MICHIGAN DEPARTMENT OF NATURAL RESOURCES
FISHERIES DIVISION

Special Report

Draft Grand River Assessment

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Suggested Citation Format

Hanshue, S. K., and A. H. Harrington. 2011. Draft Grand River Assessment. Michigan Department of Natural Resources Fisheries Division, Special Report , Ann Arbor.

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EXECUTIVE SUMMARY

The Grand River Assessment is one of a series of comprehensive river assessments prepared by the Fisheries Division of the Michigan Department of Natural Resources (MDNR) for Michigan rivers.

River assessments are prepared to provide a comprehensive reference for citizens and agency personnel who desire information about a particular aquatic resource. These assessments provide an approach to identifying fishery management opportunities and solving fishery related problems. This report describes the characteristics of the Grand River watershed and its biological communities in order to increase public awareness of the Grand River and its challenges and to promote a sense of public stewardship and advocacy for the resources of this watershed. The ultimate goal is to provide information to enable increased public involvement in the decision making process to benefit the river and its resources.

This document consists of four parts: an introduction, a river assessment, management options, and public comments and response. The river assessment is the nucleus of the report. Within it, the characteristics of the Grand River and its watershed are described in twelve sections: geography, history, geology and hydrology, soils and land use, channel morphology, dams and barriers, water quality, special jurisdictions, biological communities, fishery management, recreational use, and citizen involvement.

The management options section of the report identifies a variety of challenges and opportunities. These management options are categorized and presented following the outline of the river assessment. It must be stressed that MDNR, Fisheries Division does not necessarily recommend the options listed. Rather, they are intended to provide a foundation for public discussions and comment.

The Grand River watershed is located in Michigan's southwestern Lower Peninsula and is the second largest river basin in Michigan with the Saginaw River watershed being the largest. The basin encompasses approximately 5,575 square miles and drains all or parts of Hillsdale, Jackson, Washtenaw, Livingston, Calhoun, Eaton, Ingham, Shiawassee, Gratiot, Clinton, Ionia, Montcalm, Mecosta, Barry, Allegan, Kent, Newaygo, Muskegon, and Ottawa counties. The Grand River mainstem is 248 miles long, the longest river in the State, and drains a catchment that is 135 miles long and 70 miles wide. Within the watershed there are 5,320 miles of tributaries, ranging in size from first to fifth order. Major tributaries include the Portage River, Red Cedar River, Looking Glass River, Maple River, Flat River, Thornapple River, Rogue River and Bass River. There are 581 lakes greater than 10 acres within the basin. Spring Lake is the largest lake with a surface area of 1,097 acres.

In order to characterize the biological and physical attributes of the catchment, the Grand River mainstem is divided into five sections called mainstem valley segments. Mainstem valley segments represent portions of a river that share common channel and landscape features and were identified using major changes in hydrology, channel and valley shapes, land cover, and surficial geology. The headwater segment begins at the mainstem origin and extends 54 miles to a point upstream of the confluence with Sandstone Creek in north-central Jackson County. The upper segment includes the Sandstone Creek confluence and flows through Eaton Rapids and Dimondale. The upper segment includes 42 mainstem miles and ends upstream of the Red Cedar River confluence. The middle segment is 60 miles long and extends downstream to the confluence with the Maple River near the villages of Muir and Lyons. Two large tributaries, the Red Cedar and Looking Glass Rivers, join the mainstem in this segment. The mainstem here is characterized as a large, warm water river and is impounded by six dams. The lower segment begins with the confluence of the Maple River. The lower segment is confined in a glacial-fluvial valley formed approximately 14,000 years ago when the

Maple-Grand River drained glacial Lake Saginaw into glacial Lake Chicago. The lower segment is the largest and includes drainage from the Maple, Flat, Thornapple, and Rogue rivers. The mouth segment begins near the Village of Lamont and continues across glacial lake plain the remaining 25 miles to the confluence with Lake Michigan.

The history of the watershed can be traced back as far as the Paleo-Indians 12,000 to 8000 years ago. Several Paleo-Indian archaeological sites are located throughout the basin. During the Late-Archaic (8,000-6,000 years ago), hunting and fishing for subsistence was the way of life, and Indian communities were drawn to the Grand River area for its natural resources. Hunting and fishing camps were common in the watershed. The first European settlers in the area arrived in 1650 and established trading posts near tribal villages. The first logging operations began in the mid-1800s. The abundant and diverse forests within the watershed provided lumber for homes and led to the development of the furniture industry in Grand Rapids. The river from Grand Haven to Lyons served as a main thoroughfare for commerce and communications. Barges and riverboats traveled the channel until the development of the railroad.

The hydrology of the Grand River watershed is influenced by climate, surficial geology, soil types and land use. Climate in the watershed is determined by latitude, differences in land-surface altitude, and moderating effects of the Great Lakes. Mean precipitation is about 31 inches, whereas annual snowfall is highly dependent on proximity to Lake Michigan and can range from as low as 30 inches to over 100 inches. Surficial geology is varied and ranges from coarse-textured end moraine and ice contact topography to glacial lake plains. In some portions of the watershed glacial tills and deposits are several hundred feet thick while other areas are characterized by exposed bedrock. Coarse-textured soils are more permeable and allow for higher rates of infiltration and groundwater recharge. Watersheds with these soil types, coupled with intact, well-vegetated landscapes, are typically characterized as having higher stream flow stability. Conversely, fine-textured soils are less well drained and promote surface runoff. Streams draining catchments dominated by clays and other fine textured soils have a higher overland flow component and tend exhibit less stable flow patterns. Stream channel alterations, filling and draining of wetlands, installation of drainage networks for agriculture and urban development also contribute to stream flow instability.

Soil and land-use are, in part, controlling factors in water movement through the river basin. Soils develop over thousands of year as a result of the weathering of glacial parent materials. In general, minimally disrupted watersheds with intact vegetative cover have higher infiltration rates and less soil loss due to erosion associated with surface runoff. Changes within the land use and land cover can have dramatic effects on the channel shape. Soil groups in the Grand River watershed are widely distributed and are largely characterized as having moderately low runoff potential. Soil types with low runoff potential comprise 18% of the watershed, whereas soils with high runoff potential comprise 14%. Presettlement land cover in the watershed was primarily beech-maple, mixed oak, and coniferous forests. Forested wetlands, shrub-swamp/emergent wetland, wet prairie and open water accounted for approximately 18% of the presettlement land cover. Contemporary land use is dominated by agriculture (57%); forested land cover has been reduced to 25% and wetlands reduced by over 50%. Urban land use accounts for 9% of the current landscape. Runoff from impervious surfaces associated with large urban areas (Jackson, Lansing, and Grand Rapids) represents a threat to the quality of surface water and groundwater resources. Continued increases in impervious surfaces dramatically decreases groundwater recharge and significantly alters the timing and volume of storm water delivered to stream channels. There are over 8,600 road stream crossings in the Grand River watershed. Improper design and construction of bridges and culverts at stream crossings can result in disruption of water and sediment transport, limit movements of fish and other aquatic life, and serve a as pathway for the discharge of nonpoint source pollutants.

Channel slope or gradient is an important factor in the development of channel form and habitat characteristics of a river. Areas of higher gradient typically support more diverse and abundant populations of aquatic organisms. The elevation of the Grand River mainstem drops 551.9 feet from 1130.7 feet above sea level at the headwaters to 578.8 feet above sea level at the mouth. The average gradient of the Grand River mainstem is 2.2 feet/mile with a maximum of 5.48 feet/mile near the former rapids in Grand Rapids. The higher quality habitats located in the middle segment have been eliminated by the construction of six dams. These dams and their impoundments have eliminated and/or fragmented some of the best pool and riffle habitat on the mainstem.

In addition to channel gradient, channel cross section can be a useful measure of habitat quality. Natural channels typically provide better habitat than those that have been manipulated by channelization or degraded by altered hydrology. Expectations of habitat diversity can be made based on an analysis of channel cross section and stream discharge. Stream channels that deviate from the expected channel dimensions may have unstable flow patterns or otherwise altered channel morphology. Channel cross sections of the Grand River fall within the expected range at average flow. However, channel cross sections are too narrow at high flow and too wide at low flow. Several miles of tributaries in the Grand River watershed do not support minimally acceptable fish and aquatic macroinvertebrate communities as a result of channelization or altered hydrology due to expansion of drainage areas through field tiling and construction of storm sewers.

There are 228 dams in the Grand River watershed registered with Michigan Department of Environmental Quality. Dams alter sediment and nutrient transport, change concentrations of dissolved gases, alter flow patterns and flood frequencies, and cause warming of downstream river habitat. Dams fragment river systems and turn high gradient river habitat into slow flowing habitat more typical of a shallow lake. Dams are typically constructed in areas of highest stream gradient which are essential habitats for flow oriented (rheophilic) fish species. These high gradient areas also provide critical spawning and feeding habitats for several other species of fish. Although fish ladders provide passage for some potamodromous fish species such as salmon and steelhead, dams on the Grand River mainstem block the movements of lake sturgeon and several other species of fish. Dams located in the lower portions of the Rogue, Flat, and Thornapple Rivers block spawning runs and isolate fish populations. Fish mortality or injury often results when fish pass through or over dams, especially those with hydroelectric turbines. Many dams in the watershed serve as water level control structures designed to keep inland lakes at static levels. These structures disrupt seasonal flow patterns and alter the integrity of the lake ecosystem.

Point source water pollution from industrial and municipal sources in the watershed has decreased significantly since the implementation of the Federal Water Pollution Control Act. Historically, the river received improperly treated wastewater from a variety of industrial and municipal sources. These discharges significantly reduced water quality and resulted in the loss of pollution-sensitive aquatic species. Prior to the enactment of stringent water quality standards, the Grand River fish community was dominated by pollution-tolerant fish species. Currently, most point sources have adequate pollution controls and are in compliance with Michigan water quality standards. Water quality impairments that remain are related to exceedences of dissolved oxygen and bacteria standards. Reconstruction of sanitary wastewater collection systems is necessary in the larger urban areas to eliminate the discharge of untreated wastewater through combined sewer and sanitary sewer overflows.

Nonpoint source pollution is the greatest factor that degrades water quality. This type of pollution enters the water from atmospheric deposition and surface runoff and generally consists of sediment, nutrients, bacteria, organic chemicals, and inorganic chemicals from agricultural fields, livestock feedlots, construction sites, parking lots, urban streets, septic seepage, and open dumps. Implementing best management practices with farmland, construction sites, and urban development designs can significantly reduce runoff, erosion, and influxes of sediment, nutrients, and other chemicals in to lakes and streams.

The Grand River catchment contains several unique and rare plant communities ranging from dry mesic southern forest to southern floodplain forest to interdunal wetlands. These plant communities represent remnants of the presettlement landscape and are rich in biodiversity. These communities provide critical habitats for numerous vertebrate and invertebrate species of conservation interest including several that are identified as endangered, threatened, or of special concern.

The watershed currently supports 107 species of fish, 14 of which are present through direct or indirect introduction. The fish community includes several species of conservation interest including the lake sturgeon, river redhorse, and cisco, which are identified as threatened, and the pugnose shiner, which is endangered. Two fish species have been extirpated. The weed shiner was known from few locations in the watershed and was last reported in 1941. American eel were stocked in several lakes and streams in the watershed during the late-1800s as a food fish; however, no records of survival exist. Introduced aquatic pest species reported in the watershed include: common carp, round goby, sea lamprey, zebra mussel, curly leaf pondweed and Eurasian water milfoil. These species have had negative effects on the ecology of the waters where they have become established. Floodplain forests and nearshore environments have been significantly altered as a result of the introduction of terrestrial exotics such as the emerald ash borer, Dutch elm disease, garlic mustard, phragmites and purple loosestrife. These changes are transferred to the aquatic ecosystem in the form of reduced productivity and altered habitat.

Fishery management of the Grand River watershed began in the 1800's when the waters were initially surveyed by the Michigan Fish Commission. Direct manipulation of fish populations through species introduction or augmentation were common management actions for several decades. These actions occurred regardless of the temperature and habitat needs of the individual species. Stocked fishes include trouts and salmon, panfish, walleye, and northern pike. As fisheries science progressed, changes in management philosophies led to a reduction in the numbers and species of fish being stocked. Contemporary fisheries management in the Grand River watershed is guided by knowledge of the attributes of the individual lake and stream, emphasizing habitat protection and restoration with a goal of self-sustaining populations. The watershed supports significant and economically valuable warmwater and coldwater fisheries that are protected by managing harvest through size and creel limits. Current stocking programs in the watershed provide recreational fishing opportunities on the mainstem, tributaries, inland lakes, and Lake Michigan.

Recreational use of the river mainstem is highest in the middle, lower, and mouth segments. These areas are open to the passage of Lake Michigan salmon and steelhead and receive more angling pressure. There are numerous coldwater tributaries in the lower segment that support popular fisheries for brown trout, brook trout, and steelhead. Diverse warm water fisheries for walleye, smallmouth and largemouth bass, northern pike, panfish, and channel and flathead catfish are found on the mainstem, tributaries and inland lakes. Public access to these waters is assured through many boating and public water access sites, state game areas, and numerous publicly owned parks. Other recreational activities associated with state owned lands within the watershed include hunting, camping, boating and canoeing, swimming, hiking and biking, and nature observation. Future increases in public access will likely be necessary to meet the future demands of the population centers of Jackson, Lansing, Grand Rapids and Grand Haven.

Historical pollution as well as the current discharges from the remaining combined sewer overflows has left the Grand River with a reputation of being polluted. Although this was an accurate description of the past, the river has recovered and currently supports a diverse aquatic community. The natural resources in the Grand River catchment are substantial and provide millions of dollars of recreation-based revenue to the residents of the watershed. Several community action groups and organizations work throughout the watershed to improve habitat and provide educational outreach toward protection of aquatic resources. Citizen involvement through these local initiatives is critical in making necessary changes in planning and zoning and to ensure that habitat protection, improvement of water quality and enhancement of recreational opportunities continues.

DRAFT GRAND RIVER ASSESSMENT

INTRODUCTION

This river assessment is one of a series of documents being prepared by the Michigan Department of Natural Resources, Fisheries Division, for rivers in Michigan. We have approached this assessment from an ecosystem perspective, as we believe that fish communities and fisheries must be viewed as parts of a complex aquatic ecosystem. However, this assessment is admittedly biased towards aquatic systems.

As stated in the Fisheries Division Strategic Plan, our aim is to develop a better understanding of the structure and function of various aquatic ecosystems, to appreciate their history, and to understand changes to systems. Using this knowledge we will identify opportunities that provide and protect sustainable fishery benefits while maintaining, and at times rehabilitating, system structures or processes.

Healthy aquatic ecosystems have communities that are resilient to disturbance, are stable through time, and provide many important environmental functions. As system structures and processes are altered in watersheds, overall complexity decreases. This results in a simplified ecosystem that is unable to adapt to additional change. All of Michigan's rivers have lost some complexity due to human alterations in the channel and on the surrounding land; the amount varies. Therefore each assessment focuses on ecosystem maintenance and rehabilitation. Maintenance involves either slowing or preventing the losses of ecosystem structures and processes. Rehabilitation is putting back some of the structures or processes.

River assessments are based on ten guiding principles of the Fisheries Division. These are: 1) recognize the limits on productivity in the ecosystem; 2) preserve and rehabilitate fish habitat; 3) preserve native species; 4) recognize naturalized species; 5) enhance natural reproduction of native and desirable naturalized fishes; 6) prevent the unintentional introduction of invasive species; 7) protect and enhance threatened and endangered species; 8) acknowledge the role of stocked fish; 9) adopt the genetic stock concept, that is protecting the genetic variation of fish stocks; and 10) recognize that fisheries are an important cultural heritage.

River assessments provide an organized approach to identifying opportunities and solving problems. They provide a mechanism for public involvement in management decisions, allowing citizens to learn, participate, and help determine decisions. As well these assessments provide an organized reference for Fisheries Division personnel, other agencies, and citizens who need information about a particular aspect of the river system.

The nucleus of each assessment is a description of the river and its watershed using a standard list of topics. These include:

Geography—a brief description of the location of the river and its watershed; a general overview of the river from its headwaters to mouth. This section sets the scene.

History—a description of the river as seen by early settlers and a history of human uses and modifications of the river and the watershed.

Geology and Hydrology—patterns of water flow over and through the landscape. They are the key to the character of a river. River flows reflect watershed conditions and influence temperature regimes, habitat characteristics, and perturbation frequency.

Soils and Land Use Patterns—in combination with climate, soils and land use determine much of the hydrology and thus the channel form of a river. Changes in land use often drive change in river habitats.

Channel Morphology—the shape of the river channel: width, depth, sinuosity. River channels are often thought of as fixed, aside from changes made by people. However, river channels are dynamic, constantly changing as they are worked on by the unending, powerful flow of water. Diversity of channel form affects habitat available to fish and other aquatic life.

Dams and Barriers—affect almost all river ecosystem functions and processes, including flow patterns, water temperature, sediment transport, animal drift and migration, and recreational opportunities.

Water Quality—includes temperature, and dissolved or suspended materials. Temperature and a variety of chemical constituents can affect aquatic life and river uses. Degraded water quality may be reflected in simplified biological communities, restrictions on river use, reduced fishery productivity, and fish consumption advisories. Water quality problems may be due to point source discharges (permitted or illegal) or to nonpoint source land runoff.

Special Jurisdictions—stewardship and regulatory responsibilities under which a river is managed.

Biological Communities—species present historically and today, in and near the river; we focus on fishes. However, associated mammals and birds, key invertebrate animals, threatened and endangered species, and pest species are described where possible. Maintenance of biodiversity is an important goal of natural resource management and essential to many of the goals of fishery management. Species occurrence, extirpation, and distribution are also important clues to the character and location of habitat problems.

Fishery Management—goals are to provide diverse fish assemblages and sustainable game fish populations. Methods include protection and management of fish habitat and fish populations.

Recreational Use—types and patterns of use. A healthy river system provides abundant opportunities for diverse recreational activities along its mainstem and tributaries.

Citizen Involvement—an important indication of public views of the river. Issues that citizens are involved in may indicate opportunities and problems that the Fisheries Division or other agencies should address.

Management Options follow and list alternative actions that will significantly protect, rehabilitate, and enhance the integrity of the river system. These options are intended to provide a foundation for discussion, setting of priorities, and planning the future of the river system. Identified options are consistent with the mission statement of Fisheries Division.

A fisheries management plan will be written after completion of this river assessment. This plan will identify options chosen by Fisheries Division based on our analysis and comments received. In general, the Fisheries Division management plan will: focus on a shorter time period; include options within the authority of Fisheries Division; and be adaptive over time.

Individuals who review this assessment and wish to comment should do so in writing to:

Michigan Department of Natural Resources
Fisheries Division, Southern Lake Michigan Management Unit
Plainwell Operations Service Center
621 N. 10th St.
Plainwell, MI 49080

Comments received will be considered in preparing future updates to the Grand River Assesssment.

RIVER ASSESSMENT

Geography

The Grand River watershed is located in the southwestern portion of Michigan's Lower Peninsula and is the State's second largest river basin. The basin encompasses approximately 5,575 square miles and drains all or portions of Hillsdale, Jackson, Washtenaw, Livingston, Calhoun, Eaton, Ingham, Shiawassee, Gratiot, Clinton, Ionia, Montcalm, Mecosta, Barry, Allegan, Kent, Newaygo, Muskegon, and Ottawa counties. This area comprises 13% of the entire Lake Michigan drainage basin. The Grand River mainstem is approximately 248 miles long, the longest river in the State, and drains a catchment that is 135 miles long and up to 70 miles wide. The river origin is a series of lakes in northeastern Hillsdale and southern Jackson counties. Beginning at an elevation of 1,040 feet above sea level, the mainstem flows in a generally northwesterly arc through the cities of Jackson, Eaton Rapids, Lansing, Ionia, Grand Rapids, and Grand Haven to its confluence with Lake Michigan where the elevation is approximately 580 feet above sea level. Tributaries to the mainstem range from first to fifth order and add an additional 5,320 stream miles (Zorn et al. 2008). The watershed includes several significant tributaries including the Portage, Red Cedar, Looking Glass, Maple, Flat, Thornapple, and Rogue rivers (Figure 1).

There are 581 lakes greater than 10 acres within the basin (Table 1). Five hundred three have a surface area between 10 and 100 acres, 51 have a surface area between 100 and 250 acres, 23 have a surface area between 250 and 500 acres and 4 are greater than 500 acres in size. The largest inland lake in the watershed is Spring Lake, Ottawa County, with a surface area of 1,097 acres.

