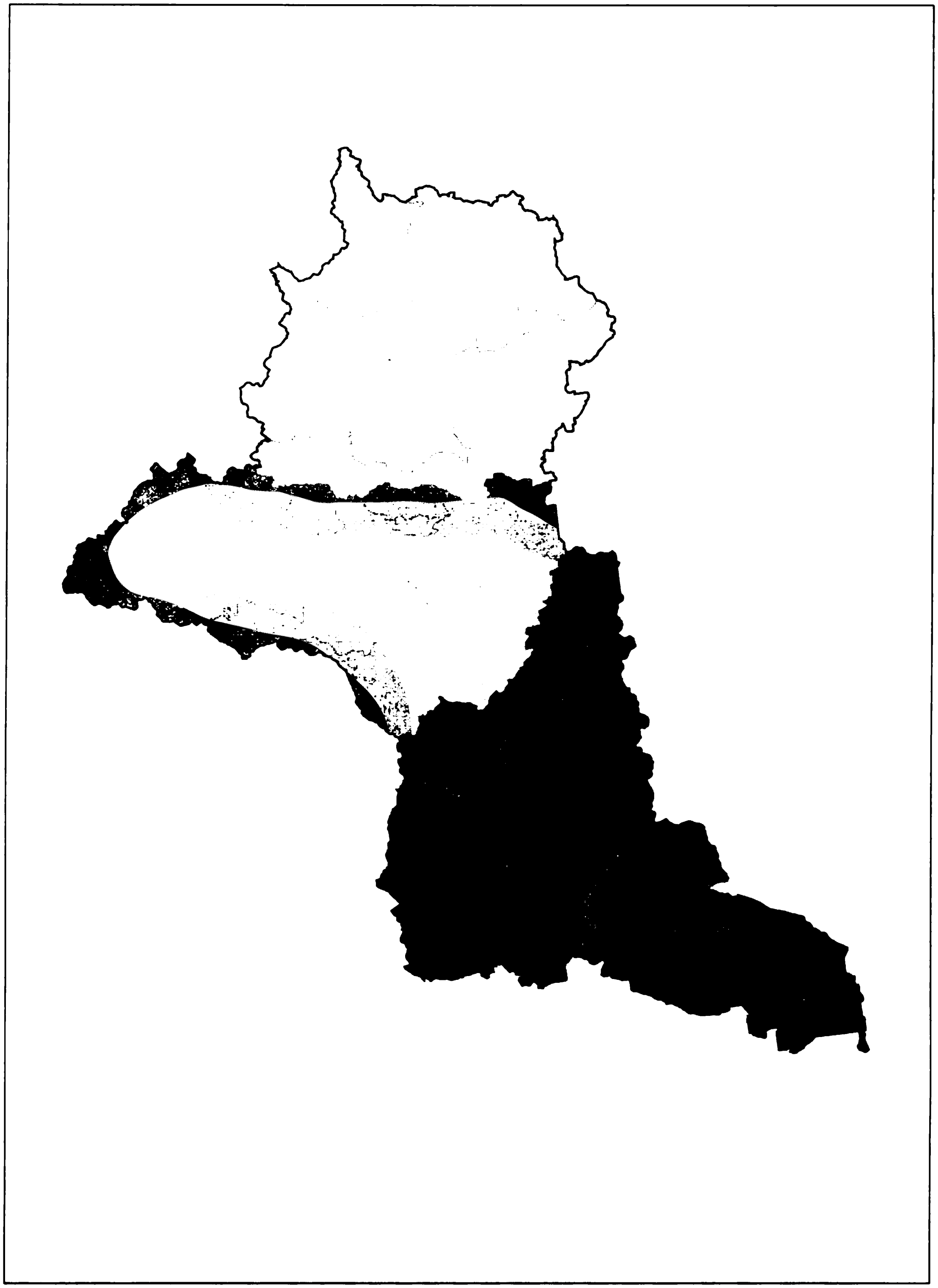


Figure 16. GIS sub-watershed delineation of the Rifle River watershed, Michigan. Upper, middle, and lower sub-watersheds comprise 31%, 30%, and 39% of the total watershed area respectively.

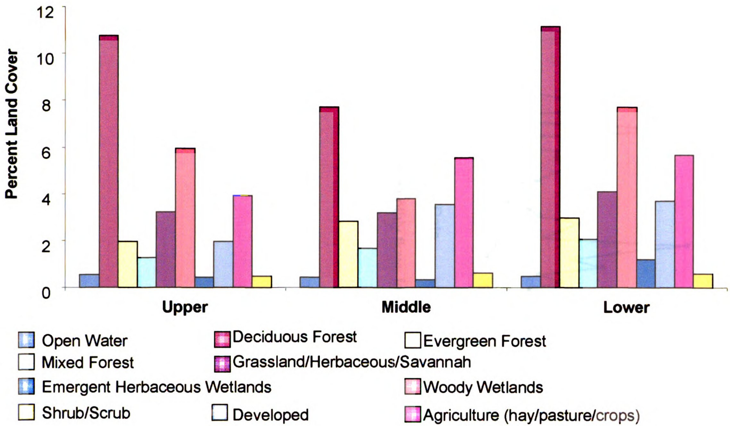


Figure 17. Results from GIS land use analysis for 2001 within sub-watersheds of the Rifle River watershed, Michigan.

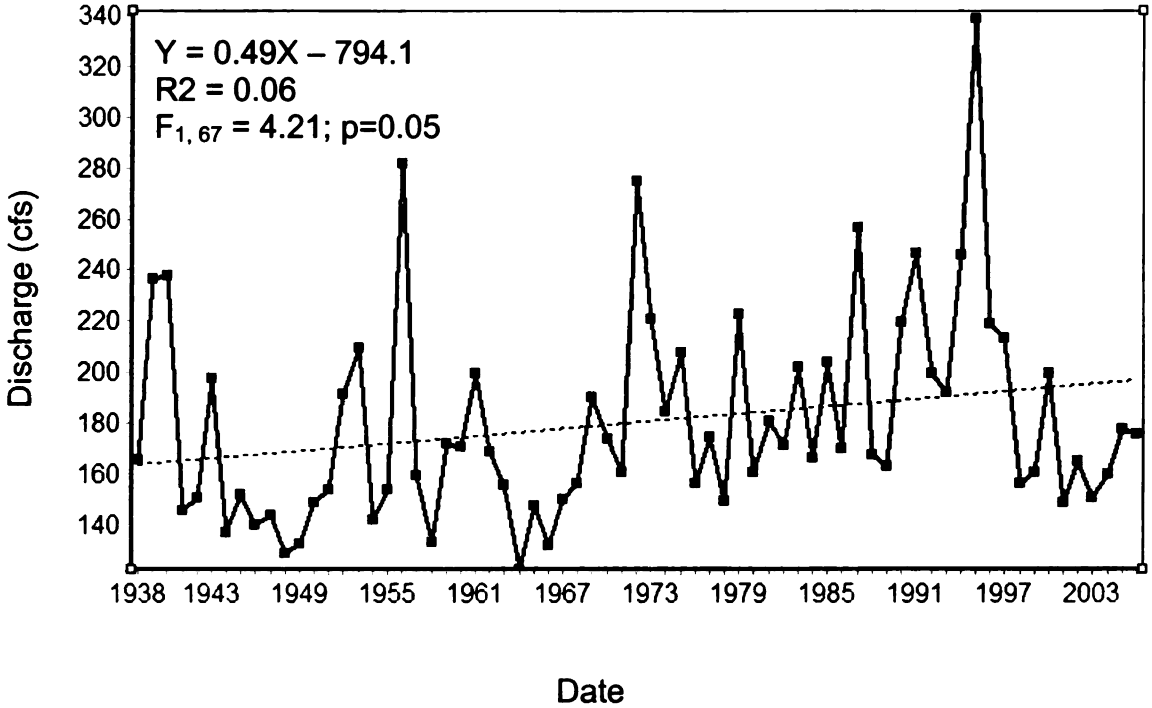


Figure 18. Parametric analysis of monthly flows for August, Rifle River at Melita Road.

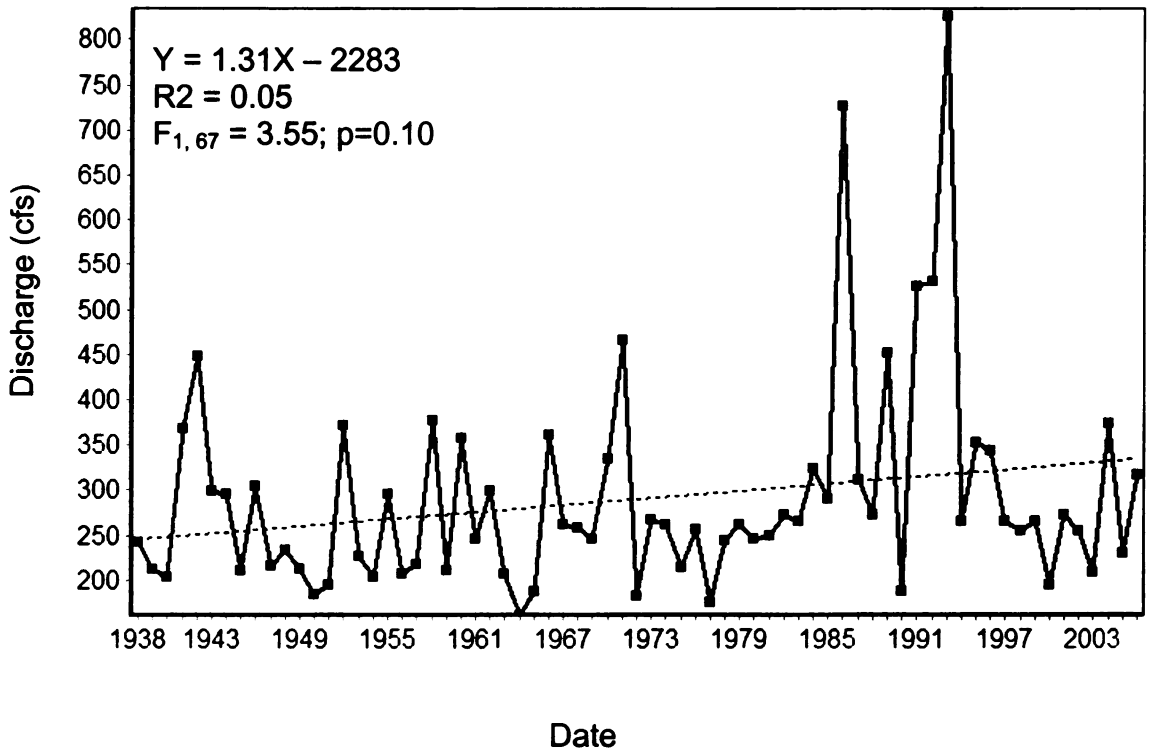


Figure 19. Parametric analysis of monthly flows for November, Rifle River at Melita Road.

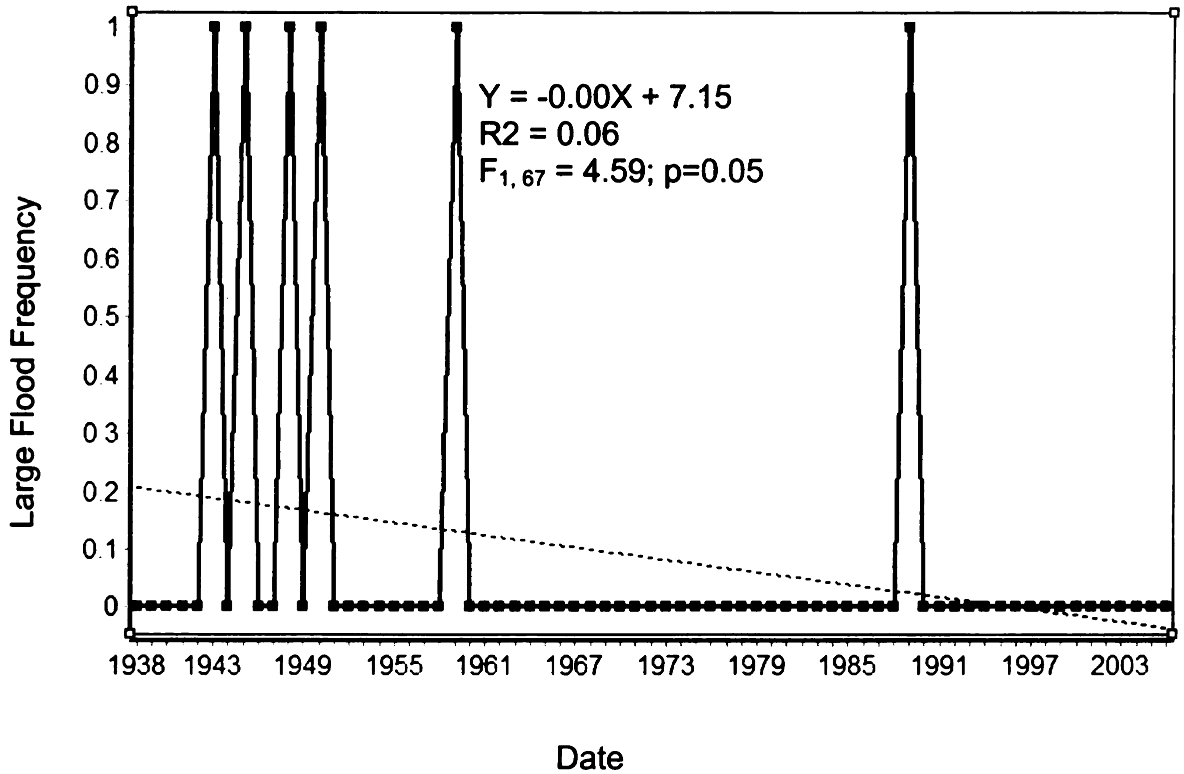


Figure 20. Parametric analysis of large flood frequency, Rifle River at Melita Road.

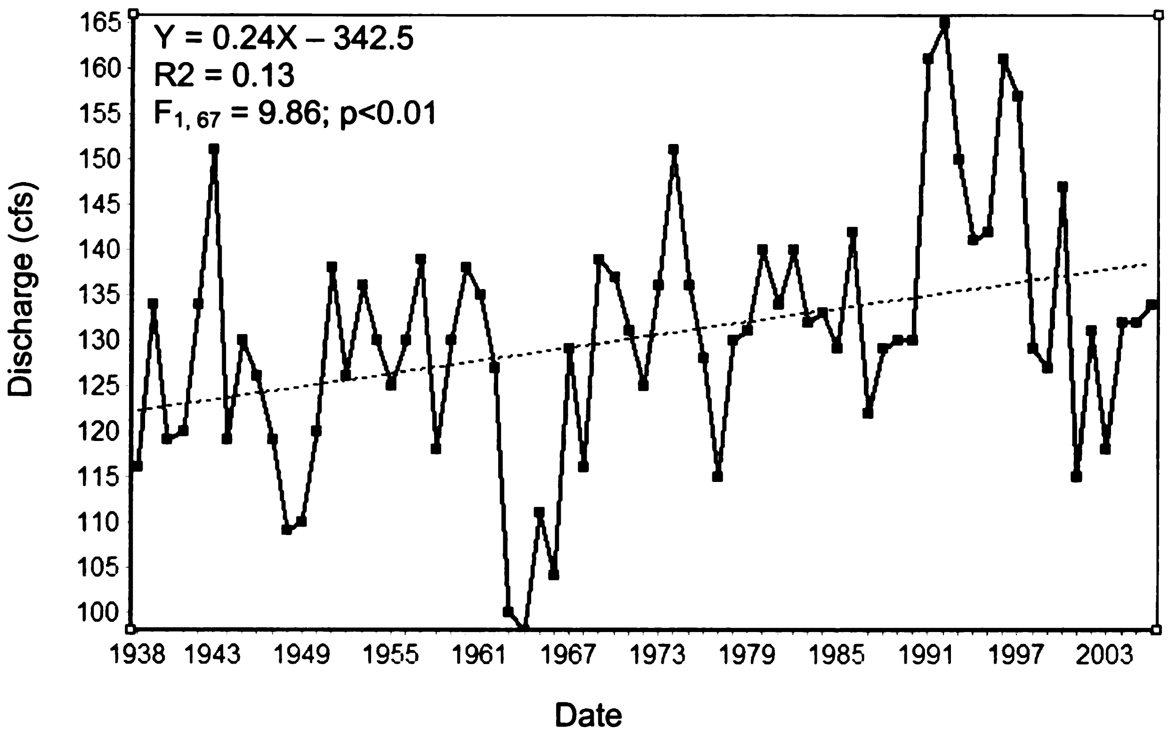


Figure 21. Annual 1-day minimum discharge for the Rifle River at Melita Road.