The physical and biological characteristics of the Grand River watershed vary considerably from its headwaters to mouth. Therefore, the mainstem was divided into five sections, or mainstem valley segments, which are described below and delineated in Figure 2. These valley segments were determined using the ecological classification system described by Seelbach et al. 1997. Each valley segment represents sections of the Grand River mainstem with similar characteristics such as land cover, hydrology, channel and valley shape, and surficial geology; and these provide a useful framework for discussing the attributes of the river system. However, these similar characteristics often do not apply to the tributaries within a valley segment. For example, there are numerous cases where small first order streams that support coldwater species enter the Grand River mainstem at a location characterized as warm water. The five mainstem segments are:

Headwaters (Origin to confluence with Perry Creek)

The headwaters segment is 48 miles long and originates from a chain-of-lakes in northeastern Hillsdale and southern Jackson counties that include: Goose Lake, Lake LeAnn, Perch Lake, Crystal Lake, Mirror Lake, and Grand Lake. The river flows north through Vandercook Lake and through the City of Jackson. The Portage River is the first major tributary and joins the mainstem just north of Jackson, after which the mainstem turns west just before the junction with Perry Creek. This section drains rolling glacial till topography with numerous lakes in the headwaters area and flows through a flat zone with numerous swamps in the vicinity of Jackson.

Upper (Perry Creek to confluence with Red Cedar River)

This segment begins at Perry Creek and contains 47 mainstem river miles. Mainstem tributaries in this segment include Sandstone Creek, Spring Brook, Columbia Creek, and Silver Creek. The mainstem is impounded by the Smithville dam near the City of Eaton Rapids. This segment is also the location of the former Wilson Dam near the Village of Dimondale. The downstream portion is impounded again by the Moores Park dam before flowing into the City of Lansing and reaching the junction with the Red Cedar River.

Middle (Red Cedar River to confluence with Maple River)

This segment extends 60 miles from the confluence of the Red Cedar River to the Maple River confluence near the Village of Lyons. The gradient in this portion of the river begins to increase as evidenced by the six mainstem dams (North Lansing, Grand Ledge, Portland, Webber, Wagar, and Lyons) that are located in this segment. The Red Cedar and Looking Glass rivers join the mainstem within this segment. Evidence of increased groundwater inputs occurs in this valley segment as Sebewa Creek, a designated trout stream, enters the mainstem. The landscape draining to this segment is characterized as a gently rolling topography with low hills and shallow valleys. The river flows through and over prominent bedrock outcrops near the City of Grand Ledge.

Lower (Maple River to Lamont)

The lower valley segment includes approximately 70 mainstem miles and is confined within the broad and flat valley of the glacial Maple-Grand channel. Significant large tributaries including the Maple, Flat, Thornapple, and Rogue rivers join the mainstem in this segment. In addition, numerous smaller (first and second order), cold and cold-transitional tributaries join the mainstem throughout this segment.

The Maple River drains a portion of the Saginaw Bay Lake Plain which has little relief and is characterized as sand-clay lacustrine plain. Much of this watershed has been modified through channelization to promote drainage of extensive agricultural lands.

The greatest relief in the Grand River catchment occurs in this valley segment. The Flat, Rogue, and Prairie Creek basins all join the mainstem from the north. This area has some more rugged relief features with rolling hills and highlands standing above deep valleys. The southern part of the area has deeply entrenched valleys with steep, well drained slopes as each of the streams incise in order to reach the lower elevation of the Grand River mainstem. Some hills in this segment reach as high as 275 feet above the Grand River. These characteristics result in relatively low gradient tributaries that drain flat headwater areas containing numerous lakes, swamps, and marshes; and then become relatively fast-flowing, steeper-gradient streams as they encounter the steep walls of the former glacial valleys.

The Thornapple River is the largest tributary to join the mainstem from the south. The upper part of the Thornapple basin has less relief and more areas of flat to gently rolling land with only a few lakes. The soils and glacial sediments in this portion of the Thornapple basin contain more clay and silt than the lower section. The exception to this is the extreme eastern part which is well drained. The lower part of the Thornapple basin is characterized as having more relief and contains numerous lakes and wetlands.

The river mainstem drops significantly in the vicinity of the City of Grand Rapids. This is the location of the former rapids where the river cascaded over limestone bedrock sills for a distance of over a mile.

Mouth (Lamont to Lake Michigan)

The mouth segment begins near the Village of Lamont and continues the remaining 23 miles to the confluence with Lake Michigan. In this segment the mainstem flows through glacial lake plain. The channel widens and has numerous bayous, particularly downstream of the Bass River confluence. Downstream of Stearns Bayou, the mainstem splits into multiple channels and becomes braided as it nears the Grand Haven-Spring Lake area. A navigational channel is maintained by the Corps of Engineers from the Bass River downstream to the outlet at Grand Haven. The Bass River, Crockery Creek, Deer Creek and Spring Lake outlet are the largest tributaries in this section.

History

The glacial Grand River was formed towards the end of the Pleistocene era, 14,000 years ago. The late stages of Lake Maumee, an early form of lakes Huron and Erie, drained north through the Imlay City Outlet and then west through the Glacial Grand River into Lake Chicago (Farrand 1988). Subsequent glacial advances and retreats formed other lake basins which also flowed westward across the "Thumb" area and then through the Glacial Grand River (see **Geology**).

About 1,800 archaeological sites have been reported in the Grand River drainage (Table 2; B. Mead, Michigan State Housing Development Authority (MSHDA), Office of the State Archaeologist, personal communication). The earliest record of human habitation in the state of Michigan dates back to the Paleo-Indians of approximately 12,000 B.C. to 8,000 B.C. They are believed to have traveled north, following the recession of the glaciers (Clifton et al. 1986). Knowledge of these people is scant, but it is believed that they traveled in small groups and lived by hunting and gathering. Most Paleo-Indian archaeological sites are located on the beaches and knolls along glacial Lake Algonquin (Cleland 1992). The Paleo-Indian's distinctive fluted spear points have been found throughout the southern two-thirds of the Lower Peninsula (B. Mead, Department of State, Office of the State Archaeologist, personal communication).

> In the Grand River region, mastodon bones dating to 1,000 years ago have been found in Ingham and Montcalm counties. Some bones show evidence of human butchering. Fluted spear points have been found here and there; these were probably hunting losses. Excavations at the Leavitt site in Clinton County showed that people camped long enough there to make stone tools and work hides for tents and clothing. Forty-eight Paleo-Indian sites have been investigated in the Grand River drainage." (B. Mead, MSHDA, Office of the State Archaeologist, personal communication).

The Archaic period occurred from 8,000 to 1,000 B.C. During this period, climate in the Great Lakes region became warmer and drier. Thus it is divided into three sub-periods: early, middle, and late. People of the Early Archaic period, from 8,000 B.C. to 6,000 B.C., hunted moose, caribou, deer and bear. In southern Michigan, hardwood trees began to replace conifers during the Middle Archaic period of 6,000 B.C. to 3,000 B.C., and nuts, berries, and fish became important parts of the diet. It was during this time that people started to form more permanent villages along the Lake Michigan shores (Clifton et al. 1986). These communities became larger and more stable during the Late Archaic period of 3,000 B.C. to 1,000 B.C. They also apparently began to trade with groups of people in other regions. Copper from Michigan appears at many Late Archaic period sites in the eastern United States and Canada, and items made from Gulf of Mexico shells have been found at sites in the Great Lakes area (Clifton et al. 1986; Cleland 1992). During the Late Archaic, hunting and fishing for subsistence continued to be a way of life in northern areas with short growing seasons. Spears were used to take sturgeon, pike, and suckers in the shallow waters of lakes and streams, while fishhooks and gorges made from copper or bone were probably used from boats or fishing through the ice (Cleland 1982). In addition to hunting and fishing, in what is now southern Michigan, local plants were harvested for additional sources of sustenance. This eventually led to the development of agriculture in the southern parts of the Great Lakes, including the Grand River basin (Clifton et al. 1986). The total number of Early and Middle Archaic sites in the Grand River drainage is 68 and the number of Late Archaic sites is 92 (B. Mead, MSHDA, Office of the State Archaeologist, personal communication).

The Woodland Period occurred from 1,000 B.C. until the first Europeans arrived in 1650 A.D. There are a total of 238 Woodland-era sites in the Grand River watershed (B. Mead, MSHDA, Office of the State Archaeologist, personal communication). It was during this time period that crops like squash and sunflowers were first cultivated, and ceramic pots to store these new foods were developed. The

Hopewell Indians, also known as the mound builders, began moving into the southern part of lower Michigan around 100 B.C. (Clifton et al. 1986). The burial mounds that they constructed are still present in many areas, including the lower Grand River watershed. Artifacts found in these burial mounds document the animal species that were present and utilized by the Hopewells. Items found in the Norton mounds near Grand Rapids include spoons made from mussel shells (e.g., pocketbook, fat mucket and spike), bowls made from turtle shells (usually Blanding's turtle) and pins made from the bones of animals such as elk and deer. The most common items not native to the area were dippers, or cups, made from conch shells imported from the Gulf Coast (Griffin et al. 1970; Kingsley 1999).

Residents of the Woodland Period moved seasonally as food was available. The river valley margins provided nuts and acorns from oak-hickory forests in the fall and deer during the fall and winter. Waterfowl were hunted during the peak migrations in the spring and fall. Floodplain lakes were a good source of fish when during spring spawning runs, they were trapped as spring floodwaters receded. High-yielding seed plants such as lambs-quarters, sumpweed, and knotweed were harvested and possibly planted as crops (Kingsley 1999). Eventually, more species of plants were domesticated and adapted to more northern climates. Corn, beans, and squashes became more common in areas that had at least 140 frost-free growing days (Tanner et al. 1987). The entire Grand River watershed is within that range; thus, due to suitable climate and soil types, the cultivation of crops has sustained human settlements since earliest times (see **Climate**).

By the time the first Europeans arrived in the Grand River watershed, there were numerous villages occupied by various tribes of the Anishnabeg people: Potawatami in the southern portion, Chippewa or Ojibwe in the east, and Ottawa in the west. There were more than 3,000 apple trees and almost 2,500 acres of corn and vegetable crops in the Grand River valley. The main villages on the lower Grand were Nowaquakezick's (Noon Day's) at the current location of downtown Grand Rapids, and Mukatasha's (Blackskin's) which was a few miles to the south at the foot of the former rapids. Present-day Lyons was the site of another important village, that of Coocoosh, a shortened version of Muckatycoocoosh (Black Hog). Muckatycoocoosh was a child captured during the War of 1812 who grew up to be a respected leader of the local Ojibwa and Ottawa (Tanner et al. 1987).

The river was originally named Owashtenong (far away water or long flowing river) by the Anishnabeg people (Chrysler 1975). The early French explorers mapped the area in 1688 and called the river "Grande Riu, Ou Riu De Sakinand", or the Grand River to the Saginaw River. Their maps show the "Portage de Sakinand", a route that connected the Saginaw River system to the Grand by way of a short portage from the Shiawassee River to the Maple River. Another portage route was established between the Big and Little Portage Lake chain northeast of Jackson to the "R.aux Ours," the current-day Huron River (USACE 1972). Early English maps referred to the Grand as "Great River", a translation of the French "grande" (Lillie 1931).

The first European settlers in the watershed established trading posts near tribal villages. These settlements relied on the river for the transport of goods from lakes Huron and Erie via the portages on the Shiawassee and Huron rivers. Trading posts were operating on the Grand River as early as 1742. They traded cooking pots, cloth, and beads for fish, game, and furs (Kent County Library Staff 1975). Missionaries followed the fur traders inland and established the first mission at the rapids in 1824. Settlement of the Grand River watershed did not begin in earnest until land surveys were completed by the General Land Office during the 1820s and early 1830s (Comer 1996). Growth was rapid in the 1830s with settlements along the river mainstem being established at Jackson, Onondaga, Eaton Rapids, Lyons, Ionia, Saranac, Grand Rapids, Grandville, and Grand Haven. These settlements were established just prior to the logging era- the most dramatic transformation of the Michigan landscape since the last glaciation (Comer 1996).

Prior to the construction of the railroads, the Grand River from Jackson to Grand Haven was the main thoroughfare for transportation and communication between settlements. Pole boats and river steamers became important means of transporting finished lumber, supplies, and people. River landings varied from large urban centers of Grand Rapids or Grand Haven to small settlements built around sawmills or a group of farms. The steamers were generally side-wheelers with shallow drafts of around fourteen inches that allowed them to navigate over sandbars and other hidden obstructions.

To promote navigational use, alterations to the Grand River channel began as early as 1836 when the settlers began to clear the "floodwood" blockage downstream of Jackson (DeLand 1903). In 1837, representatives of the Grand River region succeeded in passing a bill authorizing the survey for a canal route to unite Saginaw Bay with the navigable waters of the Maple or Grand River.

> The report of the survey was regarded as exceedingly favorable, showing the existence of a remarkable valley or depression, extending westward from the waters of the Saginaw to those of the Maple; that these waters flowing in opposite directions, were only three miles distant from each other at one point, and that between them the highest elevation necessary to be crossed was only seventy two feet above Lake Michigan. It was along this valley and across this low summit that the engineer located the route of the canal, which with certain slack water improvements to be made to the east and west of it, on the Bad, the Maple, and the Grand Rivers, was to open a line of uninterrupted navigation between Lake Michigan and Saginaw Bay, and to bring prosperity to all the country contiguous to it (Ellis 1880).

Construction of the proposed canal began in 1838 and continued for nearly a year, when work was suspended due to the State's failure to pay the contractors. A decade after the construction had been abandoned, the canal project was revived when the legislature appointed the Saginaw and Grand River Canal Company complete the project. However, no further work was ever completed, and the project was officially abandoned in 1849 (Ellis 1880).

During the legislative session of 1838, thirty thousand dollars was appropriated for the improvement of the Grand and Maple Rivers and was applied to "improving the harbor at Grand Rapids, clearing out the river channel at Monroe Street, and removing the sunken logs all the way up the river to Lyons" (Baxter 1891). In 1847, the state legislature "enacted that the supervisors of the County of Kent be authorized to construct a canal, with sufficient locks for the passage of boats and other watercraft, around the rapids of the Grand River at Grand Rapids" (Chrysler 1975). Although the locks were never completed, from this account and others (Baxter 1891; Grimsley 1904), it appears the river bed excavation associated with this project hastened the removal of the river rapids.

Periodic state and federal appropriations allowed for additional improvements of the Grand River channel from Grand Haven to Grand Rapids. Dredging of a four-foot deep channel downstream of Grand Rapids was authorized by the River and Harbor Act of 1881 to more readily accommodate the steamers. By 1886, a 60-foot wide and four and a half-foot deep channel had been dredged 11-1/4 miles below Grand Rapids. However, this channel was not considered permanent, and no further appropriations were made for maintenance. An 1887 report concluded that because of the extreme range between high and low water stages and the tendency of the river bottom materials to create shoals, a deep-water connection between Grand Haven and Grand Rapids was not possible within the banks of the river. A canal using river water was proposed but never undertaken. Siltation of the river continued to be a problem, so when steamboat traffic had ceased, Congress adopted the River and Harbor Act of 1930 and officially abandoned the Grand River above the Bass River mouth for any commercial navigation (USACE 1977). Below the Bass River mouth, a navigational channel is still maintained at an eight-foot depth.

In addition to transportation, the river and tributaries provided a source of power for sawmills and grist mills. Construction of dams and mills on the mainstem and tributaries began shortly after the arrival of the first settlers, and by the mid 1830s there were several dams throughout the watershed. In this era before steam-powered machinery, water powered these mills, and dams and canals or mill races were built to harness this source of power. For example, the original Sixth Street Dam was constructed to divert the flow of water to several mills that were located on east and west side canals. Milling operations were regionally significant; in the 1860s and 1870s flour milled in Grand Rapids was shipped down river and on to Chicago and by rail to Detroit for distribution over the eastern half of the United States. Such dams and canals were built not only on the mainstem but also on many of the tributaries and were often the sites of early pioneer settlements (see **Dams and Barriers**).

The first logging operations started in the mid 1830s, and after the Civil War, as much as 50 million board feet of logs were being floated down the Grand River each year. Tributaries such as the Rogue, Flat, and Maple rivers sustained local mills and also contributed timber to the sawmills in Grand Rapids and Grand Haven (Olson 1992). Originally, the first settlers used the standing timber as building material for their own homes or for firewood. As the population centers grew, the demand for lumber increased. New England furniture makers started moving to Michigan in greater numbers during the 1830s and '40s, drawn by what appeared to be an endless supply of lumber. By this time, much of the hardwood forests in New England had already been harvested, yet 95 percent of Michigan, or thirty-five million acres, was still covered by virgin forests. The Grand River basin was ideally located for furniture builders since the pre-settlement vegetation of the region was dominated by vast white pine forests in the north and hardwoods such as walnut, oak, maple, ash and cherry to the south. The white pine provided the material for building infra-structure such as houses, railroad ties and telegraph poles, while the hardwoods were sought after by the furniture makers (Carron 1998).

Logs were stamped with the brand of their owner and then set afloat to drift downstream to the various mills. During the peak decades of the 1870s and 1880s, more than two billion board feet of timber passed through Grand Rapids on its way to mills either in Grand Rapids or Grand Haven. Nearly 750 million board feet of lumber was cut by Grand Rapids sawmills and furniture companies during those two decades (Mapes and Travis 1976). By 1885, the lumber output from the mills began to decline, and by 1892, the pine forests of the Grand River had been essentially cleared (Moore 1915).

In addition to the timber industry, there were other industries that utilized the Grand River's resources. A scythe stone factory was built on the banks of the river between Jackson and Lansing in 1843. It sharpened the haying scythes used by farmers. Sandstone for the factory was quarried from the natural ledges along the river and floated down to the factory on a flat-bottomed boat (Huggler 1990). In Grand Rapids, limestone was quarried from the river rapids for use in the construction of homes and for curbstones in the city's streets. Following the flood of 1904, limestone was mined from the river to provide material for the concrete work and backfill used in the construction of the city's flood walls.

Another industry that formed in the early 1900s was the pearl button industry. In Michigan, this industry was restricted to the larger southern, warmwater rivers which had abundant populations of thick-shelled mussels. Sources indicate that there were at least five button factories along the Grand River: one in Lamont, three in Grand Rapids, and one in Lowell (Lydens 1967; Lowell Area Historical Museum 2004). Mussels were raked from the river bottom using crow-foot dredges and baked in long pans on the shore. The buttons were then punched from the shells, polished, and sold to market. A combination of overharvesting, habitat degradation from dam construction and pollution, caused a major decline in mussel populations leading to the closure of commercial mussel harvesting by the Michigan Conservation Commission in 1944 (van der Schalie 1938, 1948; see **Biological Communities**).

By the early 1900s, most of the marketable timber had been removed from Michigan lands. Cleared lands were then marketed to farmers, and many thousands of acres were sold. However, much of the land turned out to be unsuitable for sustained agricultural use. When word spread amongst the settlers that the timbered land was worthless for farming, the demand for the land disappeared. Owners eventually stopped paying taxes on all but their best lands. By 1932, Michigan experienced a severe tax delinquency problem, with 17.2 million acres of land falling into delinquency. By 1941, 4.5 million acres had reverted to the state. Many of these large tax-reverted parcels were retained by the state and are now state game and recreation areas. Remaining agricultural lands were often heavily modified with ditches and tile drains to drain off flood waters and to dry out wetlands sufficiently to farm (see **Soils and Land Use**).

Throughout the twentieth century, the Grand River watershed experienced rapid population growth and widespread industrial expansion and urbanization. During this period of rapid growth, the river and most of its tributaries were used to convey municipal and industrial wastewater discharges. These discharges often exceeded the assimilative capacity of the receiving streams, resulting in fish kills. The remaining fish populations were dominated by pollution-tolerant species such as common carp. Efforts to abate water pollution began with the organization of the Stream Control Commission created by Public Act 245 of 1929. Although Act 245 did not make the discharge of pollutants or sewage illegal, any injury as a result of the discharge was illegal. Initially, the Stream Control Commission was not politically supported, and its existence was challenged in nearly every legislative session. As conditions worsened, public demand for tighter pollution controls lead to the establishment of the Water Resources Commission in 1949. The Water Resources Commission required end-of-pipe treatment for all wastewater discharges to the waters of the state. During the mid-1960s, Michigan developed water quality standards, and the legislature revised Act 245 and finally declared the discharge of raw sewage illegal. This led to the wastewater discharge permit program and requirements for best treatment control technology. The federal Clean Water Act of 1972 established the goal of making all waters “fishable and swimmable” and created national standards for water quality. Over the last three decades, implementation of the Clean Water Act has resulted in the recovery of the Grand River and its tributaries. Waters that were once heavily polluted now support abundant populations of fish and offer diverse recreational opportunities.

Geology

Michigan’s bedrock geology is dominated by two rock formations. The Lower Peninsula and eastern half of the Upper Peninsula is made of sedimentary rocks that form the Michigan Basin and the western Upper Peninsula is underlain with primarily crystalline, igneous shield (Sommers et al. 1984).

The Grand River basin’s bedrock formations were deposited in large seas which covered most of the Great Lakes states and adjacent parts of Canada during the Paleozoic Era. The formations are sedimentary rock layers composed primarily of sandstone, limestone, dolomite, and shale (Figure 3). They also include some beds of salt, gypsum, and anhydrite, as well as some thin beds of coal (USACE 1970). These layers are covered to various depths by unconsolidated materials deposited during and following the Ice Age.