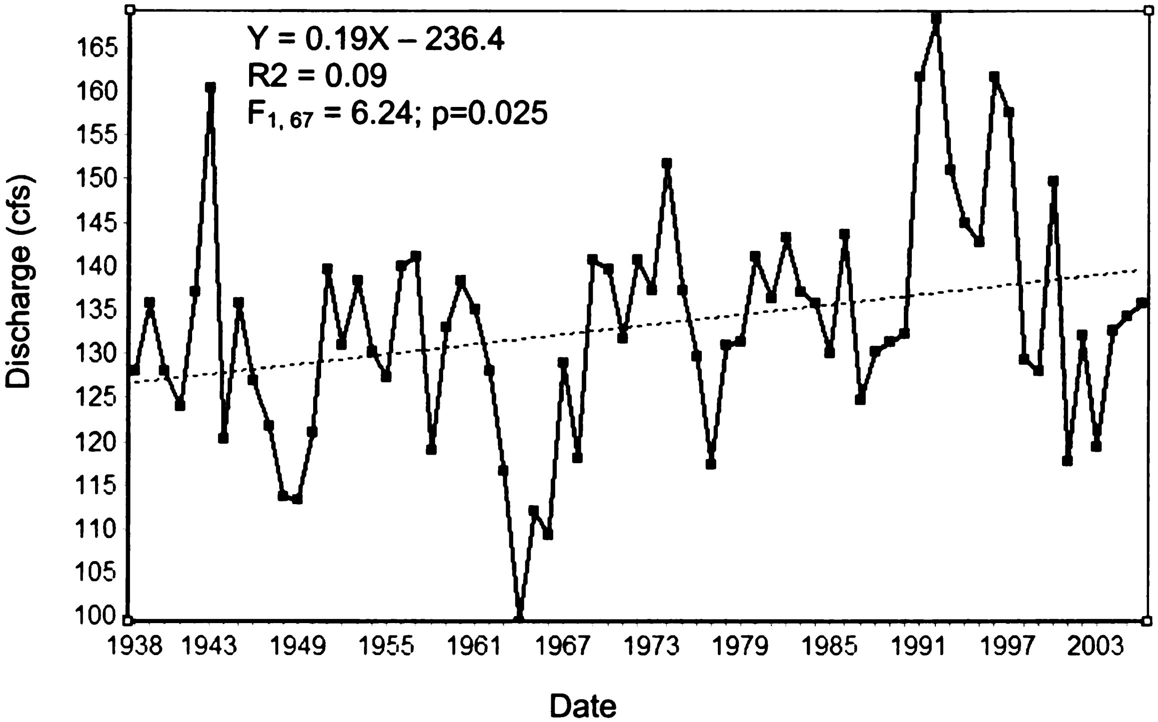


Figure 22. Annual 3-day minimum discharge for the Rifle River at Melita Road.

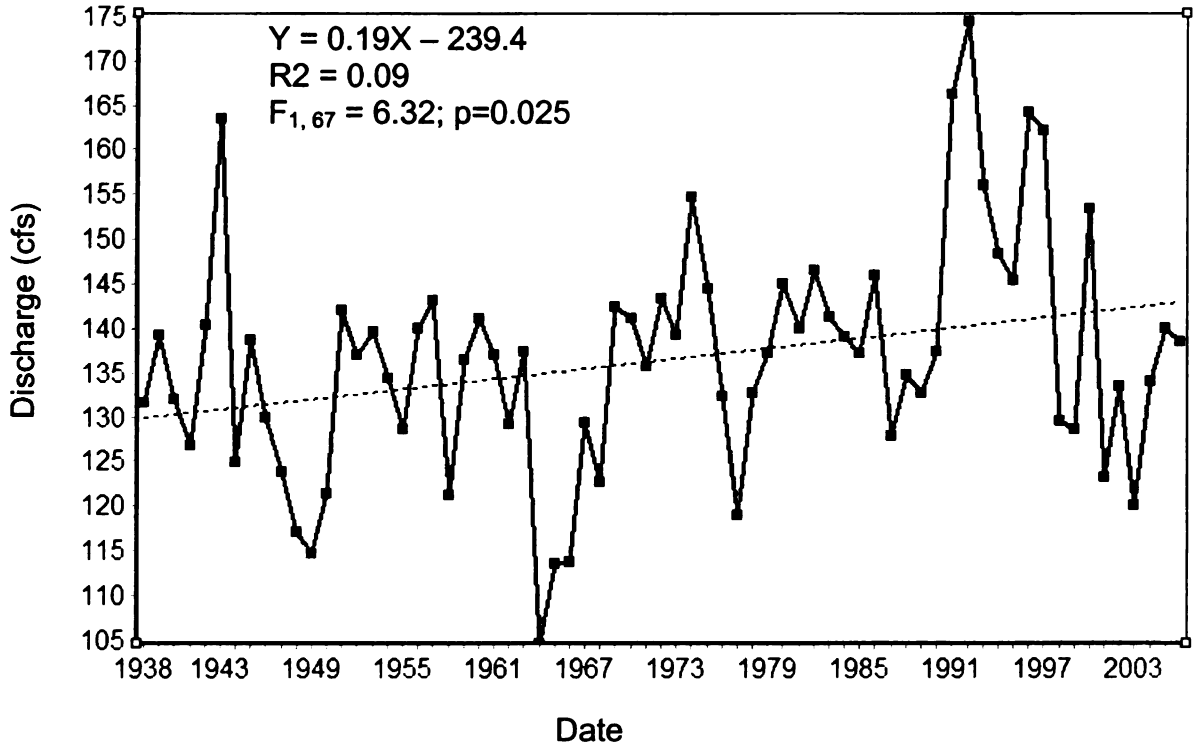


Figure 23. Annual 7-day minimum discharge for the Rifle River at Melita Road.

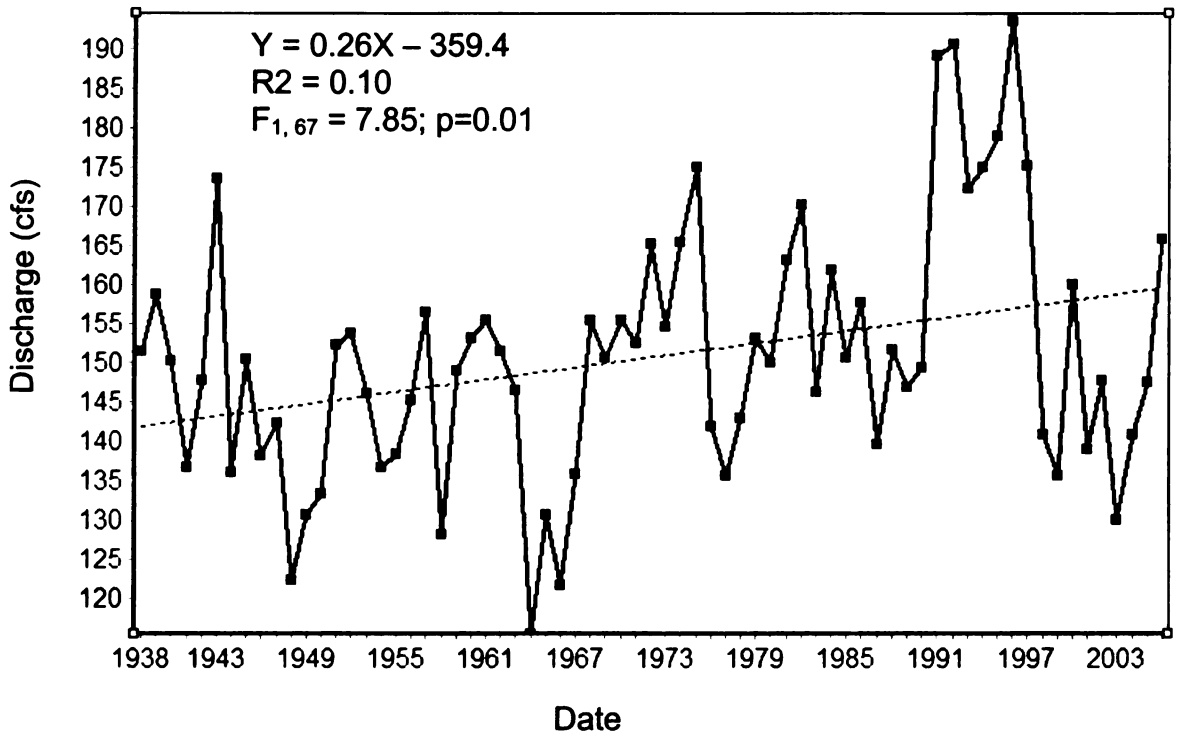


Figure 24. Annual 30-day minimum discharge for the Rifle River at Melita Road.

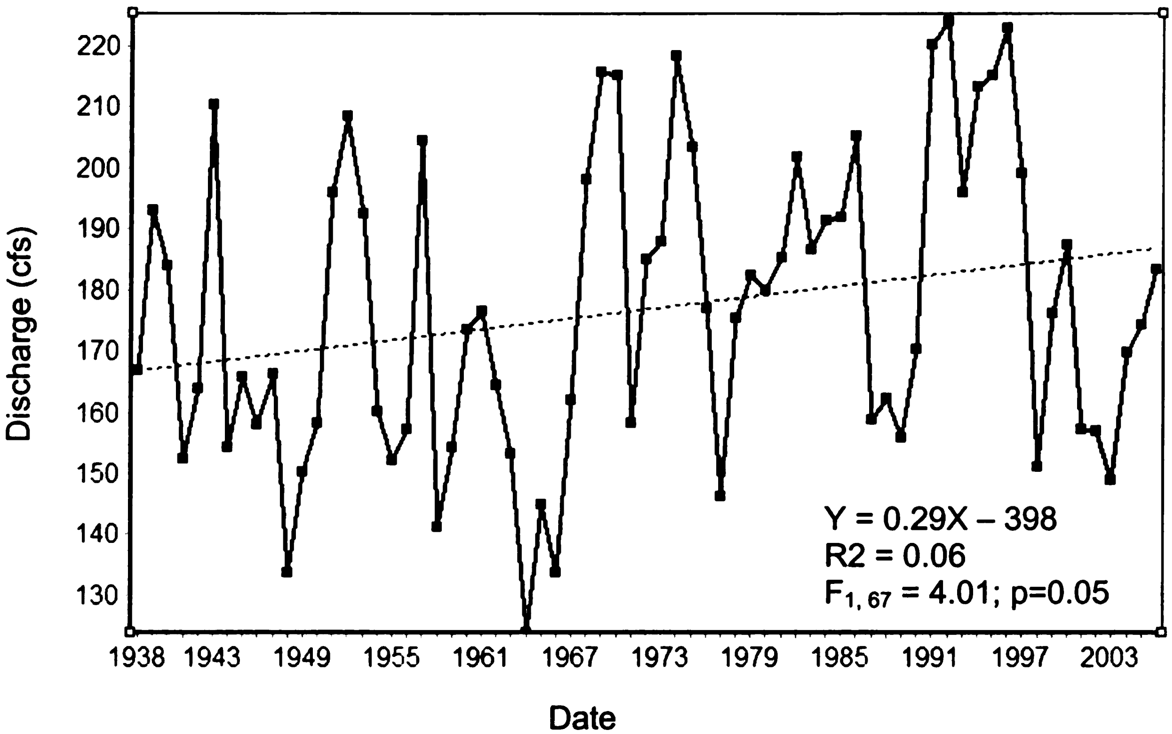


Figure 25. Annual 90-day minimum discharge for the Rifle River at Melita Road.

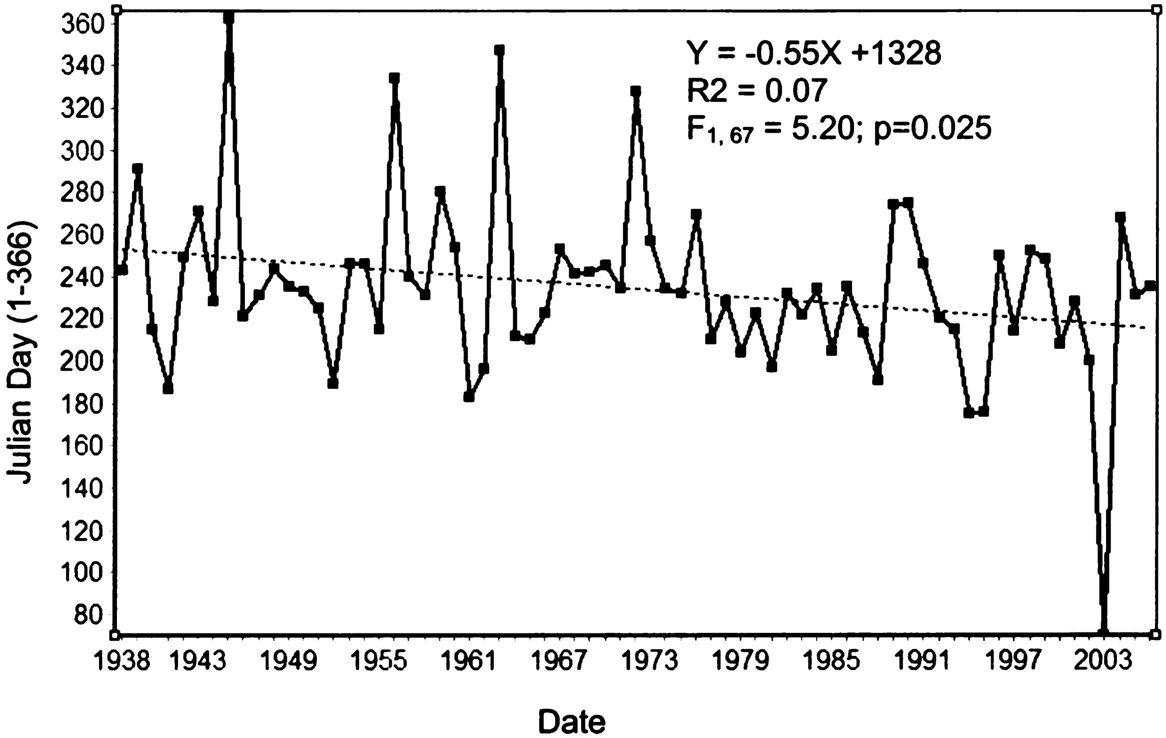


Figure 26. Date of minimum flow for the Rifle River at Melita Road.

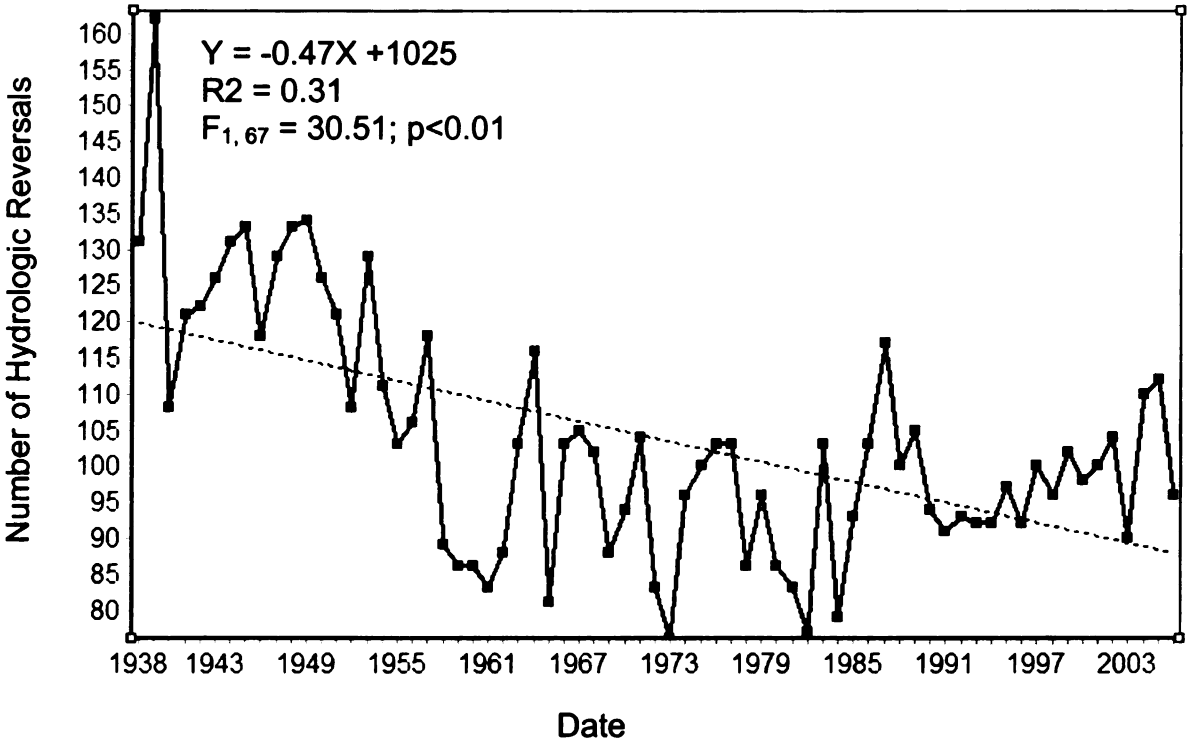


Figure 27. Number of hydrologic reversals for the Rifle River at Melita Road.