The Pleistocene Epoch, or Ice Age, occurred about 2 million years ago. During this period of extreme cold and snowfall, over one-third of the earth’s surface was covered by glaciers up to 10,000 feet deep. It is generally accepted that the Great Lakes did not exist during this period of time, but were carved out as a result of several periods of glaciation. The last of these occurred from about 18,000 to 4,500 years ago.

As the glaciers made their final advances, they came into the future Great Lakes region as a series of ice lobes with each lobe moving into the lowest existing spots on the landscape. These glacial lobes eventually formed the Great Lakes and their bays and have thus been named in accordance with them. There is a Superior lobe, a Keweenaw lobe, a Michigan lobe, a Green Bay lobe, a Grand Traverse lobe, a Saginaw lobe, and so on. They welded together south of the Great Lakes Region into one solid sheet and did not separate again until they retreated back through Michigan. The Grand River basin was covered by the Michigan and Saginaw lobes.

As the glaciers advanced and retreated across the state, they deposited a variety of sediment types (Figure 4). Most of the Grand River basin is underlain by till, which is a mixture of clay, silt, sand, gravel, cobbles and boulders. Till is not transported by water, but is deposited directly from the melting glacier. During periods of time when the ice front remained static, ridges of glacial sediment, or moraines, would form. Channels formed along the front of these moraines to carry the water flowing away from the melting glacial lobes. The mainstem and many tributaries flow within the channels of these ancient glacial meltwater streams, many of which follow the concentric rings formed by the retreating Saginaw lobe. Sand and gravel deposits are generally connected with the channels of glacial meltwater streams. Coarse materials were deposited in the fast-flowing waters and the finer particles were carried downstream to areas of quiet water before settling out. Glacial sand and gravel deposits are called “outwash” as the sand and gravel was washed out of the glacier by meltwater streams. Areas underlain by the outwash tend to be flat, narrow and long. Many of the outwash areas are now covered by swamps and marshes (USACE 1970). The percentage of outwash in the Grand River watershed is 20% (Gooding 1995). The numerous lakes of the headwaters region are located within glacial outwash plains of the Saginaw-Erie interlobate region. Similar lake districts occur in Barry and Kent counties in the Michigan-Saginaw interlobate region. Bedrock outcrops are present in only a few locations in the watershed: near Jackson, Grand Ledge, and Grand Rapids. These protrude through sandy glacial drift deposits that are generally less than 100 feet thick (USACE 1972). The rest of the watershed is covered with several hundred feet of glacial deposits. The texture and thickness of these glacial deposits are important hydrologic characteristics controlling the capacity of groundwater aquifers to transmit water (See **Hydrology).**

About 14,500 years ago, the glaciers began their final series of advances and retreats. As the Grand River flows northward from Jackson to Lyons, it cuts through the Kalamazoo, Charlotte, Lansing, Grand Ledge, Ionia, and Portland moraines, which were formed by the Saginaw lobe during these final movements.

By 14,000 years ago, the Saginaw lobe had retreated and formed enough meltwater that when it then re-advanced, it forced Lake Maumee (early Lake Erie) to drain not only through the Wabash River, but also north and west across the “Thumb” area and across lower Michigan to Lake Chicago (early Lake Michigan). This continued for about 1,000 years, and formed the large broad valley of the current day Maple River and lower Grand River. The lower mainstem segment, from the mouth of the Maple River to Lamont is located in the glacial-fluvial Maple River-Grand River valley (Figure 5). This portion of the catchment displays the highest local relief with some areas exceeding 200 feet above the broad and relatively flat valley floor (Figure 6). Tributaries to the mainstem of the Grand River in this area are incised as they cut through the high terrace, explaining why many have higher gradient in their lower reaches than in their headwaters. These incised tributary valleys represent the potential for the highest groundwater yield in the watershed (Figure 7).

Both the Maple River and the mouth segment of the mainstem were formed on the sediments of the ancient glacial lakes Saginaw and Chicago, respectively. This lacustrine geology (silt, clays and fine sands forming flat plains) comprises 7% of the Grand River basin (Gooding 1995).

Hydrology

Climate

Climate of the Grand River basin is primarily determined by latitude, moderating effects of Lake Michigan, regional air masses and atmospheric disturbances, and differences in land-surface elevation. The Grand River basin is contained in the Southern Lower Michigan Region as described by Albert et al. (1986). Compared with the Northern Lower and Upper Michigan Regions, the climate in the Southern region is warmer with an average annual temperature of 48.1^{o}F, and has a longer, less variable growing season (Albert et al. 1986; NOAA 2002a, 2002b). Precipitation is highest and snowfall lowest in this region. Potential evapotranspiration is also higher although the ratio of precipitation to potential evapotranspiration is lowest. Overall climatic differences are less pronounced here than in the northern regions (Albert et al. 1986). Due to the moderating effects of Lake Michigan, local climates differ from the headwaters to the mouth.

Headwaters

The headwaters mainstem segment is located in the Ann Arbor Moraines, Jackson Interlobate, and Lansing ecoregions of lower Michigan (Figure 8; Albert 1995). This area has a growing season of 163 days, the longest in the state (Albert et al. 1986). Summer temperatures average 69.8^{o}F with an average daily maximum temperature of 80.9^{o}F. Winters are mild with average temperatures of 27^{o}F (USDA 1981). Total annual precipitation is approximately 33 inches and average snow depth is 40 inches (Figures 9 and 10). Fairly steep slopes in the headwater valley segment result in the formation of distinctive microclimates on northeast and southwest facing slopes. Frost pockets occur in kettles in these areas (Albert et al. 1986).

Upper

This segment is in the Jackson Interlobate and Lansing ecoregions (Albert 1995). Because the local climate is influenced more by the movement of large pressure systems than the moderating influence of the Great Lakes, the climate in this district is characterized as continental (USDA 1978). Daily, seasonal and annual temperature changes recorded at the Charlotte weather station in Eaton County are larger than those recorded for Great Lakes stations in the same latitude (USDA 1978). This area experiences fewer growing days than the headwaters segment and averages 146 days. Summer temperatures average 66^{o}F and exceed 90^{o}F or higher for 15 days per year. Winter temperatures average 26^{o}F with extreme lows of -11^{o}F (Albert et al. 1986). Total annual average precipitation is approximately 34 inches (Figure 9). Average snowfall is approximately 40 inches per year (Figure 10).

Middle

This mainstem segment is primarily located in the Lansing ecoregion (Albert 1995) and follows seasonal temperature and precipitation patterns as similar to the upper mainstem segment.

Lower

The lower mainstem segment encompasses several ecoregions (Figure 6) but is largely contained in the Lansing ecoregion. Therefore the climate in the east and central portions of this segment is similar to that described for the upper and middle segments.

The extreme western portion (western Kent, southern Muskegon, and Ottawa Counties) of the lower mainstem segment is in the Jamestown and Southern Lake Michigan Lake Plain ecoregions where the climate is influenced by Lake Michigan. The climate in this portion of the lower mainstem segment is characterized by a long growing season (157 days), slightly cooler summers and significant lake effect snows and precipitation (Albert et al. 1986). Average and daily maximum summer temperatures recorded at the Grand Rapids weather station are 69.1°F and 80.6°F. Winter temperatures at this location average 23.7°F. The lowest temperature on record at Grand Rapids is -24°F (USDA 1986). Total annual precipitation is 36.5 inches and average snowfall depth is approximately 70 inches (Figures 9 and 10).

Mouth

Due to the effects of Lake Michigan, the climate in this segment differs greatly from the mainstem segments to the east. The prevailing westerly winds over Lake Michigan moderate temperature so that extreme highs and lows are rare (USDA 1972). Although spring is delayed due to the chilling effects of the cold lake waters, the growing season is warm and long (157 days), creating a maritime climate that is ideal for flowering fruits. On average, summer temperatures exceeding 90°F are uncommon. Although winter temperatures tend to be mild, lake effect snows are frequent and average snowfalls are the heaviest in the watershed (Sommers 1977).

Annual Stream Flows

Streamflow characteristics are dictated by the interaction of climate and precipitation and by physical catchment features including: topography, hydrologic soil type, aquifer transmissivity, catchment storage, local geology, vegetative cover and land use. Streamflow is comprised of a surface runoff component and a groundwater component. Surface runoff results from precipitation that flows directly into the channel overland or is otherwise intercepted and enters the stream without percolating into the aquifer. The groundwater component results from precipitation that infiltrates the soil, percolates into the aquifer and flows into the channel. Streams gain water through upwelling of groundwater through the channel bed, lose water to the groundwater as water enters the streambed, or both. Losing reaches typically occur at abrupt changes in channel slope or pattern. The subsurface pathways where stream water flows though short lengths of the channel bed and banks are referred to as the hyporheic zone (Figure 11). Areas of hyporheic exchange involve both surface and groundwater components influencing water quality constituents such dissolved gases, nutrients, and sorbtion of dissolved solutes. These flow dynamics are dictated by relative altitudes of the groundwater table and stream surface, and often are very complex (Stanford 1998; Brunke and Gonser 1997; Winter et al. 1999). These groundwater pathways can be short, as precipitation infiltrates to the shallow water table and moves across the floodplain; or long, as precipitation percolates into deeper aquifers (Wiley and Seelbach 1997).

Rates of groundwater discharge to the stream are determined by the capacity of these aquifers to receive and transmit water, which is largely controlled by catchment geology. Catchments characterized as bedrock, lacustrine fine, and thin drift over bedrock are typically associated with above average surface runoff, low aquifer transmissivity and more variable or “flashy” streamflows, whereas catchments draining lacustrine coarse-textured tills or ice-contact outwash display above average rates of infiltration, high aquifer transmissivity and more stable streamflow patterns (Neff et al. 2005; Hamilton et al. 2008). Rivers and streams that receive higher inputs of groundwater respond less to precipitation events than systems receiving high amounts of runoff. In the Grand River watershed coarser geologic materials tend to be associated with glacial meltwater channels and outwash plains. These areas have the highest relief and display the highest potential for groundwater yield (Figure 7).

The capacity of a groundwater aquifer to transmit water is referred to as its transmissivity and is a function of hydraulic conductivity and aquifer thickness (Heath 1982). The Groundwater Mapping Project, a multiagency study in Michigan, utilized the Michigan Glacial Landsystems Coverage (MDIT 2005a) classification of the surface geologic deposits of Michigan and lithologic information contained in water well drilling logs to assign aquifer transmissivity classes of low, medium, or high to each glacial land system (MDIT 2005b; Hamilton et al. 2008). In general the aquifer transmissivity in the Grand River watershed is classified as medium to high (Figure 12).

As with most Michigan rivers, the Grand River shows the following predictable annual flow pattern:

- Flood flows or high flows (variable among years) in early spring due to a combination of saturated soils, large snow melt, spring rains, and lack of evapotranspiration
- Late-summer low flows or base flows reflecting low amounts of summer precipitation, unsaturated soils increased capacity to capture smaller precipitation events, and peak transpiration demands during the growing season
- High flows in the fall as a result of seasonal rains and shutting down of vegetative transpiration
- Winter low flows reflecting water being stored as ice and snow

Annual flows in the Grand River watershed can be examined by analyzing the data from continuous stream flow gauges maintained by the United States Geological Survey (USGS) at 16 locations within the basin (Table 3, Figure 13). At some locations discharge data from these gauges have been collected for over 100 years. In the past, continuous gauges were also operated in the basin at eight additional locations, and many miscellaneous discharge measurements have been recorded (Holtschlag and Eagle 1985). Daily measurements of stream discharges (cubic feet per second or cfs) are summarized in annual water resource reports (Blumer et al. 2004).
The USGS gauging station located on the mainstem in Grand Rapids has been maintained since 1901. For the years 1901-2005 the mean annual flow is 3,775 cfs from a catchment of approximately 4,900 mi^2. During 1994 – 1995 a gauging station located at Grand Haven recorded a mean annual flow of 5,221 cfs. Based on a drainage area 5,575 mi^2, the Michigan Department of Environmental Quality estimates the average annual discharge to Lake Michigan to be approximately 4,300 cfs (M. Lesmez, Michigan Department of Environmental Quality, Land and Water Management Division, personal communication). Seasonally high flows are typical in March and April with low (base) flows in August and September, as shown by the daily hydrograph at Grand Rapids (Figure 14).

Seasonal Water Flow

Streamflow is an important factor in defining the character of a stream because of its relationship to stream channel formation and stream organisms. Seasonal high flows are important for channel-forming processes and maintaining functioning floodplains. Streams with stable flows tend to have less variation in stream temperature and have more stable channels, resulting in more diverse and robust aquatic communities compared to streams with more variable flow patterns (Angermeier and Karr 1986; Karr et al. 1986; Poff and Ward 1989; Fausch et al. 1990; Gordon et al. 1992; Poff and Allen 1995). The importance of flow stability has been discussed by previous authors.

> The flow stability of a stream is the variability in its discharge over periods of years, months, days or hours. The frequency, timing and magnitude of high flows determine stream channel characteristics, and are related to a river’s water quality, temperature, and aquatic community, (Poff and Ward 1989). In Michigan, streams with more variable flow regimes tend to have more actively changing stream channels, warmer summer temperatures, fewer coldwater fishes, and greater year-to-year variation in fish reproductive success. Fishes in Michigan streams are adapted to streamflow conditions that are relatively stable on a daily, seasonal, and annual basis. In general, streams that have stable flows tend to have more fishes with specialized feeding habits, such as feeding on benthic invertebrates, other fishes, or surface insects (Poff and Allen 1995). Fish acclimated to streams with stable flows are generally also less

> tolerant of silt and turbidity, and more commonly associated with coarser substrates than fish species more common in hydrologically variable streams. The stability, timing, and volume of streamflows have been shown to influence the reproductive success of warm-, cool-, and coldwater fishes (Starrett 1951; Coon 1987; Strange et al. 1992; Bovee et al. 1994; Nuhfer et al. 1994). Increased flow stability has been positively related to fish abundance, growth, survival, and reproduction (Coon 1987; Seelbach 1986). Habitat suitability studies have documented the importance of flow stability to many fishes, including pink salmon (Raleigh and Nelson 1985), largemouth bass (Stuber et al. 1982a), smallmouth bass (Edwards et al. 1983), walleye (McMahon and Nelson 1984), brook trout (Raleigh 1982), Chinook salmon (Raleigh et al. 1986a) and brown trout (Raleigh et al. 1986b). Incorporating the need to maintain stable flows in land use plans will help support the balanced and diverse fish communities in Michigan streams (Richards 1990). [Zorn and Sendek 2001].

Seasonal flow stability can be assessed using a variety of indices. Three methods were utilized to assess that of the Grand River mainstem and several tributaries; standardized flow-exceedence curves, 10:90 exceedence flow ratios, and low-flow yield. Standardized flow-exceedence curves are plots constructed from flow duration data from USGS gauging stations and standardized by dividing the exceedence discharge by the median flows recorded at that specific location. An exceedence value is discharge that can be expected to be exceeded for a given percentage of the time. A 5% or less exceedence value represents relatively rare high flow events, for example, spring flows during snowmelt or extraordinary storm events. The 50% exceedence value represents median discharge, meaning half of the time the flow is higher and half of the time flow is lower than this value. The 95% exceedence value is referred to as base flow (or low flow) and typically indicates the groundwater component of streamflow. The 10:90% (10:90 ratio) exceedence flow ratio provides another index of stream stability that is useful for comparing streams. The 10% exceedence flow represents high flow events whereas the 90% represents low flow events. Seasonal flow stability decreases with increasing values of this ratio. The third measure of flow stability, low-flow yield (LFY; 90% exceedence flow/catchment area) provides an index of a groundwater inputs, seasonal flow stability, thermal characteristics, summer current velocity, and other physical conditions important to fish and other aquatic life (Zorn et al. 1998).

The standardized flow-exceedence curves for the Grand River mainstem and its tributaries exhibit a broad range of seasonal flow patterns (Figures 15-26). The most stable flow on the mainstem is at Jackson (USGS Station 041090000) in the headwater segment, which has a standardized high flow that is 3.3 times greater than median flow (Figure 15). The gauge station at Lansing (USGS Station 04113000) on the mainstem had the highest standardized discharge at 5% exceedence of 4.8 (Figure 19). This indicates a fairly stable system. For comparison, the most stable streams in Michigan (e.g., the Au Sable, Manistee, and Jordan rivers) have standardized high flows that are slightly less than twice their median flows. The Kalamazoo River has a standardized high flow value of 2.8 and is considered stable (Wesley 2005), whereas the flashy (unstable) lower Rouge River in southeast Michigan has a standardized 5% exceedence of 13.7 (Beam and Braunscheidel 1998).

The 10:90 ratio calculated for the period of record at the Ionia USGS gauge is 9.68 (Table 4; Figure 27) This value would classify the Grand River mainstem at this location as “fair”, not as stable as agricultural rivers draining coarse geologic deposits such as the Kalamazoo River to the south, and not as unstable as rivers draining fine-textured glacial deposits to the east (e.g., Tittabawassee River) (Table 4; Figure 27).

Low-flow yield (LFY) provides an index of flow stability and is a good predictor of stream temperature regimes, seasonal velocity conditions, and the physical characteristics of the catchment. In general, the higher the base flow relative to overland flow, the more stable the stream. Streams with high groundwater inputs have higher summer drought flows and cooler summer temperatures relative to streams with low groundwater inputs. The LFY for the Grand River mainstem near Ionia is 0.16 cfs/mi^2 and is equal to the LFY of the similar-sized Tittabawassee River near Midland. In contrast, the LFY for the more stable Kalamazoo River is 0.52 cfs/mi^2 and for the high quality groundwater–fed trout streams such as the Manistee River LFY is 0.95 cfs/mi^2 (Table 4, Figure 28).

As discussed above, seasonal streamflow characteristics are constrained by the interaction of climate and precipitation, and physical catchment features including: topography, local geology and soil type. Given the diversity of glacial deposits throughout the watershed, these features are variable throughout the catchment, resulting in differing flow patterns. Flow patterns are further influenced by human-built dams and reservoirs which capture and store flow peaks generated by surface runoff, and allow for increased evaporative losses. Alterations to the landscape such as removal of vegetative cover or channel modifications (i.e. ditching or sewering) profoundly change flow patterns, typically accelerating deliveries of surface runoff and increasing flow flashiness. The effects of catchment physiography and anthropogenic changes on flow patterns are discussed more thoroughly for the Grand River and tributaries by mainstem segment:

Headwaters and Upper

The Grand River mainstem at Jackson exhibits a relatively stable flow pattern with standardized 5% and 95 % exceedence flows of 3.3 and 0.3 respectively (Figure 15). Flow patterns are moderated to a large extent by numerous headwater lakes and wetlands which provide a steady release of groundwater to the river. Low flow yield is 0.23 cfs/mi^2, a value equal to the relatively stable St. Joseph River at a similar location in its catchment.

The Portage River enters the mainstem downstream of the City of Jackson. Flow patterns in this subwatershed have been extensively modified through channelization and other drain practices (e.g., extensions, field tiling, etc.), which result in increased flashiness (Figures 15 and 16). The 10:90 ratio calculated for the period of record is 22.5, a value indicative of very unstable seasonal flow patterns.

The mainstem catchment area at the Eaton Rapids gauging station is approximately 660 square miles and includes the discharges of several tributaries: Portage River, Perry Creek, Huntoon Creek, Sandstone Creek, and Spring Brook. The headwaters of these tributaries have been modified to promote drainage of the fine-textured soils for agricultural land use. Here the mainstem is slightly more flashy with a 5% exceedence flow of 4.0, a 10:90 ratio of 8.4 and reduced LFY of 0.18 cfs/mi^2 (Figures 15 and 16).

Middle

The flow patterns monitored in this mainstem segment are the most unstable in the Grand River watershed. The terrain is relatively flat, with fine-textured soils and low groundwater influx (Figure 7). In addition, surface runoff rates have been increased through wetland loss and stream channelization. The tributaries located in this mainstem segment respond to rain events rapidly generating high peak discharges and returning to low base flows.

The Red Cedar River subwatershed contains five USGS monitoring stations, one each on: Deer, Sloan, and Sycamore creeks, and two on the Red Cedar mainstem. Flow instability is evident at all gauging stations. Standardized high flows range from 6.6 to 15 (Figure 17). Standardized 95% exceedence flows are also highly variable and range from 0.07 to 0.29 (Figure 18). The 10:90 flow ratios calculated for these sites range from 12.04 to 77.22, the highest in the Grand River watershed and are on par with some of the more flashy streams in the State (Figure 27). Groundwater loading to these streams is low ranging from 0.02 to 0.12 cfs/mi^2 (Figure 28).

Carrier Creek, an urban stream in the City of Lansing, displays similar unstable flow patterns. This stream is one of the flashiest gauged tributaries in the Grand River watershed and has a 5% standardized exceedence of 15 and a 95% standardized exceedence of 0.06 (Figures 19 and 20). Groundwater loading to Carrier Creek is the lowest in the Grand River watershed and is negligible at 0.01 cfs/mi^2. The extreme high and low flow result in a 10:90 ratio of 73.88 (Table 4; Figure 27).

Flow statistics for the Looking Glass River at Eagle suggest a slightly more stable flow pattern than the Red Cedar River with a 10:90 ratio of 13.12 (Figures 19, 20, and 27). Groundwater loading is slightly higher with a LFY of 0.12 cfs/mi^2 (Figures 7 and 28).

Grand River streamflow is monitored at two locations in the middle segment: downstream of the Red Cedar River confluence in City of Lansing and upstream of the confluence with the Looking Glass River near the City of Portland. Standardized 5% exceedence values at these locations are less than 5.0, and baseflow at these locations is slightly less than measured in the headwater and upper segments (Figures 19 and 20). Using the flow stability statistics the mainstem exhibits its least stable flow patterns (e.g. highest 10:90 ratio, lowest LFY) at the Lansing gauge location. As the river nears the Portland gauge the mainstem begins to descend toward the elevation of the former glacial river valley. As gradient increases, groundwater loadings begin to increase as the geology becomes coarser (Figures 6 and 7).

Lower

Within the lower segment, long term USGS flow monitoring data is available for four major tributaries (Maple, Flat, Thornapple, and Rogue Rivers), two small tributaries (Fish Creek and Quaker Brook), and two mainstem locations.

The catchment of the Maple River at the Maple Rapids gauging station is approximately 434 square miles of predominantly agricultural lands. The Maple River headwaters are in lacustrine lake plain, and the drainage is very flat with fine-textured soils. Groundwater loading in the headwaters of the Maple River is limited (Figure 7). Much of the Maple River watershed has been extensively channelized to promote drainage for agricultural use. These catchment features and channel modifications result in unstable or flashy seasonal flow patterns with relatively high standardized 5% exceedence and low standardized 95% exceedence flows (Figures 21 and 22). Compared to the other large Grand River tributaries, the Maple River has the highest 10:90 ratio and the lowest LFY (Figures 27 and 28).

In contrast to the Maple River, the Flat River drains deposits of coarse-glacial till and outwash sands and gravels in a relatively steep watershed. These characteristics provide for higher rates of groundwater movement and inflow into the channel (Figure 7). Flow stability indices (e.g. standardized exceedence curves, LFY, and 10:90 ratio) calculated for the period of record at the Smyrna gauging station indicate stable flows (Figures 21, 22, 27 and 28) The LFY calculated at this location is 0.38 cfs/mi^2 (Table 4). This value is similar to that of other stable warmwater rivers like the Kalamazoo River.

The headwater regions of the Thornapple River drain relatively flat terrain comprised of medium - textured till and end moraines. Initially, groundwater inputs to the Thornapple River are modest, and increase as the channel slope steepens and cuts through areas characterized by coarse-glacial till and end moraines (Figure 7). Several coldwater tributaries join the Thornapple River mainstem in this portion of the watershed. Seasonal flow statistics characterize the Thornapple River as more stable than that of the Looking Glass and Red Cedar Rivers, but not as stable as the Flat River (Figures 21 and 22). Low flow yield is 0.24 cfs/mi^2, which is considerably higher than the 0.05 cfs/mi^2 recorded for the Maple River at a similar location in its catchment (Figures 7 and 28).

Standardized flow-exceedence curves for the Rogue River display relatively stable flow patterns similar to the Flat River (Figure 20 and 21). The LFY for the Rogue River at Rockford is 0.47 cfs/mi^2 and is the highest groundwater loading measured in the Grand River watershed. This value is relatively high compared to other Lower Peninsula streams with similar-sized catchments (Table 4). Steady groundwater inputs from the permeable catchment provide for good seasonal flow stability. The 10:90 flow ratio for the Rogue is 3.8, a value much lower than the Thornapple River at a similar location in its catchment (Figure 27).

The flow stability of Fish Creek is rated good (Table 4; Figures 21 and 22). This Maple River tributary drains coarse-textured glacial deposits characteristic of the northern portions of the Grand River watershed. Flow stability indices for the period of record indicate Fish Creek is the most stable gauge tributary in the Grand River watershed.

Based on catchment area, at 7.6 square miles, Quaker Brook is the smallest gauged tributary in the Grand River watershed. Although groundwater input is relatively high, the 5% standardized exceedence flow and 10:90 ratio reflect moderate flow instability (Table 4; Figures 21 and 27). This flow instability is a result of extensive channelization and wetland loss within this small subwatershed.

Standardized 5% exceedence values for the Grand River mainstem at Ionia and Grand Rapids are 4.7 and 4.1, consistent with the moderately unstable flows described for the middle segment (Figure 23 and 24). The 10:90 ratios for the Ionia and Grand Rapids gauges are 9.68 and 6.38, respectively (Table 4; Figure 27). The apparent increase in stream stability at Grand Rapids is related to an increase in LFY as a result of the constant inputs from the Flat, Thornapple and Rogue rivers and inputs from regional groundwater aquifers (Mandle and Westjohn 1989).

Mouth

There are no long term monitoring data for the mainstem or tributaries within the mouth segment. USGS stations were established on the mainstem at Eastmanville from 1976 to 1977 and Grand Haven from 1994 to 1995. The short period of record for these stations limits the use of the data as both standardized high and low flow exceedence curves suggest atypical water years when compared to the Grand Rapids station in the lower segment (Figures 25 and 26). The Grand Rapids gauge is located at river mile 41. Between this location and Lake Michigan few significant tributaries enter the mouth segment, and therefore it is assumed the flow patterns in the mouth segment are similar to those for the lower segment.

Daily Water Flow

Daily flows tend to be more consistent in watersheds with a high percentage of coarse textured soils and intact land cover. Conversely, watersheds with thin, tight soils and high percentages of impervious surfaces (e.g., parking lots, roof tops, etc.), or significant surface-runoff components are likely to be event responsive and display substantial daily flow fluctuations. Aquatic production and structure and diversity of biological communities are profoundly reduced by such extreme daily fluctuations (Cushman 1985; Gislason 1985; Nelson 1986; Bain et al. 1988; Poff and Ward 1989; Poff and Allan 1995). Unstable flow regimes can induce increased bank and streambed erosion resulting in a large moving sediment bedload, which may bury quality in-stream habitats. Flow modifications can block movements of aquatic organisms and interfere with recreational uses of the river. In extreme cases the destabilized channel will begin to react in order to regain a stable pattern, dimension and profile (Rosgen 1996).

Hydrographs (graphs of daily discharge over time) are used to analyze stream flow stability, characteristics of a river channel, and the source of flow. Flow peaks for the Grand River mainstem tend to be asymmetrical during the growing season and indicate a rapid increase in discharge followed by a more gradual decline (Figure 29). The rapid rise occurs after a heavy rain event and indicates immediate runoff into the river system. The descending limb of the hydrograph can also be used to characterize the catchment (e.g. land use and soils) above the gauge station and describe much about the hydrology of a stream. The hydrograph curve declines more gradually in watersheds with coarse-textured soils, intact floodplains and well vegetated landscapes due to high infiltration rates and the slow release of water from the surrounding soils. Examples of this more natural flow regime are Fish Creek and the Rogue River (Figures 30 and 31). In contrast, watersheds dominated by fine-textured soils or impervious surfaces, or with highly modified drainage areas (field tiles, storm drains) exhibit event responsive hydrographs with a steep ascending and descending limbs. For example, Sloan Creek near Williamston in the middle segment was examined for the period April 1, 2003 to April 13, 2003. From April 1 to April 2 daily flow averaged 2.5 cfs with no recorded precipitation. Following a rainfall event of 2.0 inches on April 3 and April 4, flow in Sloan Creek increased to 72 cfs. Within 24 hours, flow decreased to 20 cfs and following two minor rain events, decreased to normal flow by April 13 (Figure 32).

Daily flow can also be influenced by hydroelectric dams that operate in peaking mode, causing severe habitat degradation (Cushman 1985; Gislason 1985; Nelson 1986; Bain et al. 1988). These dams discharge high flows during peak electrical demand (generally 8 AM to 8 PM) and store flow during low demand periods (generally at night) creating drought flows. Historically, most hydroelectric projects on the Grand River mainstem were peaking operations. Now all projects operate in run-of-river mode, meaning outflow of water roughly equals inflow of water, as required by licenses or other control documents issued by the Federal Energy Regulation Commission (FERC). However, some hydroelectric dams have not been licensed and continue to cause severe flow fluctuations. In extreme cases, such at the Hubbardston hydroelectric dam on Fish Creek, large portions of the streambed were dewatered as flash boards were added to increase the storage capacity of the impoundment (C. Freiburger, Michigan Department of Natural Resources (MDNR), Fisheries Division, personal communication). In instances such as this, fish and other aquatic organisms are stranded and die in shallow pools during extreme low flow conditions.

Instantaneous flow data for the mainstem at Portland were examined for September 21, 2004 through September 24, 2004 (Figure 33). Although unseasonably high temperatures and no precipitation was recorded during this period, instantaneous flows indicated a 24 percent increase followed by a 22 percent decrease, suggesting potential peaking at upstream dams may be occurring.

Flooding and Floodplains

Flooding in Michigan is a seasonally predictable occurrence, typically occurring in late winter or early spring when rains combine with snowmelt (Blumer 1991). Frozen soils prohibit infiltration, causing large volumes of runoff. Floods are part of the natural hydrological cycle and are vital in maintaining the physical characteristics of the river (see **Channel Morphology**) and the structure of the riparian and aquatic communities (Ward 1978; Junk et al. 1989; Wohl 2000; Stanford and Ward 1993; Rosgen 1996; Baker and Wiley 2009). Riverbanks are transitional boundaries between aquatic and terrestrial ecosystems and frequently reshaped under naturally dynamic hydrologic conditions such as flooding (Florsheim et al. 2008). Flood timing and duration, intensity, and overall inundation are important factors influencing riparian plant community development. Large flood events influence both the generation and movement of large woody material and the deposition of nutrients and sediments (Baker and Wiley 2009). Flood flows of varying magnitude are necessary to maintain the channel geometry and transport sand, gravel, cobble, boulders, and other items that make up the stream bedload. There is a direct relationship between the movement and distribution of this bedload and flood discharge. Once flows drop below a certain threshold, the stream lacks the power necessary to transport these materials, and the bedload stops moving until the next flood of equal or greater value (Ward 1978).

Floodplains are known to provide functions such as storage and release of waters, nutrients, and sediments during flood pulses (Junk et al 1989; Gregory et al. 1991; Stanford and Ward 1993; Baker and Wiley 2004; Wang et al. 2006). Both hydrology and hydraulics affect riparian ecosystems and shape biological and ecological diversity of riparian corridors (Sedell and Beschta 1991; Opperman et al. 2008). Waters flowing onto the floodplain provide critical spawning and nursery habitats for fish, amphibians, and other aquatic and semi-aquatic organisms. Periodic inundation of the floodplain is necessary to maintain floral diversity and a diversity of aquatic habitats (backwaters, meander scars, vernal pools, etc.) associated with floodplain forest communities (Wiens 2002; Baker and Wiley 2009). Riparian areas are important in maintaining biodiversity, wildlife habitat, and stream integrity. In southern Michigan, intact forested floodplain corridors represent the highest remaining levels of biodiversity in the region.

Large woody structure, an important component of river ecosystems, washes into and is moved within streams during high flow periods. Large woody material is colonized by a variety of aquatic invertebrates and, in some lake plain systems, represents the majority of the habitat utilized by fish. In this way, floods contribute to the diversity of insects and fish found in a stream. Large woody material is also important in channel hydraulics and movement of sediments. As these materials become embedded into the streambed, they act to stabilize moving bedloads. Removal of logs and large woody material to promote increased stream flow can result in channel aggradation as local sediment transport is disrupted (Smith et al. 1993).

In areas where the floodplain is intensively farmed, flooding may contribute to pollution problems in a basin. Erosion from cropland that has been heavily fertilized, or from areas where animal waste is disposed or stored, releases excess nutrients to water bodies, and increases sedimentation. In urban areas, there is also potential for the transport of contaminated sediments or hazardous material from polluted areas within the floodplain (refer to **Water Quality**).

One hundred and six communities within the Grand River basin participate in the National Flood Insurance Program (Table 5). Most of these communities have floodplain maps that delineate 100- and 500-year flood boundaries for the rivers within their municipal limits. A floodplain management study of the Thornapple River completed in 2004 provides communities in Eaton, Barry, and Ionia counties with delineations of 10-year, 50- year, and 100-year, and 500-year flood events (USDA 2004). These maps are used by state and local agencies, and individuals for planning purposes, general floodplain management, and to determine the need for flood insurance. It is important for potential floodplain users to understand the advantages and disadvantages of development in such locations. It is necessary that community planning agencies review these maps and prevent unmitigated development within the bounds of the 100-year floodplain. Floodplains are a part of an active river system and should be treated accordingly.

The severity of flooding is influenced by stream channel and land use processes. Channelization causes increased water velocity, which reduces the height of flooding in smaller stream reaches but increases the magnitude of downstream floods in larger rivers. Roads and construction in riparian corridors can act as levees and prevent high flows from expanding across floodplains. Filling and tiling of wetlands and floodplains decreases the water storage capacity of a watershed by decreasing infiltration rates and increasing runoff. Development also increases runoff by creating impervious surfaces such as roads, parking lots, and rooftops. Storm water collection systems route runoff to the stream channel more quickly and can contribute to severe flooding (Wohl 2000).

Significant flooding events in the Grand River basin are documented in the years 1904, 1947, 1948, and 1975. Flooding events have also been referenced in 1843, 1852, 1861, and 1875 (Blumer 1991). The most significant flood event on record occurred in March 1904. Maximum discharges of 54,000 cfs at Grand Rapids and 24,500 cfs at Lansing were recorded for this event (http://waterdata.usgs.gov/mi/nwis/sw). Typical flows at these locations during this time of the year are approximately 7,500 cfs in Grand Rapids and 1,900 cfs in Lansing. During the flood numerous dams were washed out or badly damaged. Highway and railroad traffic was disrupted as bridges and sections of track were washed out. In Grand Rapids, 14,000 people were temporarily homeless, 2,500 homes were surrounded by floodwaters, 30 factories shut down, and 10,000 people were unemployed. As a result of this flood event flood control walls were constructed through the City of Grand Rapids. Significant flooding events also occurred in 1986 and 2004. These events were the result of prolonged rains.

Floods create hazards for humans living along rivers. Local flood mitigation measures, in turn, may create hazards for persons living further downstream as well as nonhuman aquatic and riparian communities (Wohl 2000). Seawalls and levees are often used to protect against floods and eroding banks. Levees prevent floodwaters from entering a floodplain and constrict water flow, causing flood peaks in areas downstream. They do not allow sediments to be deposited in the floodplain and prevent fish access to seasonally flooded areas which are important for spawning and feeding. River systems require 100-year floods for valley maintenance, and levees prevent this natural maintenance, causing an imbalance to the river system. Seawalls eliminate shallow water areas and natural diverse edge habitat that can be important to macroinvertebrates. They also block animal access to and from a stream. Through permitting processes, zoning procedures, and education, riparian property owners should be encouraged or required to use less intrusive and more natural methods to stabilize banks. Rock vanes, natural riprap, log and whole tree revetments, and vegetative plantings are good alternatives to hard-engineered structures such as gabions or seawalls (Alexander et al. 1995; Rosgen 2006; Smith et al. 2008).

Water Use

The majority (61%) of water actively used in the Grand River basin is derived from the mainstem and tributaries. Groundwater withdrawals account for 26% while the remaining 13% is drawn from Lake Michigan (Figure 34; MDEQ 2002).

Electric power generation is the largest use of water withdrawn and accounts for 59%. Municipal water sources for the basin are groundwater aquifers (17%) and Lake Michigan (12%). Irrigation of agricultural fields relies primarily on groundwater aquifers (8%) and to a lesser extent surface waters (2%). Private industrial wells account for the remaining 2% of the water withdrawals in the watershed (Figure 35; MDEQ 2002).

Water use for irrigation is especially significant considering the high consumptive losses. At least 90% of the water used for irrigation is lost through evapotranspiration (Bedell and Van Til 1979). Effects of irrigation withdrawals are especially critical during summer low flow periods, when aquatic organisms are more easily stressed. Direct withdrawals from streams have the most direct effect, reducing amount of habitat available and magnifying effects of sedimentation and pollution. Wells developed near the stream channel can intercept groundwater that would have discharged to the stream, and if withdrawal rates are high enough, the well can pull water from the stream (Winter et al. 1999).

Recently the issue of consumptive water withdrawals in the Great Lakes basin led to the adoption of an Annex to the Great Lakes Charter. In Annex 2001, the Great Lakes states and provinces committed to the development of a water management system that would allow for water use while also protecting and conserving the water resource-dependent natural resources of the Great Lakes basin (Grannemann et al. 2000, Groundwater Conservation Advisory Council 2007). In response to this agreement and Public Act 34 of 2006, Michigan has developed criteria and biological indicators and instituted a water withdrawal assessment process to assess the potential for negative environmental effects posed by large water withdrawals. The water withdrawal assessment process is used to regulate new or increased large quantity withdrawals (more that 100,000 gallons per day) from any source. The process identifies withdrawals likely to cause an adverse environmental impact on the waters of the State by assessing whether the withdrawal will diminish the ability of a river or stream to support characteristic fish populations expected to be at a site (Groundwater Conservation Advisory Council 2007; Reeves et al. 2009). Mandatory water reporting from a variety of sectors, including agriculture, was instituted in 2004. As new use data are compiled, estimates of consumptive water uses in the Grand River basin will be improved.

Soils and Land Use

Catchment physiography (texture and landform) is the controlling factor in the natural hydrology of the watershed. Soils, land cover, and land use can modify water movement through the river basin. Soils develop over thousands of years as a result of the weathering of glacial parent materials and organic deposits. In general, minimally disrupted watersheds with intact vegetative cover have higher infiltration rates and less soil loss from erosion associated with surface runoff. Well vegetated stream corridors provide buffers between uplands and surface waters and prevent nutrients from nonpoint sources from entering the watershed (Sweeney et al. 2004). Because river networks, lakes, wetlands, and their connecting groundwater, receive drainage from the surrounding landscape, they are greatly influenced by terrestrial processes including many human uses or modifications of land and water. Changes in land use and land cover characteristics affect hydrologic response by affecting the rate at which water either infiltrates into the soil and groundwater aquifers or is delivered to a stream as overland flow. Land use refers to "man's activities on the land that are directly related to the land" (Clawson and Stewart, 1965) whereas land cover describes "the vegetative and artificial construction covering the land" (Burly, 1961) [Hamilton et al. 2008].

Changes in land use and land cover can have dramatic effects on channel shape. In portions of the watershed predominated by agriculture, stream channels have been artificially deepened or widened to enhance drainage. Similar channel alterations can be observed as a result of urbanization and the attendant increase in impervious land surfaces. These changes in land cover and channel form modify the delivery rates of water to streams whereby localized disturbances can result in systemic effects, such as changes in nutrient delivery, altered thermal regime (Wehrly et al. 2006), reduced fish biomass (Infante et al. 2006), and impaired fish and macroinvertebrate communities (Karr et al. 1986, Baron et al. 2002, Diana et al. 2006; Stanfield and Kilgour 2006; Wang et al. 2006)

Soils

The Grand River watershed is predominately fine-, medium-, and coarse-textured end and ground moraines; with areas of outwash and ice contact topography and lucustrine plains. Land is gently to moderately sloping with sandy loam to clay soils. Drainage conditions are variable and range from poorly to excessively well-drained (Albert et al. 1986). Detailed soil surveys including soil maps and descriptions can be obtained for a specific county of interest from the STATSGO database at http://www.mcgi.state.mi.us (MDNR SDL 1994). Due to the high diversity of the soils types and associations found within the Grand River watershed, a comprehensive review is beyond the scope of this report. For the purposes of the river assessment, soils have been mapped using the four hydrologic soil types defined by the United State Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (2007):

- Group A –Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures.

- Group B -Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures.

- Group C –Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures.

- Group D –Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures.

Using this broad classification, the Grand River watershed is comprised of 18% (991 mi^2) Group A soils, 45% (2,530 mi^2) Group B soils, 19% (1,064 mi^2) Group C soils and 14% (773 mi^2) Group D soils. Approximately 4% of the watershed is classified as water or as undefined (Figure 36). The higher clay and loam contents found in the soil classed as Groups B and C are fertile and tend to be actively farmed whereas soils in Group A are too droughty. Without artificial drainage the soils in Group D are too wet to sustain agriculture. Groups B, C, and D soils are widely distributed throughout the watershed, whereas the spatial distribution of Group A soils tends to be patchy and associated with areas of coarse-textured glacial till and outwash.

Land use and Land cover

Maps constructed from transcribed field notes of the initial 1816-1856 General Land Office surveys provide the best available information on Michigan's land cover prior to widespread settlement (Comer 1996; MDNR SDL 2000). These field notes describe vast beech-maple forest covering over 43% of the central and western portions of the Grand River watershed. Large tracts of mixed oak and oak-hickory forest covered approximately 29% of the central and southern areas of the catchment. Large coniferous forests comprised primarily of white pine made up 10% of the land cover and were largely confined to the northern areas drained by the Flat and Rogue rivers. Forested wetlands, shrub-swamp/emergent wetland, wet prairie, and open water accounted for approximately 18% of the presettlement landscape (Figure 37).