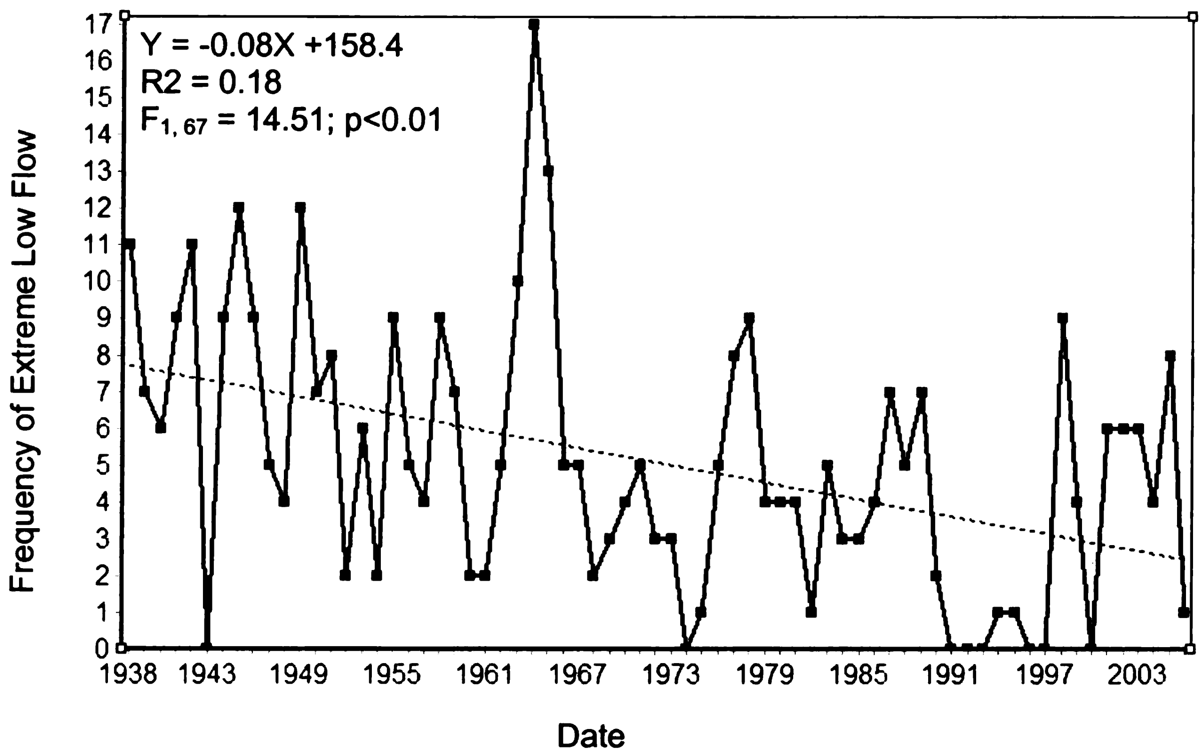


Figure 28. Frequency of extreme low flows for the Rifle River at Melita Road.

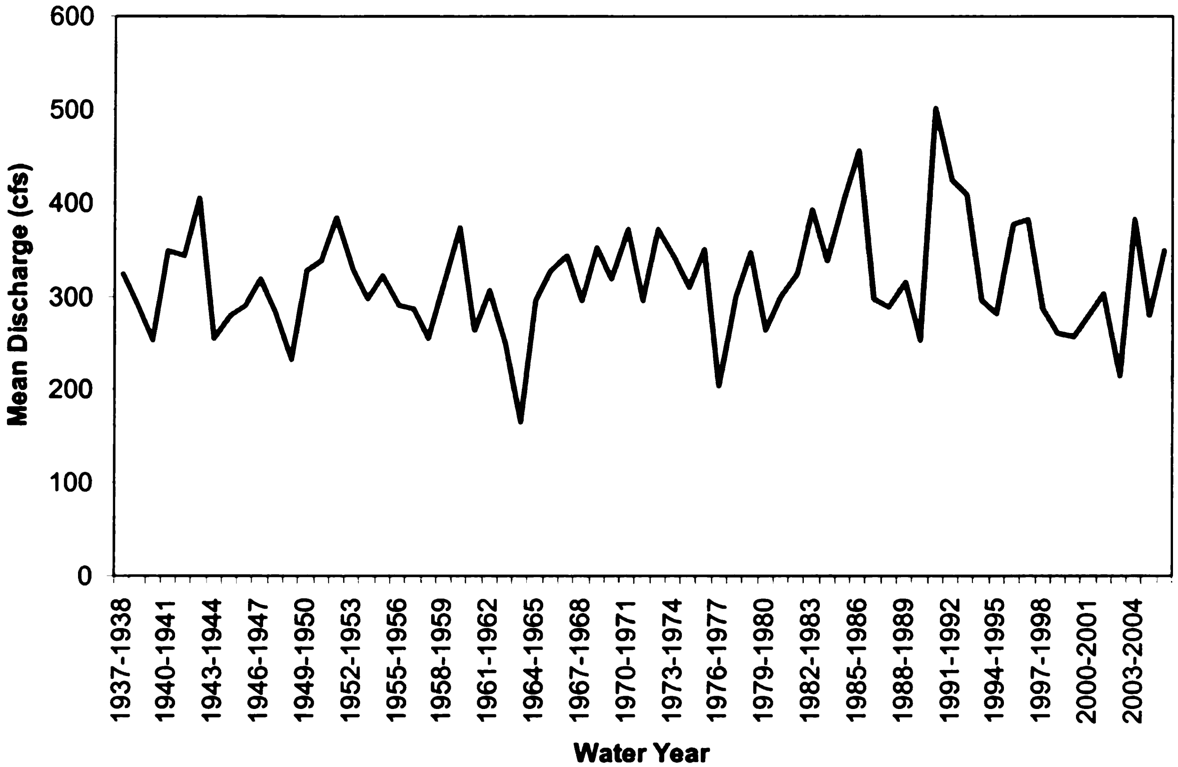


Figure 29. Mean annual discharge for the Rifle River at Melita Road.

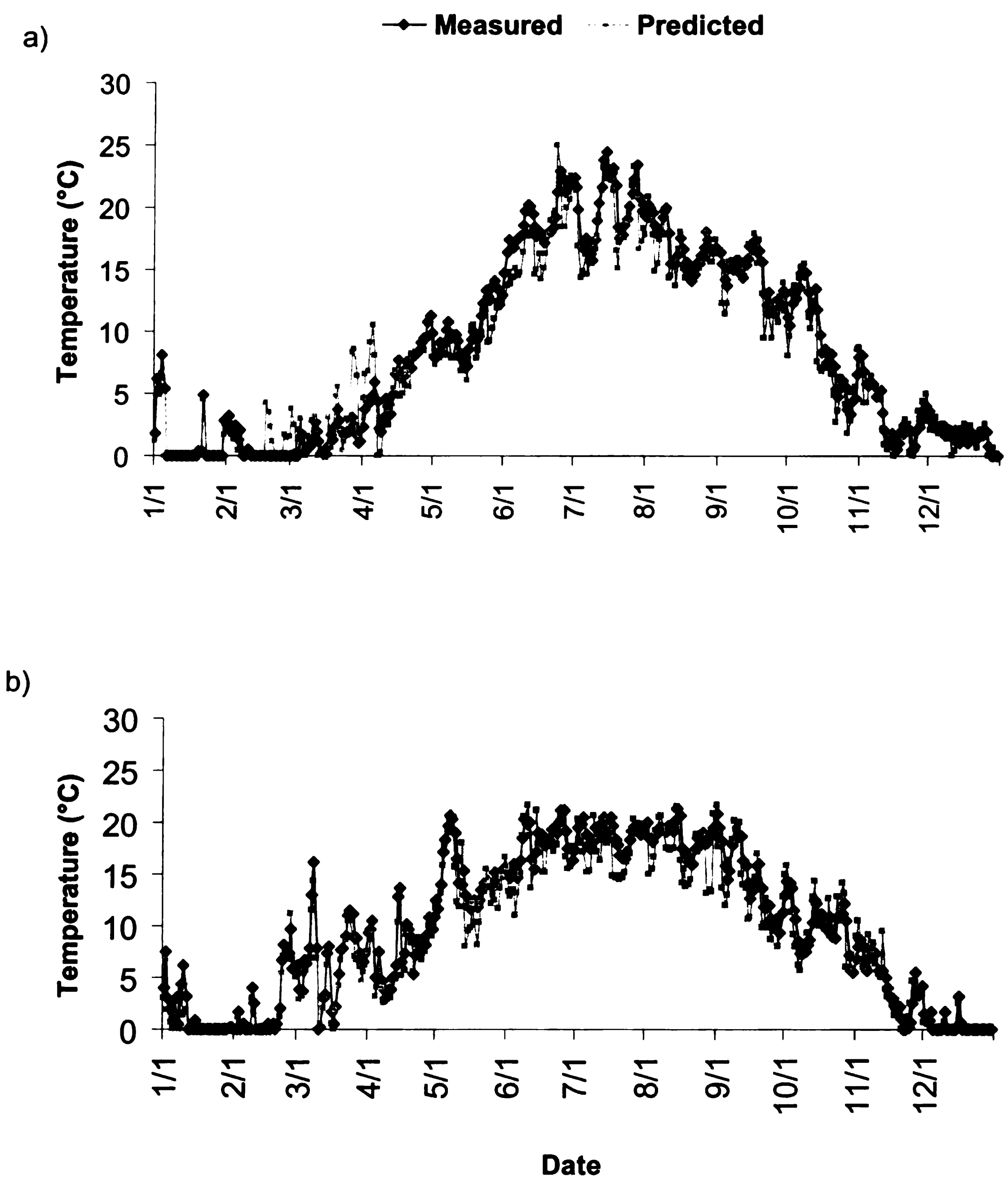


Figure 30. SNTEMP daily calibration predictions and measured temperature (°C) values from 1997 at Melita Road (0.1 rkm; figure a). SNTEMP daily validation predictions and measured temperatures (°C) values from 2000 at Melita Road (0.1 rkm) located in the Rifle River watershed, Michigan (figure b).