The State of Michigan uses the spatial data coverages in the 1978 Michigan Resources Information System (MIRIS) as the standard for hydrologic studies in Michigan (Hamilton et al. 2008). The 1978 land use and land cover imagery describes settlement activities in the basin since the completion of the circa 1800 General Land Office surveys and documents the conversion of a predominantly forested watershed to one dominated (57%) by agricultural land uses (MDNR, SDL 1999). Forested and emergent wetlands have been reduced to approximately 4% of the surface acreage. Urban and built-up areas comprise nearly 9% of the total land use. Although forested areas remain, total forested land cover has been reduced from the large continuous forests covering approximately 4,450 square miles down to 1,100 square miles of primarily fragmented woodlots (Table 6; Figures 38-40).

Headwaters

The headwaters lie in an interlobate region of coarse-textured end-moraine and outwash deposits. The northeast portion consists of steep, sandy kettle-kame topography. To the west the topography becomes gentler and is characterized by coarse-textured end-moraine ridges. The majority of the soil in the headwaters is classified as Group B and is well drained (Figure 41). In the 1820s areas underlain with Group B soils were predominantly forested (69%) and supported a mosaic of oak savanna, mixed oak forests, oak-hickory forests. Lowland areas consisted of wet prairie (13%), tamarack swamp (8%), emergent wetland (5%), and open water (2%). These communities were underlain by Group D soils and were present on the poorly drained outwash and ice contact deposits in the eastern portion of this segment. Mixed hardwood swamp accounted for 3% of the pre-settlement landscape and was common in the active floodplain of the Grand River and tributaries (Figure 42).

The predominant land use in the modern landscape of the headwater segment is agriculture (49%). Forest lands are still common and comprise 23% of the current land use. Urban areas account for 15% and open waters approximately 2%. Wetland loss and conversion in the headwaters segment is significant. Much of the wet prairie, tamarack swamp, and emergent wetlands documented in the 1820 survey have been drained or converted to another wetland type (Comer 1996). Wetland communities in the current landscape account for 11% of the surface area, a substantial reduction from the pre-settlement era (Figure 43).

Upper

The upper segment topography is mostly gentle, rolling ground moraine with broad, coarse textured ridges surrounded by deposits of outwash sand. The soils in the northern portion of the upper segment are primarily a mix of soil Groups B and C (Figure 44). Pre-settlement vegetation in this area was largely beech-maple forest interspersed with areas of mixed conifer swamp. Soils in the southern portion of the upper segment are primarily Group B with areas underlain by Group D soils along riparian corridors. In the 1820s, the upland vegetation in this area was a mix of oak-hickory forests and oak savanna. Mixed hardwood swamps of American elm, black ash, red ash, silver maple and white oak were common in floodplains. Wet prairies, shrub swamp and emergent wetlands were also found on poorly drained ground moraines in the southern portion of this segment (Figure 45).

Agricultural land uses represent 63% of the present day land use in the upper segment. Forest cover has been reduced to 19% of the landscape. Wetland and aquatic communities (i.e., forested, wet prairie, shrub/emergent, and open water), which historically covered 18% of the landscape, have been reduced to approximately 7%. Urban and residential land cover accounts for approximately 11% of the modern landscape (Figure 46).

Middle

Similar to the upper segment, topography in the southern and eastern portions of the middle segment is characterized as gently rolling till plain traversed with east-west oriented ridges. To the northeast, the surface is gently rolling to flat ground moraine and lake plain. In the western portion the topography begins to steepen with end moraine ridges alternating with flat ground moraines. Clay-rich soils characterize the middle segment with Groups B and C being the predominant soil types (Figure 47). Pre-settlement vegetation in areas underlain with these soil types was largely mixed beech, sugar maple, and basswood forests. Mixed oak forest, oak-hickory forest, and oak savanna were common in the uplands area of the Red Cedar and Looking Glass river watersheds. Areas underlain with poorly drained Group D soils were characterized by wet prairie and emergent wetland. Mixed hardwood and coniferous swamps, along with emergent wetlands, and shrub swamps were common in active floodplain areas. Large swamps of mixed hardwoods, black ash and tamarack were found on poorly drained portions of ground moraine. Smaller swamps and emergent wetland were also common on outwash and ground moraines (Comer 1996; Figure 48).

Present day land use and land cover is characterized as 58% agricultural, 14% forested, 12% urban and built up, 10% rangeland, and 1% open water (Figure 49). A comparison of General Land Office survey notes with the 1978 MIRIS land coverage indicates significant declines in wetland coverage from approximately 19% down to 5%. Although most wetland types are found on the current landscape, nearly all of the 52,300 acres of lowland coniferous forest present prior to settlement have been drained or converted to other wetland types (Comer 1996).

Lower

The topography in the lower segment ranges from flat lake plains in the northeast to gently sloping ground moraines in central portions to moderately steep sloping ridges in the west. To the north, outwash channels are found at the bottom of steeply sloping valleys formed by adjacent moraines. Several mainstem tributaries including the Flat and Rogue rivers are confined in these valleys. Soils in the lower segment are primarily Groups B and C (Figure 50). Pre-settlement forest in areas underlain by these soil types was primarily beech-maple (45%) and oak-hickory (15%). Approximately 15% of the pre-settlement land cover was mixed white pine forests and occurred in the northern areas underlain by Group A soils (Figure 51). In the poorly drained portions of the glacial Maple-Grand River outwash channel, soil types are predominantly Group D. Pre-settlement vegetation in this broad valley was mixed hardwood swamp, tamarack swamp, and emergent wetland. Pre-settlement vegetation maps indicate open water and wetland communities comprised approximately 15% of the land cover in the lower segment. The 1978 MIRIS coverage indicates that wetlands account for slightly more than 3% of the current landscape, a reduction from pre-settlement of more than 230,000 acres (Table 6, Figures 39,40).

Current land use in the lower segment is described as: 59% agriculture, 20% forest land, 10% rangeland , 7% urban and residential, and approximately 4% wetlands, lakes and streams (Figure 52).

Mouth

Sandy lake plains cover most of the mouth segment with some steep, coastal sand dunes and fine-textured end-moraines present. Most soils are Group A and Group C (Figure 53). Poorly drained sands associated with the lake plain typically overlay a shallow clay sub-soil. Outwash deposits found between moraine ridges contain the stream bed and floodplain of the Grand River and its tributaries. Poorly drained Group D soils in the outwash deposits are primarily associated with streams draining into the Grand River. Moraine ridges with Group B and C soils are located in the eastern portion of this segment. In the 1820s, beech-sugar maple forests dominated the end moraine ridges in the eastern portion of the mouth segment. Hemlock and beech forests were dominant on the sand lake plain and dunes near Lake Michigan. Mixed oak-pine forests were common on sand lake plain and outwash deposits close to the Grand River mainstem. Lowland hardwoods and black ash swamp were common in the active floodplains. Near the mouth of the river, extensive Great Lakes marsh and alder-willow swamps were common (Comer 1996). In the central portion of the mouth segment, large swamps of tamarack, white pine, hemlock, black ash, and mixed hardwoods were common in areas of poorly drained lake plain and ground moraine (Figure 54).

Much of the historical beech-maple forest cover found in the eastern portion of the mouth segment has been converted to agricultural uses which now accounts for 60% of the overall land use. Forested lands are found primarily in areas underlain by Group A soils in the west and cover approximately 28% of the current landscape. Urbanized lands account for approximately 8% of current land use. In the 1820s, wetland communities accounted for approximately 15% of the land cover in the mouth segment. Comparison of historical data with the land coverage contained in MIRIS indicates substantial losses of hardwood and coniferous swamps and emergent marshlands (Comer 1996). On the current landscape, wetlands account for less than 2% of the land cover. Rivers, streams, and lakes make up 2% of the current landscape (Figure 55).

Bridges, Culverts and Other Stream Crossings

Bridges and culverts are among the most ubiquitous man-made channel modifications in a river network (Burford et al. 2009) These structures have been historically designed to pass a given storm event while minimizing the costs of the construction. In instances where the stream channel dimensions were not considered in the crossing design, several problems can occur. Most commonly these designs do not consider bank-full channel dimensions (see **Channel Morphology**) and result in undersized structures. Such structures can cause a backwater effect upstream of the crossing, resulting in channel widening due to aggradation as sediment transport is interrupted. Downstream of such structures, increased outlet velocities can result in bank instability and channel widening due to scour. Bank instability can also be induced if the culvert is not properly aligned with the thalweg and flow is directed toward the stream bank.

From a biological perspective, culverts with high exit velocity, inadequate water depth, or excessive outlet drops can result in the blockage of fish movements. Fish and other aquatic organisms have generally adapted to live near the channel margins where water velocities are slowest. With the exception of some of the larger introduced potamodromous fishes (steelhead, salmon) most fish species found in Michigan do not have the swimming and leaping ability to negotiate channel velocities greater than 3 feet per second, (S. Verry, Ellen River Partners, personal communication). When bridges or culverts with less than bank-full width restrict streamflow at road crossings, exit velocities can exceed the 3 feet per second threshold and partially or completely impede fish movements (Peake 2004; Leavy and Bonner 2009). Restricted movements associated with road crossings are documented for several warmwater fishes, including cyprinids (minnows) and centrarchids (basses and sunfish). Many species of fish found in the Grand River watershed spawn in early spring, ascending tributaries during peak annual flows. Movement to spawning areas can be blocked or limited by excessive exit velocities of undersized culverts. Such restriction or blockage of fish passage results in a direct loss of upstream spawning and rearing habitats, thus reducing overall productivity of the fish community (Fausch et al 2002; Gibson et al. 2005).

Properly sized culverts can also disrupt sediment transport and represent a barrier to fish movement if these structures are not installed correctly. Culverts that are not properly recessed during placement can lack adequate water depth and represent a barrier during periods of low flow. Placement must be at the same slope as the stream channel. If the pitch is too steep then exit velocities can exceed the 3 fps threshold. If the culvert slope is too low, sediment deposits can form upstream and inside of the culvert. Improper placement of the culvert can also result in a jump barrier if the downstream end of the culvert is too high resulting in a “perched” culvert (Warren and Pardew 1998; Burford et al. 2009).

Many of the problems associated with road crossings can be mitigated with appropriate design and construction methods. The MESBOAC approach to culvert design was initially developed through a cooperative effort between the Forest Service and Minnesota Department of Natural Resources. The method employs a geomorphic approach to design a crossing that properly sizes, orients and installs culverts based primarily on the stream's physical characteristics. MESBOAC is an acronym comprised of the first letter of each of the six steps in the method: **M**atch culvert width to bank-full stream width; **E**xtend culvert length through the side slope toe of the road; **S**et culvert slope the same as stream slope (failure to set culverts on the same slope as the stream is the primary reason that many culverts impede fish passage); **B**ury the culvert into the streambed to provide roughness along the channel margins; **O**ffset multiple culverts; **A**lign the culvert with the stream channel; and, **C**onsider head-cuts and cut-offs (S. Verry, Ellen River Partners, personal communication).

Fisheries Division considers the MESBOAC method as the best approach to ensure unimpeded fish passage. This approach also minimizes the risk of a culvert being washed out during a significant storm event. Following construction, a regular schedule of crossing maintenance is necessary as culverts and bridge pillars tend to become blocked with debris. These conditions can lead to flooding or erosion problems by restricting natural stream flow. This is especially true at multiple culvert crossings.

Many road crossings are located in valleys, thus road runoff is commonly directed to the road shoulder and down slope toward the stream channel, creating “point source discharges” of sediment, nutrients, and other pollutants. Crossing designs should incorporate stormwater best management practices to minimize or eliminate this potential pollutant source.

According to intersect counts using the Michigan Geographic Framework county transportation database, there are 8,639 road stream crossings in the Grand River watershed (Table 7; MCGI, SDL 2004). Kent County has the most road crossings with 1,698 or nearly 20% of total crossings in the watershed. Clinton, Ionia, and Ingham counties also had high numbers of road crossings with 990, 871 and 752, respectively (Figure 56). This high density of road crossings increases the potential for restricted fish passage and the potential to reduce the overall productivity of the Grand River fish community. Through the environmental permit review process, negative geomorphic and biological effects associated with road crossings are being corrected when replacement of a structure becomes necessary. When clear span bridges cannot be included in the crossing design, bottomless culverts are the preferred design. Fisheries Division routinely requests restricted work dates to protect the movements of spawning fish. Designs requiring channel enclosure or relocations should be permitted in only limited situations and only if accompanied by appropriate mitigation.

Submerged crossings (pipelines) are usually less evident unless erosion of the stream bottom has exposed them. The number and location of submerged crossings in the Grand River watershed are unknown. Depending on diameter and amount of pipe exposed in a stream channel, some crossings can act as low head dams, catch debris, or impede navigation. Installation of submerged crossings can also be a major source of sedimentation to a stream. In the past , failure of old pipeline crossings in the Grand River watershed has resulted in the release of polluting substances such as sewage and petroleum products, leading to significant reductions in water quality. In instances where a pipeline failure occurs over a prolonged period, these continuous releases can go undetected for a long time. Through Part 301 of the Natural Resources and Environmental Protection Act (1994 PA 451), proposed crossings are reviewed to ensure that proper construction techniques and best management practices are used to minimize stream degradation.

Channel Morphology

A description of channel form includes the pattern (sinuosity), dimension (width to depth ratio), and profile (slope) of the stream channel. Stable river channels are in dynamic equilibrium with the amount of water and sediment that is transported from headwaters to mouth. Although channel morphology can be altered by large flood pulses (e.g., 50- or 100-year events), maintenance of channel form is associated with the bank-full event which has typical recurrence interval of 1.5 to 2 years. Bank-full is the discharge which governs both channel size and shape.

> The bank-full stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or

> removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels (Dunne and Leopold 1978).

When the stable discharge-sediment balance is altered through removal of vegetative land cover or when streams are directly modified though deepening or widening (dredging), impounding, or hardening (i.e. riprap, levies), channel adjustment is expected and the response is predictable (Rosgen 1996). For example as a result of channelization, the stream becomes incised and is cut off from its adjacent floodplain. Therefore, the channel is forced to convey discharges that exceed original bank-full. The kinetic energy that would normally be dissipated in the vegetated floodplain is directed to the stream bank, resulting in higher sheer stress and bank instability. As the banks begin to fail, sediment loads increase, resulting in increased bar deposition, further acceleration of bank erosion, increased sediment supply, channel widening and aggradation. The stream channel will continue to evolve toward a balance between the slope and valley and will ultimately form a new floodplain at a lower elevation. As these adjustments occur, subsequent responses to tributary morphology can be expected.

Presented within this section are three river measures that describe channel characteristics and stability of the Grand River mainstem and its tributaries. These measures are gradient, specific power and channel cross section.

Gradient

Gradient is the change in river channel slope over channel length and is commonly reported in feet per river mile. Together with flow volume, gradient is one of the main controlling influences on river habitat. Typically, as land elevation increases, so does gradient. Steeper gradients accelerate water flows with accompanying changes in depth, width, channel meandering, and bedload transport and distribution (Knighton 1984). River gradient is strongly influenced by surficial materials in the catchment. In areas of erodible materials, such as sands, gradient may change as flow varies. In the glaciated Midwest, higher stream gradients typically occur where streams flow across less erodible materials, such as glacial end moraines. These glacial deposits typically contain more rock and therefore are resistant to erosive downcutting of the channel. When the deposits are coarse-textured (e.g. sands or gravels) and elevation changes are large, stream channels receive high inflows of groundwater (Wiley and Seelbach 1997; Baker et al. 2003). Thus stream gradient is related to other important variables such as stream temperature, current velocity, bottom substrate, and flow stability. For this reason gradient can be used to describe habitat requirements of many fish species including smallmouth bass (Trautman 1942; Edwards et al. 1983), largemouth bass (Stuber et al. 1982a), bluegill and green sunfish (Stuber et al. 1982b, 1982c), northern pike (Inskip 1982), flathead catfish (Lee and Terrell 1987), white sucker (Twomey et al. 1984), black crappie (Edwards et al. 1982), blacknose dace (Trial et al. 1983), and creek chub (McMahon 1982).

In addition to the influences of soil type and surficial and bedrock geology, local channel gradient is also influenced by modifications in land use and land cover. Unstable flow patterns as result of excessive storm water runoff can create flood channels that are too wide and aggrade during low flows. Bridges, culverts, bank erosion and other channel modifications can also alter channel formation and thus gradient. Dam construction inundates productive high gradient areas reducing overall habitat diversity and lowering aquatic species diversity (see **Dams and Barriers**).

The elevation of the Grand River mainstem drops a total of 551.9 ft, from 1,130.7 ft above sea level at the headwaters to 578.8 ft above sea level at the mouth (Figure 57). The average gradient of the Grand River mainstem is 2.2 ft/mi from the headwaters to the mouth. Grand River gradient is low relative to other southern Michigan rivers of similar size. For example gradient of the Kalamazoo

River is 3.0 ft/mile (Wesley 2005), the Muskegon is 2.6/mile (O'neal 1997) and the St. Joseph is 2.5 ft/mile (Wesley and Duffy 1999). Rivers typically have steep gradient in their headwaters with more moderate gradient further downstream. However, gradient in the mainstem between Lansing and Lyons remains relatively steep as evidenced by the close proximity of the dams in this reach. Gradient varies in different sections of the river, with some sections falling very rapidly and others falling very little (Figure 58). These different gradient areas create different types of channel, resulting in different types of habitat for fish and other aquatic life. Broad predictions concerning fish community habitat, channel characteristics, and hydraulic diversity can be made from knowledge of gradient (Table 8).

Hydraulic diversity refers to the variety of water velocities and depths found at a particular site in the river. The most productive river habitat offers a good hydraulic diversity to support various species. Fish and other life are often more diverse in those parts of a river with gradient between 10 and 69.9 ft/mi. These are relatively rare in Michigan because of our low relief landscape and particularly so in the Grand River watershed (Figure 59). High-gradient stream reaches that did occur in the state were often sites for dams and most are now inundated beneath impoundments.

Specific Power

The specific power of a stream is dependent on the gradient (or slope), rate of discharge, and width. Specific stream power, reported as watts/m^2, provides a measure of the potential energy supplied to a stream channel and its banks. Power is the amount of work done per unit time, and specific power is an important measure in understanding the dynamics of sediment transport and the channel forming processes of a river system. Specific power is expressed as:

$$\omega = 1000(pgQ_f\, s/w)$$

where Q is the discharge at exceedence flow f, s is the channel slope in meters/meter, w is cross-sectional width in meters, p is water density and g is gravitational acceleration. A value of 10 is used to approximate pg (Wiley and Gough 1995).

As the slope increases or as the volume of water increases, stream power also increases, and, as width decreases, specific power increases. As specific power increases, more energy becomes available for moving channel materials and is cumulatively highest during bank-full events (Dunne and Leopold 1978; Rosgen 1996). Materials of varying sizes from clays to boulders make up the bedload that is transported by a river. Sand particles are approximately 0.1 to 1.0 mm in size and are more readily transported than larger particles such as gravel or cobble. Clay materials are more cohesive and are less readily eroded, but tend to remain in transport over longer distances. (Figure 57).

Rivers and streams, regardless of the bed materials they flow through, are dynamic in nature and move laterally within their valleys. As the stream channel migrates, diverse floodplain habitats (e.g., oxbow lakes, secondary channels, temporary pools) are created as cut and fill processes redistribute organic and inorganic materials previously transported downstream. When a river moves laterally, the outside bank erodes as materials are deposited on the inside bank. Easily eroded materials such as sand are transported downstream while coarser materials (gravels, cobbles) are deposited in the streambed.

Rivers flowing through sand begin to adjust when specific power exceeds a threshold of 15 watts/m^2. That is, they may begin to erode laterally to increase sinuosity, become incised, overtop their banks, or a combination of these. These adjustments result in a reduction of specific power. Rivers flowing through clay channels require greater specific power to induce similar erosive responses.

Channel Cross Section

Similar to gradient, channel cross section is another measure of channel complexity and quality of aquatic habitat. In unaltered sinuous channels, glide-riffle-run-pool complexes contain diverse microhabitats that support higher aquatic species diversity and abundance. River systems that have been altered (straightened, deepened) typically lack a diversity of habitats and consequently support less diverse biological communities.

Measured channel width compared to predicted width is an indicator of channel alterations and riparian land use practices. In unaltered river systems, mean channel width typically increases downstream. When actual channel width is less than the expected width at 95% exceedence flow, the channel is incised. Overly narrow channels could be a result of channelization, bank armoring, bulkheads, or similar artificial construction that restricts channel width (Madison and Lockwood 2004). Channelization and land use modifications in the upstream areas often result in unstable flow regimes and excess bedloads leading to channel aggradation. As a result, channels become excessively wide given their low flow discharge. These channels are characterized by shallow water depths and low habitat diversity.

Mean expected widths and their upper and lower 95% confidence bounds are calculated using the following formulas (G. Whelan, MDNR, Fisheries Division, unpublished data):

Mean expected width *W* is calculated as:

$$W_e = 10^{(0.741436 + (0.498473 \cdot \log Qe))},$$

where *Q* is the discharge at exceedence flow *e*. Upper 95% confidence bound for expected width W_e is calculated as :

$$W_{upper} = 10^{(0.819976 + (0.525423 \cdot \log Qe))}$$

and lower 95% confidence bound for expected width W_e was calculated as:

$$W_{lower} = 10^{(0.662895 + (0.471522 \cdot \log Qe))}$$

Actual and expected widths at 5% exceedence, 95% exceedence, and average discharge were determined for each USGS gauge site in the Grand River watershed using available flow data. The expected widths at average discharge all fall into the normal range except at the Portland gauge site which was wider than expected (Table 9). Measured channel widths at most of the gauge stations exceeded expected channel widths at 95% exceedence (Table 10). At high flow rates, (5% exceedence), many of the sites were narrower than expected (Table 11). Since all but one of the USGS gauge stations are located near road crossings, the variances in expected widths may be artifacts of bridge construction.

Headwaters

The headwaters segment of the mainstem has the highest average gradient of the mainstem at 4.2 ft/mi from the headwaters to Perry Creek. It varies from 25.4 ft/mi upstream of Goose Lake to 0.75 ft/mi at the Portage River mouth (Figure 57). The high average is deceiving because only 7% of this segment is high gradient while 93% is low gradient. These areas of higher gradient are found where the river steps down across deposits of glacial moraine.

The only gauge station is located at Jackson in the downstream end of the segment in the low gradient portion. Gradient in this area is 2.17 ft/mi. Specific power at this location is 0.3 watts/m^2 at 95% exceedence flow and 16.5 watts/m^2 at 5% exceedence flow with an average of 1.0 watts/m^2.

Measured channel width at the Jackson gauge is within the expected range at average and low flows, but too narrow at 5% exceedence (Tables 9-11). The river mainstem at this location is incised as a result of channelization.

Upper

The upper segment has an average gradient of 1.67 ft/mi with a range of 1.47 to 2.44 ft/mi. The change in slope between the confluences of Spring Brook and Perry Creek is 1.60 ft/mi. Gradient increases to 3.5 ft/mi near Eaton Rapids; however, habitat diversity is lost by the impounding effects of the Smithville and Mix Dams. The Moores Park Impoundment is in the lower end of the segment and has an overall slope of 1.68 ft/mi.

The only gauge station in this segment is located just north (downstream) of Eaton Rapids. Gradient in this area is 2.44 ft/mi. Specific power is 0.5 watts/m^2 at 95% exceedence flow, 29.7 watts/m^2 at 5% exceedence flow, and 1.8 watts/m^2 at average flow. Channel width at Eaton Rapids is within the expected range at average and 5% exceedence flow, but wider than expected at 95% exceedence flow (Tables 9-11).

Middle

The middle segment has an average gradient of 3.02 ft/mi with a range of 2.26 to 3.78 ft/mi. Although gradient is lower than that of the headwaters segment, a higher percentage (44%) is considered to be fair gradient (Table 8).

Due to the construction of several dams in this segment, some of the most hydraulically diverse habitats are inundated by impoundments. The North Lansing Dam is at the beginning of the middle segment. At this location the river channel has an average gradient of 3.0 ft/mi. Gradient increases toward Grand Ledge and reaches approximately 3.88 ft/mi at the Grand Ledge Dam. The gradient at Portland Dam is 3.0 ft/mi. The tailwater of the Portland impoundment is the upper end of the Webber impoundment which stretches just over 7 miles to the dam. At Webber Dam the river channel drops 30 feet from impoundment to tailwater, and this impoundment covers an area with a gradient of 4.24 ft/mi. The village of Lyons has the last intact dam in the valley segment. This impoundment extends upstream to about the 650 ft. contour line, three miles upstream. The gradient through this stretch is 4.0 ft/mi (Figure 58).

The two gauge stations on the mainstem are in Lansing and Portland. The Lansing gauge station is located just downstream of the Lansing dam. Gradient in this area is 2.81 ft/mi. The specific stream power at 95% exceedence flow is 0.5 watts/m^2. At 5% exceedence flow it is 50.3 watts/m^2 with an average of 2.4 watts/m^2. The width of the mainstem at Lansing is within the expected range at average and 5% exceedence discharge, but wider than expected at 95% exceedence flow (Tables 9-11).

The Portland gauge station is located near Kent Street in the city of Portland, upstream of both the Portland impoundment and the Looking Glass River. Gradient in this stretch is 3.22 ft/mi. The specific stream power at 95% exceedence flow is 0.5 watts/m^2. At 5% exceedence flow it is 56.7 watts/m^2 and at average flow it is 2.1 watts/m^2. Channel width at Portland is greater than expected at both the 95% exceedence and average flows, and within the expected range at the 5% exceedence discharge (Tables 9-11).

The mainstem of the Red Cedar River has very low gradient, 1.9 ft/mi at Williamston and 2.0 at East Lansing. The specific stream power at the Williamston gauge station is 0.1 watts/m^2 at 95% exceedence, 8.1 watts/m^2 with an average of 0.6 watts/m^2. At East Lansing, specific stream power is 0.1 watts/m^2 at 95% exceedence flow, 22.1 watts/m^2 at 5% exceedence flow, and 0.9 watts/m^2 at average flow. Measured channel widths at both locations are wider than expected range at low flow (Tables 9-11).

There are active USGS gauges on two Red Cedar River tributaries, Sloan Creek and Deer Creek. Both streams have higher gradients than the Red Cedar River but do not have very high specific stream power. The gradient in Sloan Creek is 11 ft/mi. Specific stream power at 95% exceedence is 0.1 watts/m^2, 18.9 watts/m^2 at 5% exceedence, and 0.7 watts/m^2 at average flow. Deer Creek has a gradient of 4.9 ft/mi. Specific stream power ranges from 0.1 watts/m^2 at 95% exceedence flow to 13.5 watts/m^2at 5% exceedence flow. Measured channel widths for Sloan Creek and Deer Creek are wider than expected at 95% exceedence flow and narrower than expected at 5% exceedence flow (Tables 9-11).

The Looking Glass River has one stream gauge located near the town of Eagle. Gradient in this stretch of river is 3.8 ft/mi. Specific stream power is low except during high flow conditions. Specific stream power is 0.2 watts/m^2 at 95% exceedence, 34.0 watts/m^2 at 5% exceedence, and 1.5 watts/m^2 at average flow. Measured channel width is wider than expected at 95% exceedence flow and less than expected at 5% exceedence flow (Tables 9-11).

Lower

This is the river segment that flows in the former glacial Grand River channel. The lower segment is very flat, with an average gradient of 0.8 ft/mi and a range of 0 to 5.48 ft/mi. The largest change in channel slope occurs near the City of Grand Rapids. Gradient of the mainstem near the confluence with the Rogue River approaches 0 ft/mi and increases to 5.48 ft/mi through the location of the former rapids.

Ionia and Grand Rapids are the two gauge stations in this segment. Mean gradient at the Ionia gauging station is 0.81 ft/mi. Specific stream power was 0.2 watts/m^2 at 95% exceedence flow, 21.7 watts/m^2 at 5% exceedence flow, and 1.2 watts/m^2 at average flow. Measured channel width at Ionia is within the expected range at average and 5% exceedence discharges. At 95% exceedence flow the measured channel width of 225.8 ft. is wider than expected. Minimum and maximum expected widths are 74.6 ft. and 147.4 ft, respectively (Tables 9-11).

The Grand Rapids gauge station was established in 1901, providing long term flow data for the area. Gradient in this stretch is 5.5 ft/mi. The specific stream power is 2.3 watts/m^2 at 95% exceedence flow, 169.7 watts/m^2 at 5% exceedence flow, and 8.2 watts/m^2 at average flow. Measured channel width at this location also exceeded the expected range at 95% exceedence flow (Tables 9-11).

Much of the Maple River drainage was once glacial lake bed and thus is comparable to the lower and mouth segments of the Grand River mainstem in terms of channel slope. Gradient of the Maple River at the Maple Rapids USGS gauging station is approximately 0.8 ft/mi. Specific stream power is very low: 0.1 watts/m^2 at 95% exceedence flow, 6.4 watts/m^2 at 5% exceedence flow, and 0.4 watts/m^2 at average flow. Measured channel width is within expected range at average and 5% exceedence flows. During low flows the channel is wider than expected (Tables 9-11).

Fish Creek, tributary of the Maple River, has moderate gradient at 6.1 ft/mi. Specific stream power figures are 0.6 watts/m^2 at 95% exceedence flow, 15.4 watts/m^2 at 5% exceedence flow, and 0.6 watts/m^2 at average flow. Measured channel width is within the expected range for low, median, and high flows (Tables 9-11).

The Flat River near Smyrna has a gradient of 6.0 ft/mi. Specific stream power at this site is as follows: 2.6 watts/m^2 at 95% exceedence flow, 89.1 watts/m^2 at 5% exceedence flow, and 5.1

watts/m^2 at average flow. Measured channel width of 90.3 ft is within the expected range at low and average flows but narrower than expected at high flows (Tables 9-11).

The gradient of the Thornapple River near the City of Hastings is relatively low at 1.2 ft/mi. Specific stream power is also low at 0.2 watts/m^2 at 95% exceedence flow, 13.8 watts/m^2 at 5% exceedence flow, and 0.6 watts/m^2 at average flow. The width of the Thornapple River at the Hastings USGS gauge is within the expected range during average flows. The channel is wider than expected at 95% exceedence flow and less than expected width at the 5% exceedence flow.

The gradient of Quaker Brook near the Village of Nashville is 15.3 ft/mi. Specific stream power is 0.6 watts/m^2 at 95% exceedence flow, 27.3 watts/m^2 at 5% exceedence flow, and 0.6 watts/m^2 at average flow. Channel widths fall within the expected range at average and 95% exceedence flows. Measured channel width at the 5% exceedence is 12.9 ft and is less than the expected range of 17.9 to 30 ft (Tables 9-11).

The USGS stream gauge on the Rogue River is located downstream of Rockford. Gradient at this location is 12.4 ft/mi. Specific stream power is 2.8 watts/m^2 at 95% exceedence flow, 112.3 watts/m^2 at the 5% exceedence flow, and 6.4 watts/m^2 at average flow. Measured channel width is within the expected range during average flows. The channel is wider than expected at 95% exceedence flow and less than expected width at the 5% exceedence flow (Tables 9-11).

In September of 1986, record rainfall resulted in a large flood event that caused the failure of the Childsdale Dam and nearly breached the structure at Rockford. Flows during the event were recorded at nearly ten times the 5% exceedence flow. Based on those flow estimates, specific stream power at the time of the 1986 flood would have been approximately 139.2 watts/m^2.

Mouth

The mouth segment flows across a landscape that was formerly glacial lake plain (see **Geology**). Thus the river channel has an extremely flat slope of 0.27 ft/mi. Such extremely flat gradient results in very little specific stream power and no attraction for use as water power. Due to the low gradient, Robinson Township in Ottawa County is particularly vulnerable to the formation of ice dams at a large bend in the river in the northwest part of the township. This was also the site of a massive log jam that occurred during high water in June and July of 1883. The water rose so high during this event that the captain of the steamboat *W. H. Barrett* was said to have taken a shortcut around the log jam across cornfields, where he “found plenty of water” (Kuiper 1983).

No long term USGS gauge stations were located within this portion of the mainstem; specific power and expected channel width were not calculated.

Dams and Barriers

There are 228 dams in the Grand River watershed that are regulated pursuant to the dam safety provisions of the NREPA 1991 PA 451. Less than 10 percent of these structures are located on the river mainstem (Table 12, Figure 61). These dams have been classified according to their purpose: 17 for hydropower generation, five retired hydropower projects, 117 for recreation (including lake-level control structures), eight flood-control dams, seven for irrigation, and 80 for other reasons (private ponds, county park ponds, hatchery ponds etc.). It is not known how many small, unregistered dams exist in the basin.

Dams were an important component of early settlement in the Grand River watershed. The earliest mainstem dam on record was constructed in 1830 near Jacksonburg (Jackson) to power a small sawmill (DeLand 1903). As settlement increased, the need for additional milling capacity increased. During 1835, the first official approval was given for the construction of a dam on the mainstem in Summit Township, Jackson County.

> At the session of the legislative council in the winter, they obtained “concession” to “build a dam across the Grand River on the southeast quarter of section 3, town 3 south, 1 west, not to exceed seven feet above the water surface, with a lock or sluice of sufficient width to allow the passage of logs, rafts, of flat boats to float upon and navigate said river (DeLand 1903).

Early dams were located at high gradient stream reaches to harness water power for lumber and grist mills at numerous locations throughout the watershed. These dams and milling operations became the focus of settlement, and many present day communities were established at these locations. Construction of these dams continued until approximately 1944. Several of the older dams (circa 1850) were originally constructed for mechanical purposes and were later converted to hydroelectric generating facilities. According to dam safety records, most of the active and retired hydroelectric dams in the watershed were constructed between 1850 and 1939. The majority of dams in the watershed have been constructed for recreational purposes and are largely lake-level control structures.

Dams are regulated under Michigan’s Dam Safety Act, Part 315 of the Natural Resources and Environmental Protection Act (NREPA), 1994 P.A. 451 as amended; and the Federal Energy Regulatory Commission (FERC) Regulation 18 of Part 12 of the Code of Federal Regulations. Most of the existing hydroelectric dams on the Grand River are operating under license agreements issued by FERC. In certain cases, hydroelectric projects may qualify for an exemption from full licensing. These facilities are exempt from the requirements of Part I of the Federal Power Act and are issued an exempt license. However, the exempted project is subject to mandatory terms and conditions (e.g., run-of-river operations) set by federal and state fish and wildlife agencies and by FERC. Dams which are constructed for the purpose of maintaining static water levels on inland lakes are regulated under Part 307 of NREPA and are typically maintained and operated by the local County Drain Commissioner.

As dams age, failure risks increase, and economic and environmental costs associated with these failures can be substantial. Over 30 percent of the registered dams in the Grand River watershed were constructed prior to 1960 and have exceeded their design life. Many of these aging structures are in varying states of disrepair. All registered dams in the watershed have been evaluated and assigned a hazard level rating pursuant to the dam safety provisions of Part 315 of the NREPA 1991 PA 451. These hazard levels are based on the potential that a catastrophic loss of the structure would result in either the loss of human life or severe property damage. Of the 231 registered structures in the watershed, twenty seven dams have been classified as having a high hazard potential. Eight dams are of hazard type 1 (dam failure would cause the loss of life), 19 are of hazard type 2 (dam failure would cause severe property damage), and the remaining 207 dams are of hazard type 3 (have low heads in remote areas). Most high hazard dams have a head of over 12 feet and are hydroelectric or retired hydroelectric facilities.

Dams interrupt and alter the ecological processes of rivers by changing the hydrology, disrupting sediment and nutrient transport, and modifying habitats (Ligon et al. 1995; Bednarek 2001; The Heinz Center 2002; Graf 2003). Most dams are located in areas of highest channel gradient in order to create the largest hydraulic head possible for energy production. Some segments of the Grand River and tributaries contained rapids and fast riffle areas before being impounded. These habitats were important areas for fish spawning and typically supported the highest diversity of fish and other aquatic organisms. These habitat types are now scarce in the watershed due to dam construction.

Dams further degrade aquatic habitat through changes in thermal regimes and concentrations of dissolved gases. Impoundments act as thermal sinks, and spilling of heated surface waters often causes an increase in downstream temperature (Lessard 2001). Impounded waters also act as sinks for nutrients and sediment. As these artificial lakes age and become nutrient enriched, large diurnal fluctuations in dissolved oxygen concentrations upstream and downstream of the dam can occur. Dams disrupt the sediment-water transport equilibrium of streams. Waters entering an impounded reach are slowed, thereby reducing sediment transport capacity, and resulting in channel aggradation and burial of high quality habitats. Sediment-free water released below the dam has unusually high erosive power, causing increased scour and bank erosion (American Rivers 2003). Woody structure, which is important for fish habitat, is caught in impoundments and eventually sinks, depriving downstream segments. The ability of dams to control flows can disrupt the incidence and severity of flooding both up and downstream if the reservoir has storage capacity. Reduced inundation of floodplains can decrease available backwater habitat for fish spawning and juvenile rearing. The decrease in flooding may also reduce the diversity of aquatic habitats associated with floodplain resources (Sparks 1995).

Dams have significant detrimental effects on the biology of streams. They impede fish movements creating isolated fish populations (Schlosser 1991, Porto et al. 1999), affect species distributions and fish community structure (Poff et al. 1997; Pringle 1997; McLaughlin et al. 2006; Catalano et al. 2007), and can lead to localized extinctions (Matthews and Marsh-Mathews 2007). Dams fragment river systems, blocking the longitudinal movements of fish and other aquatic life. Many species of fish (e.g., northern pike, suckers, salmon and steelhead) move upstream significant distances to spawn, and their offspring disperse back downstream using available habitats. Dams block these upstream movements thereby decreasing the overall productivity of the fish community. Mortality or injury resulting from fish passage through hydraulic turbines or over spillways during their downstream migration can be significant (Larinier 2000). Entrainment often causes mortality or injury as a result of fish being struck by turbine blades, pressure changes, sheer forces in turbulent flows, and water velocity accelerations (Cadwallader 1986; Cada 1990). Except in cases were fishways have been constructed on the mainstem, upstream movement for nearly all species is blocked (see **Biological Communities**, *Factors affecting fish communities*).

Dams also have detrimental effects on benthic invertebrates (Stanley et al. 2002; Doyle et al. 2005; Tuckerman and Zawiski 2007). Seasonal fish movements are critical to native freshwater mussels for both reproduction and dispersal as mussels use fish as hosts for parasitic larval glochidia. Some species of mussels have very specific host fish requirements, and blockage of these fish species could result in local extirpation of the mussel species (Watters 1995; Vaughn and Taylor 1999; Sethi et al. 2004; Strayer 2008). Henry van der Schalie (1948) noted the decline in freshwater mussel populations in the Grand River as a result of river flows being altered by peaking operations at hydropower facilities. Additionally, many species of aquatic insects move upstream to deposit their eggs. Downstream areas are then re-colonized through downstream drift. This dispersal mechanism is disrupted by the presence of dams (see **Biological Communities)**.

Lake-level control structures are frequently operated in a manner that benefits lake riparians at the expense of both the lake and outlet stream. During periods of high water, it is common practice to lower the structure to quickly drain the lake to “normal” levels. This practice results in the loss of shallow water spawning, feeding, and nursery habitats (O’Neal and Soulliere 2006). For example, critical spring spawning areas for fish such as northern pike are eliminated on some lakes when water levels are kept artificially low to protect riparian property. If the drawdown rate is too rapid, fish can be trapped or exposed in shallows, often leading to death. Less mobile aquatic life such as mussels, snails, and aquatic insects are also lost as a result of rapid dewatering of shallows. Downstream channel erosion in the outlet stream may result as water is rapidly released. Conversely, during periods of drought, the lake-level control structures retain water to maintain an unnaturally high lake level. This action intensifies low flow conditions and can result in the drying of the outlet channel. Lake-level control structures also block the movement of fish and other aquatic life. Typically these structures represent a jump barrier preventing fish from ascending into the lake to spawn, feed, or escape harsh downstream conditions.

Other barriers to fish movement in the Grand River watershed include poorly constructed road crossings such as perched culverts and poorly designed bridges which result in physical or velocity barriers to fish movement (see **Soils and Land Use Patterns**, *Bridges and other stream crossings*). In some instances, dredged stream channels designed for the rapid routing of water are too wide during summer low flows. During drought flow periods, fish become stranded in isolated pools as the channels become too shallow and prevent their escape to locations with adequate depth.

Headwaters

Four of the five mainstem dams in the headwaters are lake-level control structures on Crystal Lake, North and South Lake Le Ann, and Mirror Lake. These structures were built in the early to mid 1960s. The remaining mainstem dam at Liberty Mills was constructed in 1848. This dam was originally constructed to power a grain mill and was later converted to produce electricity. Currently the dam is used only to maintain the pond elevation. Removal of this structure would restore river connectivity and provide upstream fish passage. All mainstem dams in this valley segment represent barriers to the movement of fish and other aquatic life.

The mainstem was formerly impounded by the Holton Dam in the City of Jackson. This municipally owned hydroelectric structure was constructed in 1936. At one time, this portion of the river was routed in a capped concrete channel. The Holton dam and cap were removed in 2001 (Lane 2007).

Other dams in the headwaters segment were created largely for recreational purposes and serve as lake control structures or create wildlife floodings in the Waterloo State Recreation Area. The hazard levels for the 26 dams in the headwaters range from low to significant (Table 12).

Upper

There are 13 dams within the upper mainstem segment with five on the Grand River mainstem. The three largest, Smithville, Mix, and Moore’s Park, are active hydroelectric dams operating under license agreements issued by FERC.

Smithville Dam was built in 1887. It is an earthen structure with a 13 ft head and 500 kW generating capacity. The dam is currently operating under a 2001 license agreement (No. 11150) which expires in 2041. The license requires the dam to be operated in run-of-the-river mode but does not include fish passage provisions. The structure is currently classified as a Type 1 hazard (i.e., dam failure would cause the loss of life).