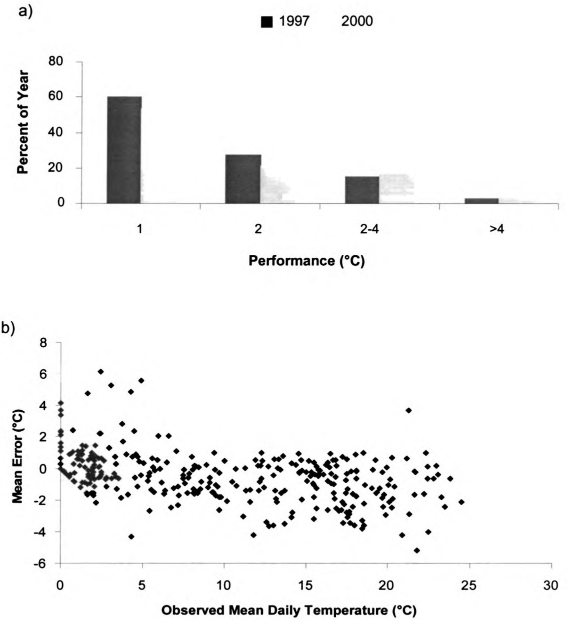


Figure 31. SNTEMP model's predictive performance for calibration (1997) and validation (2000) datasets based on the percentage of time predictions exceeded measured temperatures: <1°C = optimal, <2°C = acceptable, 2-4°C = marginal, and >4°C = unacceptable (figure a). Plot of model error (predicted-measured) against measured water temperatures for 1997 calibration dataset to assess simulation quality (figure b).

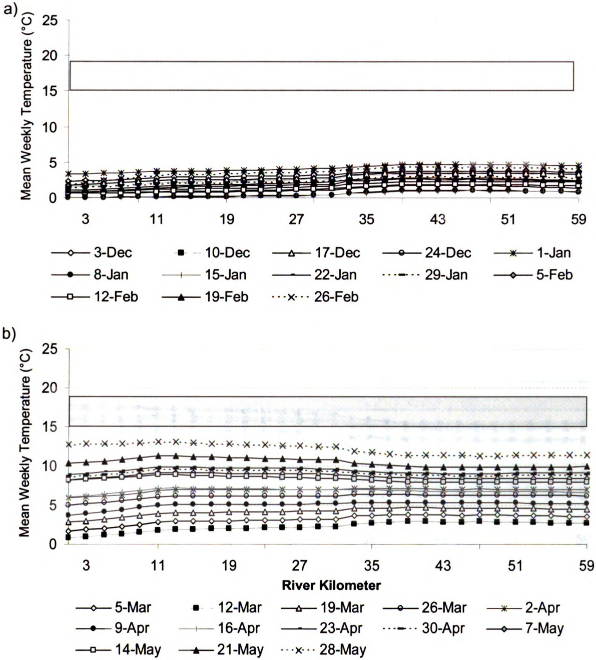


Figure 32. Mean weekly temperatures for the Rifle River watershed as predicted by the SNTEMP model from the headwaters to Melita Road, Sterling, Michigan. Model simulation conditions represent a) winter and b) spring temperatures. Shaded area represents optimal growth temperatures for salmonids (Werhly et al. 1999).

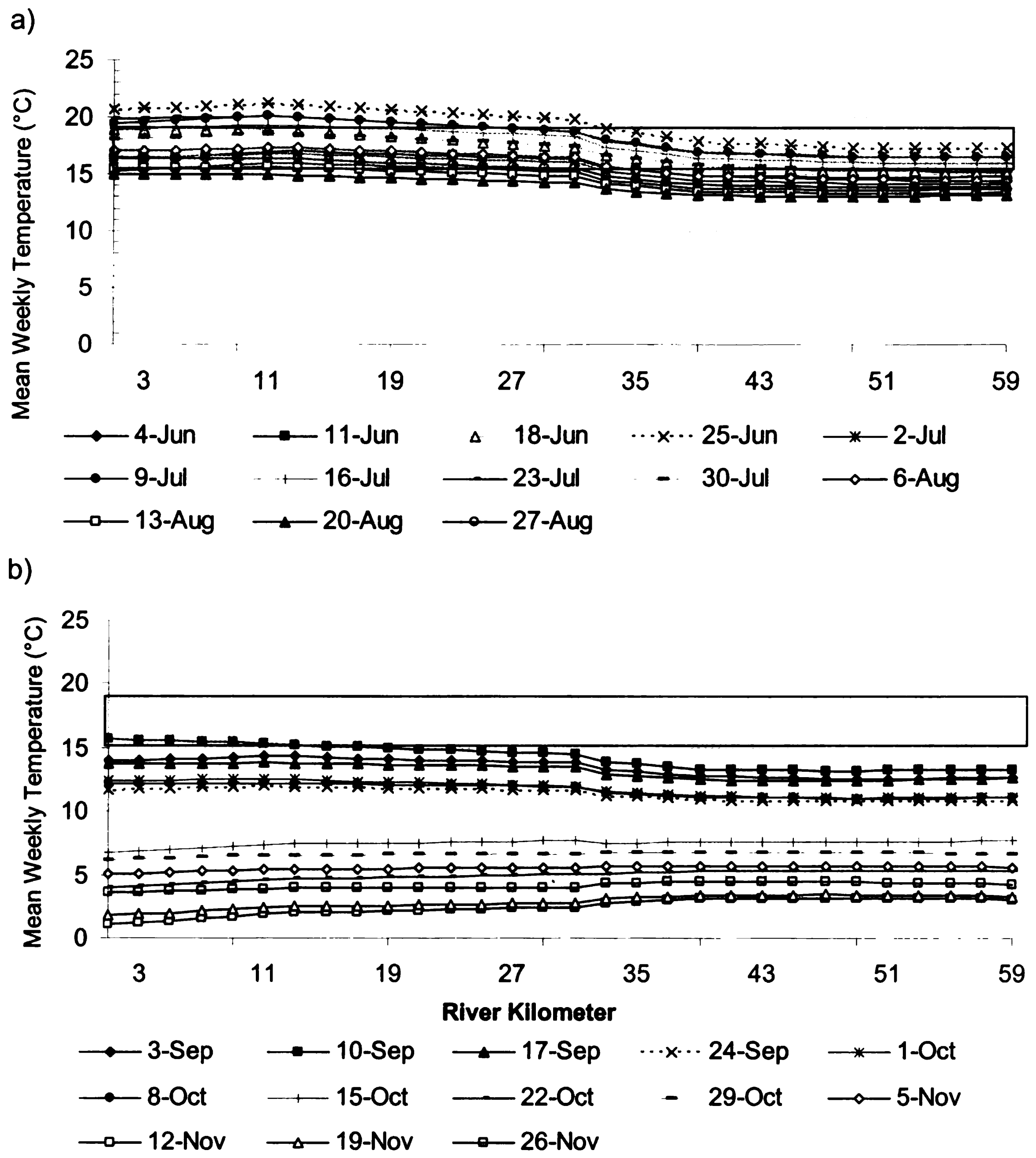


Figure 33. Mean weekly temperatures for the Rifle River watershed as predicted by the SNTEMP model from the headwaters to Melita Road, Sterling, Michigan. Model simulation conditions represent a) summer and b) fall temperatures. Shaded area represents optimal growth temperatures for salmonids (Werhly et al. 1999).