The Mix Dam is an earthen structure that was built in 1933. It is currently operating under a FERC license (No. 11150) issued in 2001 which expires in 2041. The license agreement requires run-of-the-river operation and a minimum flow of ten cubic feet per second in the bypass channel. Fish passage is not provided at this project. The structure has nine feet of head and a generating capacity of 202 kW. This structure is considered to be a low hazard.

Moores Park was built in 1908 and with 15 feet of head is the largest in this valley segment. The 600 kW generating project is owned by the City of Lansing and is being operated under a 1994 license agreement (No. 10864) which expires in 2024. The license requires run-of-the-river operation but does not contain fish passage provisions. The Moores Park Dam has a Type 1 hazard rating.

The remaining mainstem dams in this valley segment are municipally owned and are not regulated by FERC. The City of Eaton Rapids owns a structure identified in the records as the Sanitation Dam. The structure has two feet of head and was constructed in 1918. The structure is identified as low hazard and likely represents a seasonal barrier to most species of fish.

The Wilson (Dimondale) Dam and bypass channel were originally built in 1850 and then reconstructed in 1852. Originally the dam was used to power mills located at the dam site. In later years it served to maintain a shallow impoundment. In 1996, the dam partially failed, leaving the structure with a large bow facing downstream and a 40 foot breach on the east side. Because the majority of the mainstem flow was shunted through this large breach, the structure was a velocity barrier to fish and was a safety hazard to boaters and anglers. The remaining structure maintained approximately five feet of head and due to the breach was considered a low hazard. In 2003, the Village of Dimondale was awarded an Inland Fisheries Grant by the MDNR to remove the structure and restore this portion of the Grand River. The project design was based on principals of natural channel design with the project goal of restoring the river to a functioning, self-sustaining channel (Rosgen 1996). The project was successfully completed in 2007.

Most of the remaining dams in this valley segment are located on tributaries at the sites of old mills or are lake-level control structures used for recreation. These dams have the potential to reduce summer flows in small creeks, increase water temperatures, and prevent fish access to important habitat. The MDEQ has classified these as low hazard structures.

Middle

This segment has 26 recorded dams with five existing structures and one remnant located on the mainstem. Two of the structures, Portland Dam and Webber Dam, are the remaining operating hydroelectric dams in the middle mainstem segment.

The Portland hydroelectric project is municipally owned and is operating under FERC license (No. 11616) issued in 2001, with an expiration date in 2041. The dam was built in 1894 and has 11 feet of head, an approximately 100-acre pond, and a generating capacity of 375 kW. The facility's operation license requires run-of-the-river and maintenance of 25 cubic feet per second in the fish ladder during periods of open water. The fish ladder is a vertical slot design constructed at the site in 1981. Portland Dam is considered to be a low hazard structure.

Webber Dam is the largest dam in the middle segment. It is privately owned and operated by Consumers Energy Company. Construction of the structure began in 1906, and operations were initiated in 1907. The dam is earthen with a concrete core, has a head of 33 feet, and impounds approximately 660 acres. The dam is capable of generating 3,250 kW and is currently operating under a 2001 FERC license (No. 2566) that expires in 2041. License requirements include run-of-the-river operation and maintenance of minimum flow through the fish ladder during the spring and fall fish spawning migrations. The Webber Dam fishway was constructed in 1981-82 and is a pool-weir design. The fishway design includes a viewing chamber equipped with a video monitor that is used to count and identify fish using the ladder (See **Fishery Management**). During the spring of 2001 the Webber ladder was monitored 24 hours a day from February through April. During that period 14 fish species were recorded either ascending and/or descending the ladder (Dexter 2002). Upstream migrating steelhead were the most common species to use the ladder during this period. Bluegill, channel catfish, largemouth bass, and walleye were also recorded using the ladder during this time frame. In fall, 2001 the ladder operated from late August through December. In this period, passage of over 3,500 coho salmon, 313 Chinook salmon, and 819 steelhead was recorded. Warmwater species recorded during this monitoring period included bluegill, channel catfish, smallmouth bass, walleye, and various sucker species. Monitoring conducted during fall 2008 fish passage period reported similar findings (Taylor and Wesley 2009).

The Webber Dam FERC license also requires a two week shutdown period to allow for the passage of coho salmon smolts that are stocked upstream in the City of Lansing. The exact shutdown period is not specified in the license; therefore, it is the responsibility of Fisheries Division to notify Consumers Energy as to the appropriate shutdown period each spring. In 2005, the coho smolts failed to move downstream during the anticipated period and began to show up at the Webber project after the designated two week period, resulting in the entrainment of many smolts. Following notification, Consumers Energy voluntarily extended the shut-down period and discontinued power production until the smolts moved past the dam. This commendable action saved many of the coho smolts that had been tagged and clipped as part of a Fisheries Division research project.

Other mainstem dams in the middle valley segment include the North Lansing Dam owned by the City of Lansing, the Mudge Dam owned by the City of Grand Ledge, and the Lyons Dam owned by the Village of Lyons.
The North Lansing Dam, constructed in 1936, is a retired hydroelectric project that is maintained at about an eight-foot head. The 92-acre pond is long and narrow and extends upstream to Moore's Park Dam and the confluence of the Red Cedar River. Although the dam has aesthetic and recreational value to the City of Lansing, it no longer serves the purpose for which it was constructed. Because maintenance costs are high, the City of Lansing began a study in 2005 to examine the possibility of a permanent drawdown or complete removal of the structure. The fishway at North Lansing Dam, the William A. Brenke Fish Ladder, is a pool and weir design constructed in 1981. This structure allows ascending salmon and steelhead access to the Red Cedar watershed.

The Grand Ledge Dam is an earthen structure constructed by J.S. Mudge in 1900 to provide adequate draft for recreational river traffic by numerous steamboats using the river during this era. In its current condition the dam is maintained at approximately five feet of head with a one- acre pond. Fish passage is provided by a vertical slot ladder constructed in 1981. This structure is classified as low hazard.

The Lyons Dam was originally built in 1857 under the name of Hales Mill. The structure was acquired by Consumers Power (Energy) in 1915 and rebuilt in 1929 following a dam failure that occurred between 1913 and 1919. The dam was capable of producing 450 kW of hydroelectric power until 1956 when operations ceased. The existing structure is essentially a rock-filled log crib capped with concrete. The dam has eight feet of head and forms an approximately 120-acre impoundment. Fish passage at this location is provided by a vertical slot fishway that was constructed on the site in 1981.

Due to the age and poor condition of the existing structure, the Village of Lyons has been actively seeking funds for dam removal. The structural integrity of the dam and ladder was further brought into question in 2001, when a large sinkhole formed adjacent to the fishway. To alleviate safety concerns, Fisheries Division acquired approximately $65,000 in emergency funds to repair the damage. These emergency repairs will not withstand, therefore, the removal of the Lyons Dam and fishway has been identified as a priority by Fisheries Division. In 2008, the village was awarded an Inland Fisheries Grant from Fisheries Division to facilitate the removal of the structure.

Between the Lyons Dam and the Webber Dam lie the remnants of the former Wagar Dam. The dam was constructed in the early 1900s and retired in 1956. The dam was demolished shortly after. In 1984, Fisheries Division allocated $17,000 to remove approximately 50 feet from the right bank of the remaining structure to allow fish passage. The remaining foundation spans nearly the entire channel and during low flow conditions is a barrier to fish movement and navigation; therefore, removal of the remaining structure should be considered.

The remaining dams in this segment were constructed on tributaries to produce mechanical power for lumber and grist mills, to create small impoundments, or are lake-level control structures used to maintain court-ordered lake elevations. The majority of these are classified as low hazard structures.

Lower

The only two registered mainstream dams in the lower valley segment are the Sixth Street Dam and the beautification dam, both located within the Grand Rapids city limits.

Originally built in 1849 of rocks, logs and brush, the Sixth Street Dam was constructed as part of a lock and canal project to allow boat passage around the mile-long rapids of the Grand River. By 1850 the dam and canals were constructed, but the lock work was never finished. The project was terminated in 1855, and the remaining funds were used to construct a new dam at its present location in 1866. The river water was diverted to the canals constructed east and west of the river channel and was used to power several milling operations. Currently, the Sixth Street Dam is classified as a retired hydroelectric dam and maintains approximately eight feet of head. Although the structure is classified as a low hazard to downstream properties, the dam tailwater produces a dangerous hydraulic undertow that represents a significant risk to anglers and boaters. During the spring and fall spawning runs, trout and salmon concentrate below the dam creating excellent fishing opportunities. Unfortunately this also creates crowded fishing conditions, and anyone that ventures too close to the dam can become trapped in the boil created by the hydraulic undertow. The Sixth Street Dam has been the site of many rescues. The fishway at the Sixth Street Dam was the first operational fish ladder on the Grand River. The ladder was constructed in 1975 and is a pool-weir design.

The other registered mainstem dam was built in 1931 and is one of four low-head structures that were constructed as part of a river beautification project. The structure has approximately two feet of head and provides only aesthetic functions. Although the structure does not block the movement of ascending potamodromous fish, it likely represents a barrier to native fish species (e.g., walleye, suckers) during low flow conditions.

The steep valleys of the lower mainstem segment created several high gradient locations on tributaries that were ideal for establishment of hydropower dams. Although many that were constructed for milling operations are no longer functioning, several tributary dams were retrofitted for hydroelectric generation.

The Hubbardston Dam is located on Fish Creek, a coldwater tributary of the Maple River. The dam was originally constructed circa 1850 to provide mechanical power and was converted to hydroelectric generation sometime before 1920. The dam is currently undergoing licensing with FERC. As with all FERC-licensed facilities, Fisheries Division, is recommending that FERC include the following provisions in the license agreement: 1) establishment of run-of-river flow; 2) a minimum flow study in the bypass channel; 3) entrainment and impingement studies to estimate fish mortality and to mitigate for losses; 4) upstream fish passage options; 5) woody structure passage; 6) a dam retirement funding proposal; and, 7) funding for installation and maintenance of a stream gauge below the project. Hubbardston Dam creates 15 feet of head, impounds approximately 35 acres, and has 240kW generating capacity. The dam is considered to be a low hazard structure.

Significant dams on the Flat River include: Greenville, Belding, Whites Bridge, Fallasburg, and King Milling.

Greenville Dam is a municipally owned, retired hydroelectric structure constructed in 1914. Prior to the gate failure, the dam impounded approximately 149 acres and had 8 feet of head. The dam is considered to be a significant hazard by the MDEQ Dam Safety Section. There are no provisions for passage of aquatic species at this location. The Greenville City Council is currently considering a proposal to replace the dam and re-establish the pond when the Franklin Street Bridge is reconstructed.

Belding Dam was constructed in 1887. The dam has 15 feet of head, impounds approximately 110 acres, and has a generating capacity of 280 kW. In 1989 FERC issued an order granting the facility an exempted license. However, the terms and conditions of the agreement require the dam is operated in run-of-the-river mode and in a manner protective of fish and wildlife resources. MDEQ considers the structure to be a low hazard. The dam is a barrier to the movement of aquatic organisms.

Whites Bridge Dam is a privately owned hydropower constructed in 1929. The dam height is 16 feet creating a 91-acre pond. The dam has a generating capacity of 775 kW. This facility was also granted an exempt license from FERC. The terms of the exempt license require run-of-the-river operation. There are no provisions for fish passage at this location. The hazard rating is low.

Fallasburg Dam is an earthen structure constructed in 1900. The dam has 35 feet of head creating an approximately 260-acre impoundment. Similar to the Belding and Whites Bridge dams, the Fallasburg hydroelectric project has an exempt license from FERC. Operations at the dam are required to operate at run-of-the-river and maintain a minimum of 110 cubic feet per second in the bypass channel. Provisions for fish passage were not included in the 1985 exemption agreement. Due to the dam's height and location, it is considered to be a significant hazard.

King Mill Dam is located near the confluence of the Flat River and the mainstem and as such serves as the primary barrier to fish migration into the Flat River watershed. The earthen structure built in 1942 provides 14 feet of head and creates a 53-acre pond. Because the dam produces mechanical power instead of electricity, FERC has concluded the operations are exempt from license requirements. The structure is considered to be a type 2 hazard (i.e., dam failure would result in severe property damage).

The relatively steep gradient in portions of the Thornapple River also attracted energy development resulting in the construction of numerous hydroelectric dams. Five operations are currently active and include Irving, Middleville, LaBarge, Cascade, and Ada dams.

Irving Dam was constructed in 1939. The dam is operated under a 2002 FERC license (No.11516) which expires in 2042. The license requires the dam to be operated at run-of-the-river; however, provisions for fish passage were not included in the agreement. The dam has 16 feet of head and creates approximately 32 acres of shallow impoundment. The structure is considered a low risk.

Middleville Dam is a gravity-earthen structure completed in 1938. The dam is 12 feet in height, with a 35-acre impoundment, and is capable of generating 250 kW. Middleville Dam is licensed by FERC (No. 11120-002) and is required to operate at run-of-the-river. The dam is a barrier to the movement of fish and other aquatic life. MDEQ considers this structure to be a significant hazard.

The LaBarge Dam was constructed in 1901 and is a gravity-earthen design. The project received a 40-year operating license (License No. 11300) from FERC in 2002. The license requirements include run-of-the-river operations but failed to include requirements for fish passage. The generating capacity of the LaBarge turbines is 800 kW. The dam has 19 feet of head creating a 100-acre impoundment. The LaBarge Dam represents a high hazard risk to downstream inhabitants.

The hydroelectric dams at Cascade and Ada were completed in 1926 and currently generate 3,000 kW and 1,100 kW, respectively. The Cascade Dam is the taller with 28 feet of head and a 270- acre pond. Ada dam is 23 feet in height and creates a 318-acre impoundment. The structures were considered exempt from Part I of the Federal Power Act and were granted exempt licenses from FERC in the early 1980s. The exemption agreements require run-of-the-river operations and both impoundments have court-ordered drawdown requirements in April and October. Requirements for fish passage were not included in either document. Although the Cascade and Ada impoundments receive a large amount of recreational use, these waters have limited access and are largely private.

Another significant dam on the Thornapple River was located in the Village of Nashville. The structure was built in 1894 to provide power to local mills. At full pool the dam provided approximately 11 feet of head and created a 56-acre pond. Over the years, the dam had fallen into disrepair and maintenance of the structure became a significant financial liability to the village. In 2006, the Village of Nashville contacted Fisheries Division for information regarding options for the removal or repair of the structure. In 2007-2008, the Village of Nashville partnered with the MDNR, MDEQ, USFWS, NFWF, and Barry Conservation District to remove the dam and restore this portion of the Thornapple River. The structure was successfully removed in 2009.
Numerous other dams exist in the lower mainstem segment. Many are small structures constructed for the purpose of regulating lake water levels or are former mill sites that are now maintained for recreational purposes. One of the tallest dams in the basin is located in this valley segment. Rainbow Lake Dam has 42 feet of head and impounds 238 surface acres. The earthen structure was constructed in 1961 on Pine Creek in Gratiot County to create a manmade lake. In 1986, following several days of heavy rain the Rainbow Dam failed resulting in extensive property damage. The dam has since been rebuilt and is considered a significant hazard by MDEQ.

Mouth

All eight registered dams in this segment are constructed on tributaries with none located on the mainstem. With the exception of the Crockery Lake Dam, which is maintained by Ottawa County, all of the structures are privately owned and are largely maintained for recreational uses. All of the dams in this valley segment are small, with less than four feet of head, and are considered low risk.

Water Quality

Overview

Water quality in the Grand River basin is influenced by many human activities including agriculture, industry, and urban development. Surface water quality in Michigan is outlined in the Part 4 Water Quality Standards promulgated pursuant to Part 31 of the Natural Resources and Environmental Protection Act (NREPA), 1994 PA 451, as amended. At a minimum, waters of the state are protected for the following designated uses: warmwater or coldwater fisheries; other aquatic life and wildlife; agriculture; industrial and municipal water supply; navigation; and recreation. Waters of the state that are designated as trout streams (Table 13) or are principal migratory routes for potamodromous salmonids have more stringent dissolved oxygen and temperature standards to protect coldwater fish (Tables 14a and 14b). The Grand River mainstem from Lake Michigan to the Moores Park Dam is identified as a principal migratory route for salmon and steelhead and therefore receives this additional protection.

State and Federal laws have been developed to protect water quality for a variety of given uses (e.g., NREPA 1994 PA 451; Wolf and Wuycheck 2004). Regulatory agencies monitor river and lake water quality and water uses in a basin to ensure minimum water quality standards are met, to determine compliance with the law, and to document water quality conditions in the basin. The MDEQ, Water Resources Division is the lead regulatory agency for water quality in Michigan. Through its various water quality monitoring programs the MDEQ, Water Resources Division has conducted biological and chemical surveys of a number of lakes and streams in the Grand River watershed. Aquatic habitat and water quality vary throughout the watershed, with some areas supporting designated uses, while other areas are seriously degraded and do not meet minimum water quality standards. Federal Water Pollution Control Act reporting requires MDEQ, Water Resources Division to provide a biennial report to the United States Environmental Protection Agency (USEPA) detailing the status of monitored water bodies. Water Bureau utilizes a numeric rating system (1 to 5) to describe the status of a water body and the extent to which water quality standards are being supported (Wolf and Wuycheck 2004). Waters that are fully supporting all designated uses receive a score of 1; whereas degraded waters requiring the development of a restoration plan, or Total Maximum Daily Load (TMDL) threshold are rated category 5 (Table 15).

It should be noted that Michigan does not list water bodies in category 1 because comprehensive data are not available for most locations. Water bodies in category 2 are considered to be supporting designated uses. Category 3 includes waters that were not assessed or require further evaluation. Categories 4 and 5 are those waters that do not support designated uses. Waters listed under categories 4a and 4b have been studied, and restoration plans have been implemented. Category 4c includes river and stream miles that have been physically altered pursuant to the activities authorized by the Michigan Drain Code PA 40 of 1956. The systems have been so highly modified and degraded they can no longer support minimally acceptable biological communities. Category 5 is those waters that are impaired and require the development of a TMDL (Table 16). Rivers, lakes, and streams are assigned to the various attainment categories as new monitoring information becomes available or as listing criteria are developed. Because listing criteria and thresholds are regularly updated, it is recommended that the reader consult the most recent listing assessment methodology to determine the attainment status of a particular water body (S. LeSage, MDEQ, Water Resources Division, personal communication).

The following description of the Grand River watershed attainment status is based on a review of the 2004 biennial report (Wolf and Wuycheck 2004). The 2004 report to USEPA indicated that of the 2,218 perennial river and stream miles assessed during the reporting period, 960 (43%) miles were considered to be supporting designated uses. A total of 1,257 miles were considered to be in nonattainment and failed to support one or more designated uses. Over half of the nonattaining waters were classified as such due to channelization and other drainage practices authorized by the Drain Code of 1956 (Category 4c). This percentage would increase considerably if intermittent stream mileage was included in the total.

The water quality in the Grand River basin has historically suffered from poor water quality due to unregulated discharges from municipal and industrial point source discharges. Water quality in the basin has steadily improved, and virtually all point source discharges are now regulated through the National Pollutant Discharge Elimination System (NPDES) permitting program administered by the MDEQ, Water Resources Division. Contemporary causes for non-attainment of water quality standards include poorly designed sanitary sewer systems that allow for combined sewer overflows (CSO) and sanitary sewer overflows (SSO) near urban centers, discharges from Confined Animal Feeding Operations (CAFOs), nonpoint source pollution from the lack of best management practices in the uplands, deposition of airborne pollutants, and localized degradation from contaminated sediments and venting groundwater from adjacent sites of contamination.

The USEPA, MDEQ, and USGS conducted the Lake Michigan mass balance project in 1994 and 1995. The study documented elevated loadings of pollutants coming from the Grand River into Lake Michigan. The mass balance study included 12 major Lake Michigan tributaries and focused on PCBs and trans-nonachlor, atrazine, mercury, and nutrients. These substances, among others, were studied because they are representative of classes of pollutants (i.e., persistent chlorinated compounds, herbicides, metals, etc.) of environmental significance in Lake Michigan and throughout the Great Lakes. Based on the analysis of the 1994-95 data, the Grand River was reported to be one of the most significant contributors of contaminant loads to Lake Michigan (USEPA 1999). The Grand River had the highest annual total nitrogen loading (1.4 x 10^7 kg/yr) and second highest loading of the herbicide atrazine (approximately 400 kg/yr), and the second largest source for mercury. The Grand River was rated sixth in total PCB loads to Lake Michigan and was significantly lower than the Kalamazoo and Fox rivers, both of which are listed on the USEPA National Priorities List (Superfund) pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (USEPA 2003, 2004).

Point Source Pollution

There are a total of 189 municipal and industrial discharges to surface waters in the Grand River basin (Table 17a). These discharges are commonly referred to as point source pollution because the source of the pollutants is distinct. Discharges are permitted by the State of Michigan through the National Pollution Discharge Elimination System (NPDES), which regulates discharges to surface waters.