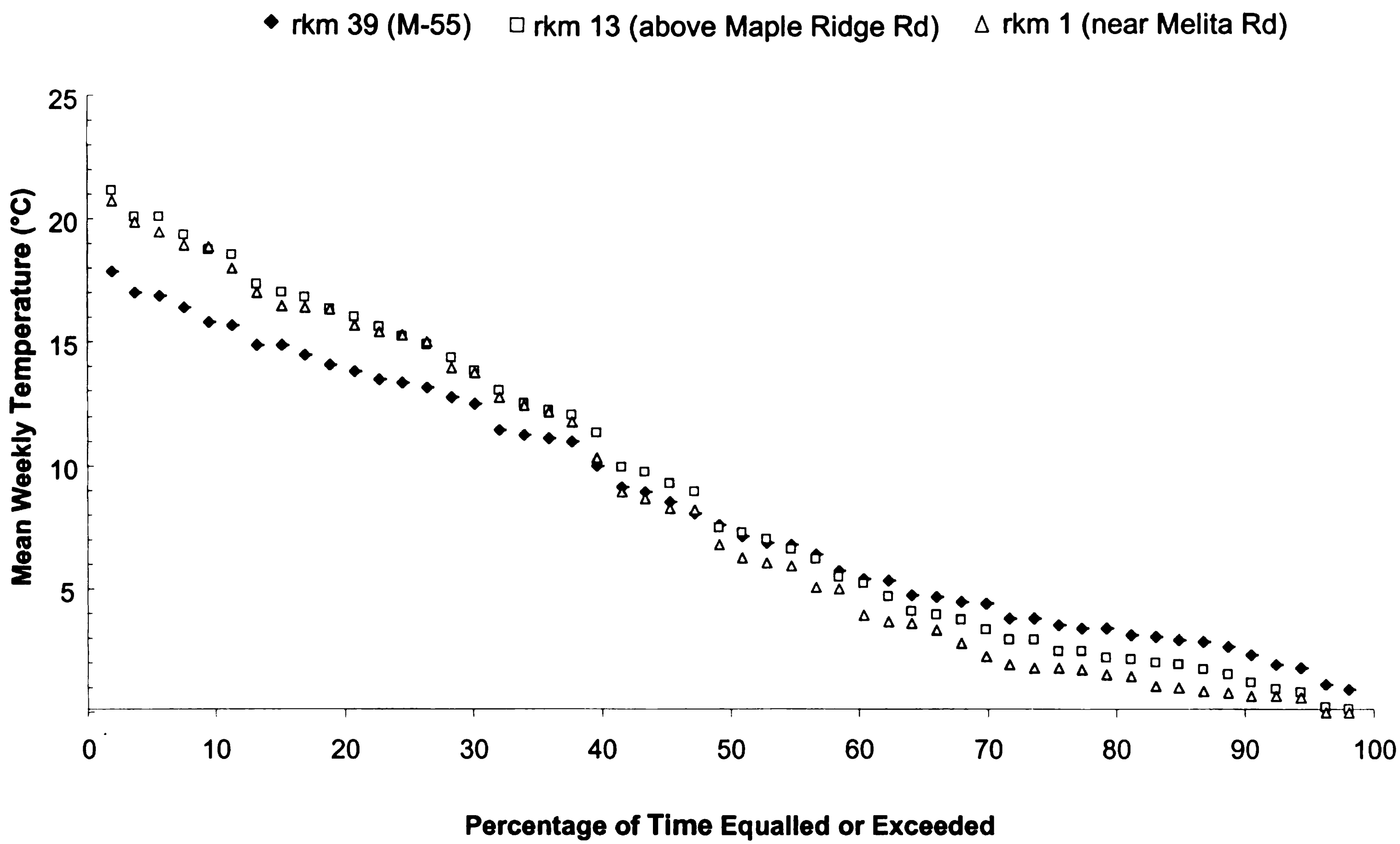


Figure 34. Temperature duration curve for the upper (rkm 39), middle (rkm 13), and lower (rkm 1) sections of the Rifle River watershed, Michigan.

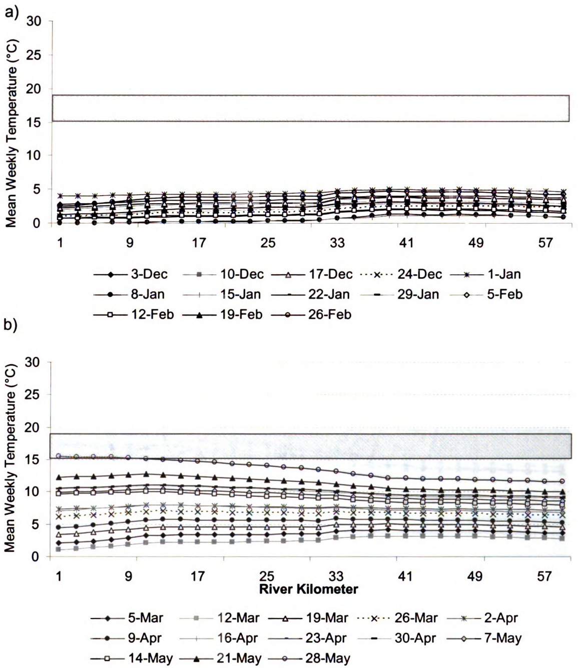


Figure 35. Mean weekly temperatures for the Rifle River watershed as predicted by the SNTEMP model from the headwaters to Melita Road, Sterling, Michigan. Model simulation conditions represent a global increase of 2.7°C in mean annual air temperature for a) winter and b) spring. Shaded area represents optimal growth temperatures for salmonids (Werhly et al. 1999).

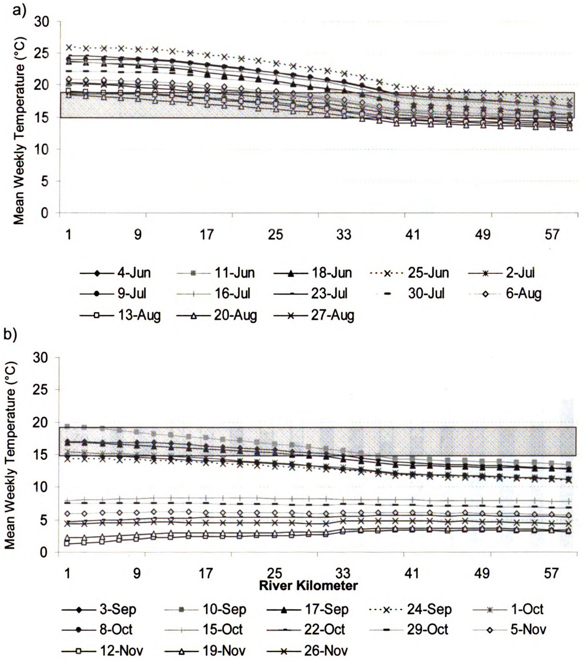
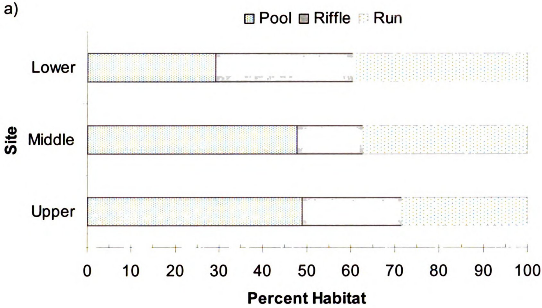


Figure 36. Mean weekly temperatures for the Rifle River watershed as predicted by the SNTEMP model from the headwaters to Melita Road, Sterling, Michigan. Model simulation conditions represent a global increase of 2.7°C in mean annual air temperature for a) summer and b) fall. Shaded area represents optimal growth temperatures for salmonids (Werhly et al. 1999).



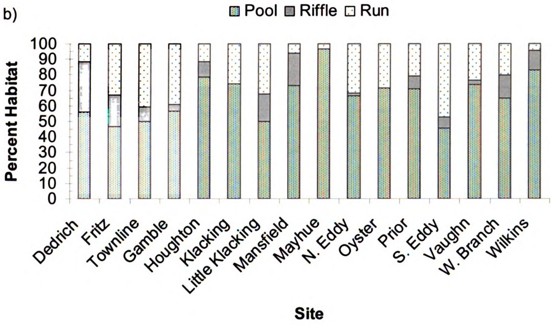


Figure 37. Mesohabitat characteristics based on in-stream habitat assessment of the Rifle River for a) segments of the mainstream Rifle River and b) tributaries to the Rifle River.

a)

b)

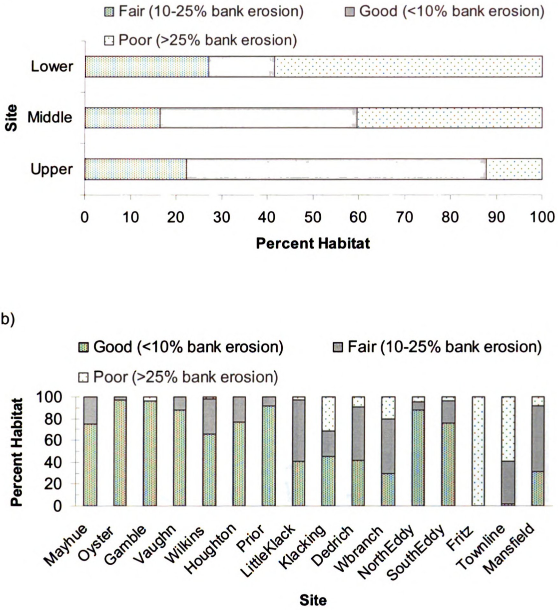


Figure 38. Site quality (percent streambank erosion) based on in-stream habitat assessment of the Rifle River for a) segments of the mainstream Rifle River and b) tributaries to the Rifle River.

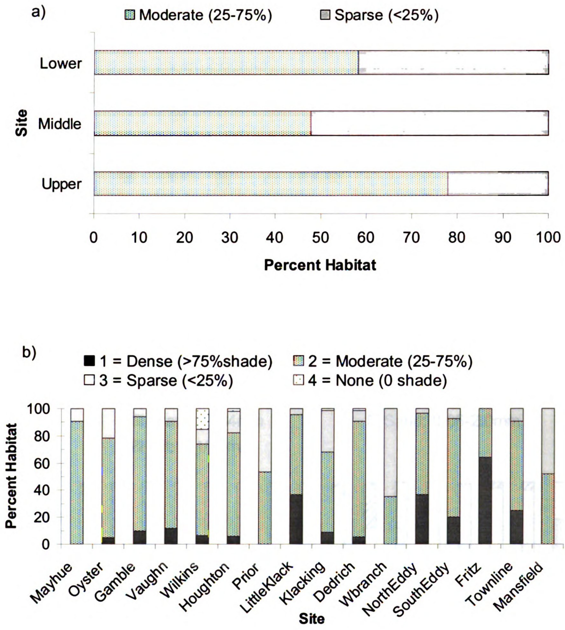


Figure 39. Stream canopy results based on in-stream habitat assessment of a) segments of the mainstream Rifle River and b) tributaries to the Rifle River.

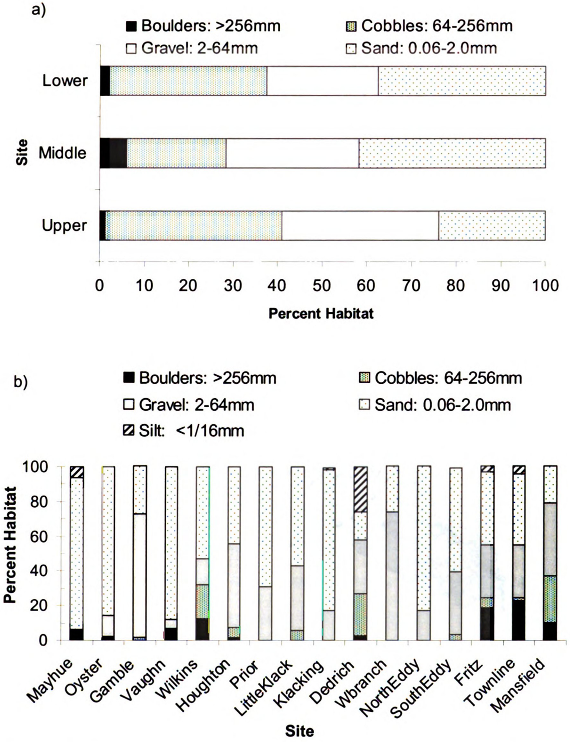


Figure 40. Substrate results based on in-stream habitat assessment of a) segments of the mainstream Rifle River and b) tributaries to the Rifle River.

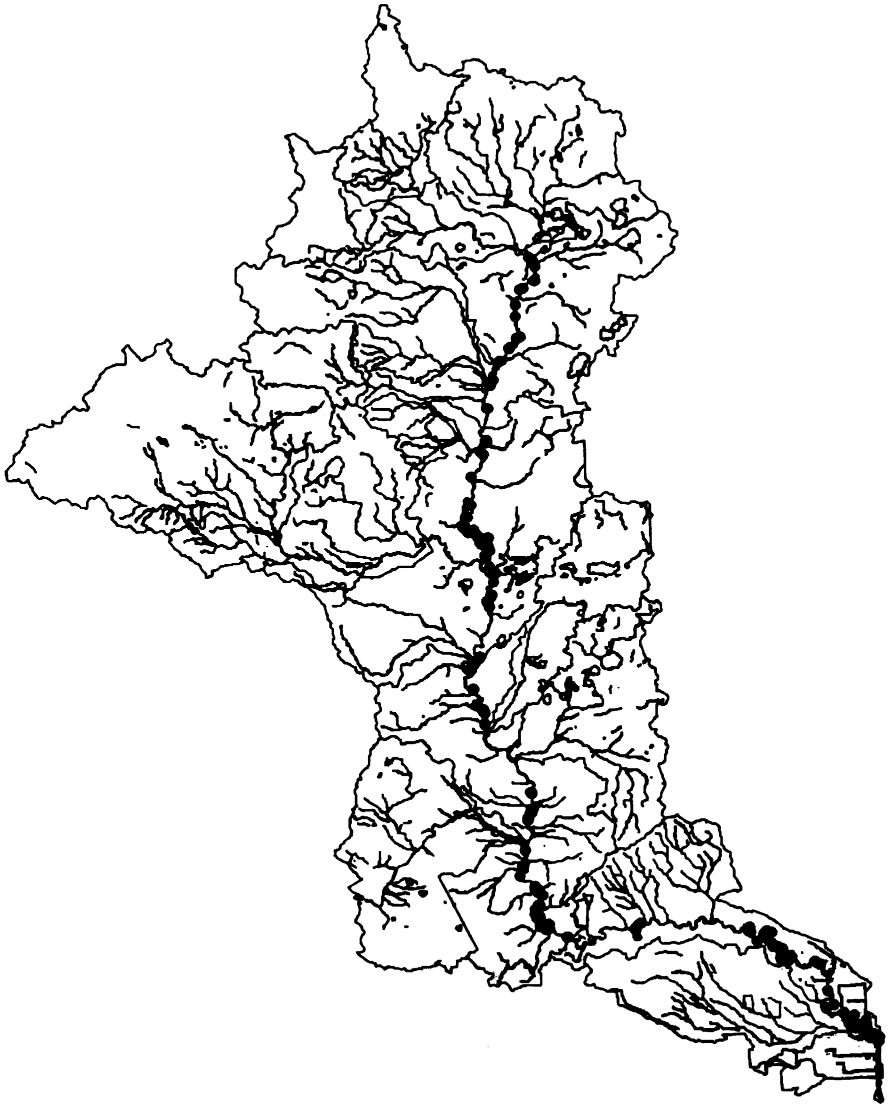


Figure 41. Rehabilitation sites (signified by dots) completed from 1998-2005 throughout the Rifle River watershed, Michigan.

APPENDIX A

Ecosystem Analysis at the Watershed Scale, Federal Guide for Watershed Analysis Version 2.2, Revised August 1995, p. 3., p.12 (RIEC 1995).

Summary of the Six-Step Process

The process for conducting ecosystem analysis at the watershed scale has six steps:

1. *Characterization of the watershed.* The purpose of step 1 is to identify the dominant physical, biological, and human processes or features of the watershed that affect ecosystem functions or conditions. The relationship between these ecosystem elements and those occurring in the river basin or province is established. When characterizing the watershed, teams identify the most important land allocations, plan objectives, and regulatory constraints that influence resource management in the watershed. The watershed context is used to identify the primary ecosystem elements needing more detailed analysis in subsequent steps.
2. *Identification of issues and key questions.* The purpose of step 2 is to focus the analysis on the key elements of the ecosystem that are most relevant to the management questions and objectives, human values, or resource conditions within the watershed. The applicability of the core questions and level of detail needed to address applicable core questions is determined. Rationale for determining that a core question is not applicable are documented. Additional topics and questions are identified

based on issues relevant to the watershed. Key analysis questions are formulated from indicators commonly used to measure or interpret the key ecosystem elements.

3. *Description of current conditions.* The purpose of this step is to develop information (more detailed than the characterization in step 1) relevant to the issues and key questions identified in step 2. The current range, distribution, and condition of the relevant ecosystem elements are documented.
4. *Description of reference conditions.* The purpose of step 4 is to explain how ecological conditions have changed over time as a result of human influence and natural disturbances. A reference is developed for later comparison with current conditions over the period that the system evolved and with key management plan objectives.
5. *Synthesis and interpretation of information.* The purpose fo step 5 is to compare existing and reference conditions of specific ecosystem elements and to explain significant differences, similarities, or trends and their causes. The capability of the system to achieve key management plan objectives is also evaluated.
6. *Recommendations.* The purpose of this step is to bring the results of the previous steps to conclusion, focusing on management recommendations that are responsive to watershed processes identified in the analysis. By documenting logical flow through the analysis, issues and key questions

(from step 2) are linked with the step 5 synthesis and interpretation of ecosystem understanding (from steps 1, 3, and 4). Monitoring activities are identified that are responsive to the issues and key questions. Data gaps and limitations of the analysis are also documented.

Core Topics

The core topics represent the major and common ecological elements, and their relationships, in all watersheds. The topics are purposely broad and general, as they encourage a watershed-level perspective of the system as opposed to a site or project-level perspective. The purpose of the core topics is to ensure that responsible officials and their teams adequately address the major elements and their relationships in the watershed. The core anlysis topics help ensure that analyses are sufficiently comprehensive to develop a basic understanding of the watershed. The analysis team should demonstrate understanding and knowledge of the basic ecological conditions, processes, and interactions in the watershed by addressing the following core topics through the six-step process:

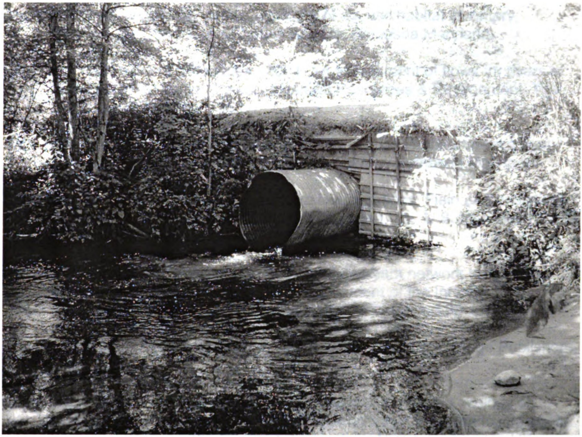
- Erosion processes
- Hydrology
- Vegetation
- Stream channel
- Water quality
- Species and habitats
- Human uses

Appendix B

Site: Oyster Creek at Rose City Road near Lupton, Michigan.

Problem: Culvert is inundated with silt.

Appendix B (Continued)



Site: North Eddy Creek at Patricia Lane.

Problem: Perched culvert.

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