Discharges to the Grand River include effluents from municipalities: wastewater treatment plants, water treatment facilities, and storm sewers; industrial discharges: contact and non-contact cooling waters, process wastewater, sanitary wastewater, groundwater remediation sites; and miscellaneous discharges from trailer parks, campgrounds, concentrated animal feeding operations, and highway rest areas. Permits issued to these dischargers contain limits for parameters of concern (i.e. organic and inorganic toxicants, oxygen demanding pollutants, solids, nutrients, oil and grease, temperature, and chlorine) and are specific to each discharge. Water quality-based effluent limitations are developed based on the assimilative capacity of the receiving waters and incorporate a mixing zone, which is determined by the applicable volume, or design flow of the receiving waters. Permits are issued for five years and are reviewed by Water Bureau staff before being reissued. Permit review and re-issuance is based on the location of the discharge, and the 8-digit USGS Hydrologic Unit Code for the receiving waters: Upper Grand River, Looking Glass/Maple rivers, Flat/Rogue/Thornapple rivers, and the lower Grand (Lesage and Wuycheck 2004). In general, permitted discharges are in compliance with specified limits and conditions contained in the NPDES permits.

Nonpoint Source Pollution

Nonpoint source pollution originates from diffuse sources and is delivered to surface waters through atmospheric deposition or through water transport. It can be generated locally (e.g., surface runoff from an agricultural field) or regionally (e.g., stacks for power plants). Pollutants associated with nonpoint sources include: nutrients, sediment, bacteria, bioaccumulative organic compounds, and other chemicals including metals, salts, etc. Sources of these pollutants include: agricultural fields, livestock feedlots, surface runoff from construction sites, parking lots, urban streets, uncontrolled septic seepage, groundwater contamination, open dumps, industrial sites, and inadvertent chemical spills.

Pollutants discharged from nonpoint sources can exert an increased oxygen demand on the stream potentially lowering local concentrations of dissolved oxygen. Discharges of plant nutrients can lead to nuisance conditions and high diurnal fluctuations in dissolved oxygen concentrations. Introduction of increased sediment loadings can alter sediment transport mechanisms and destroy habitat due to bed aggradation. Additionally, metals, herbicides and pesticides, and other toxicants readily bond to fine sediments and can concentrate in depositional areas, potentially harming benthic organisms. Atmospheric deposition of mercury and PCBs is responsible for the general fish consumption advisory on inland lakes issued by the Michigan Department of Community Health.

Unlike the pollutant loadings from point source discharges, nonpoint source pollutant loadings in surface runoff from urban and agricultural lands are largely uncontrolled and contribute to water quality impairments throughout the Grand River watershed. Nonpoint source pollution may be best addressed through the implementation of best management practices (BMPs). BMPs are structural, vegetative, or managerial practices used to prevent, treat or reduce negative effects of pollutants on water or habitat quality (Peterson et al. 1993). Section 319 of the federal Clean Water Act provides funding for addressing nonpoint source problems. The MDEQ, Water Resources Division is responsible for providing grants to local agencies or organizations to develop watershed management plans with the goal of reducing nonpoint source pollutant loadings. Section 319 watershed management plans have been approved for: the Upper Grand River, Upper Looking Glass River, Buck Creek, Coldwater River, Plaster Creek, and the Rogue River. Watershed plans are being drafted for other portions of the watershed (e.g., Thornapple River, Lower Grand River).

Storm Water Control

Storm water sewers can convey both point and nonpoint sources of pollution to the river. These discharges typically have elevated concentrations of dissolved solids and metals, and high nutrient and sediment loads. Because storm water collection systems typically drain large impervious areas, they can deliver flood pulses from relatively small rain events. Storm water discharges are regulated by the MDEQ, Water Resources Division or local unit of government. There are 714 permitted storm water discharges within the watershed (Table 17b).

Sites of Environmental Contamination (Part 201 Sites)

The Remediation Division of the MDEQ has identified 307 sites of environmental contamination within the Grand River watershed as of 2004 (Table 18). These sites are regulated under Part 201 of NREPA, 1994 PA 451 or the Comprehensive Environmental Response Compensation and Liability Act of 1980 as amended (CERCLA) and the Superfund Amendments and Reauthorization Act (SARA) of 1986. Part 201 provides laws and administrative rules for the identification and remediation of sites of environmental contamination, determines liable party responsibilities, and provides the regulatory framework for the remediation of these sites. Most of the listed sites have identified pollutants of concern in surface soils or groundwater and therefore are potential sources of contaminants to the Grand River mainstem and tributaries. Corrective actions to control the further release of pollutants have been taken at most of the identified sites.

Dissolved Oxygen, Temperature, Nutrients, and Bacteria

Chemical and physical characteristics of water, such as temperature and dissolved gases, are important components of fish habitat and largely dictate the composition of the resident fish community. Summer temperature is one of the major factors in controlling growth, survival, abundance, and distribution of fish (Wehrly et al. 2003; Zorn et al. 2002; Zorn et al. 2004; Zorn et al. 2008). Fish species can be categorized based on their optimal thermal preferences, upper thermal tolerance limits, and temperatures at which they spawn. These categories are broadly classed as cold, cold-transitional, warm-transitional and warm (Lyons et al. 2009). Further, most fish require moderate levels of dissolved oxygen (above 3 mg/l) in order to survive. Standards for temperature, dissolved oxygen, and other parameters have been established to protect fish and other aquatic organisms. These standards are included in Part 4 Water Quality Standards (Part 31 of NREPA, 1994 PA 451) and are used when modeling water quality-based effluent limitations for NPDES permitted discharges (Table 13b).

MDNR Fisheries Division has collected stream temperature data at several locations on the mainstem and numerous tributaries throughout the watershed. These data show that several tributaries are cold or cold-transitional streams with little variation in summer temperature (Table 19). This is consistent with the considerable groundwater flows to these streams. Although coldwater habitats are common in some of Michigan's northern watersheds, they are a relatively rare resource in the Grand River basin and should be protected through careful land use management.

Ambient chemistry monitoring has been conducted throughout the basin by the various federal, state, and county agencies prior to the signing of the Federal Water Pollution Control Act. Monitoring analyses included: temperature, dissolved oxygen, total and dissolved solids, chlorides, ions, nutrients, and toxicants. Many of these data have been archived in the US Environmental Protection Agency's Storage and Retrieval (STORET) database. The database can be accessed at http://www.epa.gov/storet. The more dated information, circa 1960 to 1999, is housed in the STORET Legacy database, while newer data are contained in the modernized format. Water quality data collected by the United States Geological Survey is available at http://water.usgs.gov.nwis. Recent water chemistry analyses have been compiled for the mainstem (Table 20) and select tributaries (Table 21). The following discussion provides a summary of water quality issues by mainstem segment.

Certain types of bacteria pose a health concern to humans and animals because they cause disease. *Escherichia coli* is the bacterium usually associated with human and animal waste. The total body contact standard (head immersion) is exceeded when there are over 300 *E. coli* colonies per 100 ml of water and the partial body contact (fishing, bathing) is exceeded with counts of 1,000 colonies per 100 ml of water. Regulatory compliance is based on geometric means of three or more samples within a defined sampling area. Bacteria sampling is conducted by the various County Health Departments and reported to MDEQ Water Bureau. In some instances bacterial counts exceed standards, requiring swimming beach closures and potentially requiring the development of corrective measure (e.g., TMDL). Data regarding the results of monitoring activities can be accessed at http://www.mcgi.state.mi.us/miswims.

Headwaters

The water quality of the Grand River in the headwaters upstream from the City of Jackson is generally good. Water bodies identified as supporting designated uses include 42 miles of the mainstem, 16 miles of assessed tributaries, and five inland lakes (Table 116). Areas of non-attainment include 25 miles on the mainstem and Portage River due to untreated sewage discharges, violations of dissolved oxygen standards, and degraded biological communities. MDEQ has prepared TMDLs for biota (Wuycheck 2003), and dissolved oxygen (Sunday 2002) to restore designated use attainment in these areas. Other areas of nonattainment are related to fish consumption advisories due to elevated mercury concentrations in fish tissue.

There are 17 individual NPDES permits and 93 storm water permits issued for discharges to surface waters in the this valley segment (Tables 17a and 17b). The MDEQ has identified 36 sites of environmental contamination in the headwaters. Pollutants of concern include heavy metals, volatile organic compounds, waste oils, and polychlorinated biphenyls (Table 18).

Historical discharges, direct and indirect, from several area plating companies have resulted in elevated concentrations of heavy metals in mainstem sediments downstream of the City of Jackson (Rockafellow 2003a). Several of these contaminants exceed threshold and probable effects concentrations suggesting the potential for these sediments to be toxic to aquatic life (MacDonald et al. 2000).

Upper

Water quality is also good in the upper segment with portions of the mainstem and 86 miles of tributaries identified as supporting designated uses. Nonattaining waters include seven miles of Columbia Creek, due to degraded biota as a result drain maintenance, and the Moores Park Impoundment for exceedances of fish consumption trigger levels for mercury in fish tissue.

The MDEQ has issued 10 individual discharge NPDES permits and 30 storm water related permits in this valley segment. Fifteen sites of environmental contamination have been listed by the MDEQ Remediation and Redevelopment Division.

Biological surveys conducted in this valley segment reported generally acceptable macro-invertebrate communities (Goodwin 2000; Rockafellow 2003b).

Middle

The middle segment and tributaries flow through the major urban areas of Lansing and East Lansing. Within this segment, there are 35 individual NPDES permits, 138 permitted storm water discharges, 72 sites of environmental contamination, five solid waste landfills, 11 hazardous waste management operations, and 50 permitted oil and gas development sites.

Exceedances of water quality standards in this valley segment include 12 miles of the mainstem and Red Cedar River due to combined sewer overflows from the Cities of Lansing and East Lansing. During the warmer seasons, violations of the 5.0 mg/l dissolved oxygen standard have also been reported on the mainstem and Red Cedar River (Sunday 2003). The mainstem has a low current velocity through the City of Lansing resulting in reduced reaeration rates. During extended periods of high temperatures, fish kills as a result of low dissolved oxygen concentrations have been documented (Brunsen 1999). Biological surveys conducted at several locations on the mainstem reported good to excellent macroinvertebrate communities upstream and downstream of the City of Lansing (Rockafellow 2003a).

One hundred and seventeen miles of tributaries were considered to be supporting designated uses in this reach (Wolf and Wuycheck 2004). Biological communities sampled in the Red Cedar River subwatershed were considered to be generally acceptable but some areas were limited by degraded habitat. Water and sediment chemistries were found to be within acceptable ranges for the measured parameters (Rockafellow 2003c). Water and sediment monitoring results in the Looking Glass River watershed were also reported to be within expected ranges, and no exceedances of water quality standards were identified. Fish and macroinvertebrate communities sampled during the survey indicated designated uses were supported (Roush 2003a).

Violations of the dissolved oxygen standard were also noted as the cause of nonattainment on 79 miles of tributaries. Other impairments include biological degradation and fish consumption advisories. Biological degradation due to drainage maintenance activities was reported on 188 tributary miles in this segment.

Lower

The lower mainstem segment includes drainage from the most significant tributaries in the watershed including the Maple, Flat, Thornapple, and Rogue rivers. Stream types in this segment range from high quality first order trout streams to the warm water reaches of the mainstem. There are 107 individual NPDES permits (Table 17a) and 408 storm water permits (Table 17b) that authorize the discharge to the surface waters. Potential sources of contamination in the lower segment include 152 sites of environmental contamination, four solid waste landfills, 30 hazardous waste management operations, and 123 oil and gas operations.

Water quality sampling was conducted on the mainstem Grand River at several locations in 2003. No exceedances of Michigan's Water Quality Standards for measured parameters were documented, suggesting designated uses are largely being supported (Rockafellow 2005). The water quality standard for mercury was exceeded on the mainstem in Ionia County (Wolf and Wuycheck 2004). Exceedances of the pathogen standard were also reported due to wet weather discharges from combined sewers in Kent County.

Biological and chemical monitoring surveys on the major subwatersheds in this valley segment document attainment of standards on approximately 630 perennial stream miles (Wolf and Wuycheck 2004). Attainment of designated uses as evidenced by the presence of good to excellent biological communities was reported at all sample locations in the Flat River subwatershed (Hanshue 2002a). The Rogue River subwatershed is also considered high quality and supporting designated uses. Water chemistry data for tributaries in this subwatershed tended to have low concentrations of nutrients and total solids, which is typical of groundwater dominated systems (Rockafellow 2003d). The lower portion of Prairie Creek in Montcalm and Ionia counties was also identified as a high quality tributary meeting coldwater designated uses despite extensive modification of the headwaters (Cooper and Rockafellow 2005). Water quality impairments due to agricultural runoff, nutrient enrichment, and habitat degradation associated with channelization were reported in the Maple River watershed (Hanshue 2002b; Roush 2003b; Rockafellow 2003e). Nutrient enrichment and habitat degradation were also identified as impairments in the Thornapple River (Hanshue 2002c; Rockafellow 2004). Degradation associated with hydrologic overloading from excessive storm water discharges has been reported in Plaster Creek and York Creek (Wuycheck 2002).

The MDEQ Water Bureau classified 561 miles of perennial stream channel in the lower valley segment as nonattaining waters. A TMDL to restore 12 miles of Plaster Creek has been developed and TMDLs are scheduled to restore designated uses on approximately 115 miles of category 5 streams. Failure to support acceptable biological communities as a result of channel modifications and other activities undertaken pursuant to the Drain Code was documented on 434 miles of perennial water courses in this segment.

Mouth

There are 20 individual NPDES permits issued for this segment, and most of them are for sanitary wastewater treatment plants, noncontact cooling water, or the discharge of treated groundwater (Table 17a). The majority of the 45 storm water permits are for sites in Spring Lake and Grand Haven (Table 17b). There are 32 sites of environmental contamination, two hazardous waste management sites, one solid waste landfill, and eight oil and gas wells in this valley segment.

The mainstem within this section is considered nonwadeable and limited biological sampling has occurred. Violations of pathogen and mercury standards on the mainstem have been reported. Elevated concentrations of heavy metals, PCBs, DDE, and polycyclic aromatic hydrocarbons (PAHs) have been documented in Grand Haven, Harbor Island, and Middle Bayou (USEPA Great Lakes National Program Office 1999). Although many of these values exceed threshold and/or probable effects concentrations (MacDonald et al. 2000), additional study is necessary to determine the areal extent and magnitude of the contamination.

Tributaries meeting designated uses in this valley segment include Norris Creek, North Branch Crockery Creek and the mainstem of Crockery Creek (Wolf 2000). Nonattaining waters include the entire Bass River subwatershed (66 miles) and the entire Deer Creek subwatershed (47 miles). These waters fail to support designated uses due to exceedances of standards for pathogens, dissolved oxygen, elevated nutrients, and degraded fauna (Wolf and Wuycheck 2004).

Fish Contaminants

As part of water quality surveillance activities, the MDEQ, Water Resources Division coordinates the Fish Contaminant Monitoring Program (FCMP) between several state and federal agencies and tribal organizations. The goals of FCMP are to: 1) evaluate whether fish contamination problems exist in specific surface waters; 2) identify spatial differences and temporal trends in the quality of Michigan’s surface waters with respect to persistent, bioaccumulative chemicals; 3) evaluate whether existing pollution prevention, regulatory, and remedial programs are effectively eliminating or reducing chemical contamination in the aquatic environment; and 4) support the establishment or removal of public health sport fish consumption advisories by the Michigan Department of Community Health (MDCH). The Michigan fish contaminant monitoring program consists of both fish collections from streams and caged fish studies. MDCH is responsible for establishing, modifying, and removing sport fish consumption advisories for Michigan's surface waters. Fish samples are analyzed for contaminants and compared to the fish consumption advisory trigger levels (Table 22). If a concentration of contaminants exceeds a trigger level, a consumption advisory is issued for that species and water body.

Most fish consumption advisories in the Grand River watershed have been issued due to elevated tissue concentrations of PCBs. The advisories include the mainstem from Grand Haven upstream to Webber Dam. Within this reach, women of child bearing age and children are advised to limit their consumption of common carp, channel catfish, northern pike, redhorse suckers, and walleye. The same advisory has been issued for Webber Dam upstream to the headwaters but also restricts consumption of white sucker. No consumption advisory exists for the general population for these species.

Restricted consumption of common carp and rock bass from the Flat River and common carp from Morrison Lake (Ionia County) is also advised to women of child bearing age and children.

In addition, there is an advisory on mercury for all inland lakes and reservoirs in Michigan. No one should eat more than one meal per week of rock bass, yellow perch, or crappie over nine inches or bass, walleye, northern pike, or muskellunge of any size. Mercury is an airborne pollutant that can contaminate lakes and reservoirs regardless of the environmental health of a watershed.

Anglers should consult the latest Michigan Fish Advisory published by the Michigan Department of Community Health, Environmental Epidemiology Division. Fish Consumption Advisories are published on the web at: http://www.michigan.gov/mdch.

Stream Classification

In response to concerns over increased consumptive water use and potential diversion of water resources, the Michigan legislature enacted Public Act 34 of 2006. The act required the development of an integrated assessment tool to determine the potential for water withdrawals to diminish or otherwise adversely impact water or water-dependent natural resources. To assess adverse resource impacts, a model was developed to determine how fish communities would respond to reductions in stream base flows. Model inputs included stream catchment size, base flow yield, and July mean temperature to predict fish community structure and characteristic fish assemblages in different river segments under a range of base flows. This model builds on the valley segments classification describe by Seelbach et al. (1997) and provides a landscape-based ecological classification system of streams in Michigan (Zorn et al. 2008; Lyons et al. 2009). Each stream reach is classified by size, (stream, small river, large river), thermal regime (cold, cold-transitional, warm-transitional, warm) and characteristic fish community (Figure 62). This classification system provides the ecological foundation for water withdrawal assessment process outlined by the Groundwater Conservation Advisory Council (GWCAC 2007) (see **Hydrology**, *Water Use*).

Special Jurisdictions

There are several federal, state, and local jurisdictions regarding rivers, riparian zones, and floodplains. The various MDEQ Divisions administer some federal laws and several state statutes protective of the aquatic resources in the Grand River watershed (Table 23a and 23b).

Navigability

Issues associated with public rights on Michigan waters, including navigability, are discussed in detail by the MDNR Law Enforcement Division (MDNR 1993). Water laws are complex and are established through both legislative and judicial action. A navigable inland lake is any lake accessible to the public via publicly-owned lands, contiguous waters or highways, or via the bed of a navigable stream. It also must be reasonably capable of supporting a beneficial public interest, such as navigation, fishing, hunting, swimming or other lawful purposes inherently belonging to the people. A navigable inland stream is defined as: 1) any stream declared navigable by the Michigan Supreme Court; 2) any stream included within the navigable waters of the United States by the U.S. Army Corps of Engineers for the administration of the laws enacted by Congress for the protection and preservation of the navigable waters of the United States; 3) any stream which floated logs during the lumbering days or has sufficient capacity for the floating of logs in the condition which it generally appears by nature, notwithstanding there may be times when it becomes too dry or shallow for that purpose; 4) any stream having an average flow of approximately 41 cubic feet per second, an average width of some 30 feet, an average depth of about one foot, capacity of floatage during spring seasonal periods of high water limited to loose logs, ties and similar products, used for fishing by the public for an extended period of time, and stocked with fish by the state; 5) any stream which has been or is susceptible to navigation by boats for purposes of commerce or travel; 6) all streams that have been meandered by the General Land Office Survey in the mid 1800s (MDNR 1993).

The origin of utilizing the floating log test for navigability stems from a dispute during the logging era in which riparian landowners claimed water rights and tried to make a profit from them during log drives. A lawsuit over the issue on the Pine River in St. Clair County in 1853 clarified that a stream with capacity for floatage was navigable, and therefore all persons using it had equal rights. This set a legal precedent that not only allowed lumbermen to float logs downstream without interference from property owners, but has also been utilized for many other cases regarding navigability to the present time (Allen 1941).

Fisheries Division is interested in the definition of a navigable stream because anglers have the common interest of fishing in a navigable stream, subject to the restraints and regulations of state laws. For the water ways to best serve the public, recreational uses should be considered in the determination of navigability. There should be a means of determining the public accessibility of a stream without the need for judicial determination. “A statutory determination of a navigable stream is urgently needed to clarify the fishing, boating, and recreational rights of the public, as well as provide criteria of navigability, and direction to state agencies in the implementation of existing laws and regulations (MDNR 1993).”

The United States Army Corps of Engineers (USACE) exercises jurisdiction over several waterways in Michigan for the protection and preservation of the navigable waters of the United States. The areas of jurisdiction extend from their mouths to the heads of navigation as listed. For the Grand River, the USACE has jurisdiction from the mouth of the Grand River up to Fulton Street in Grand Rapids, 40 miles from the mouth.

The Michigan Supreme Court has adjudicated the navigability of several lakes and streams in the state. In the Grand River watershed, the Supreme Court has adjudicated the following waters as navigable (MDNR 1993):

Grand River, Kent County, downstream from Grand Rapids
Long Lake, Barry County
Thornapple Lake, Barry County

The Michigan Supreme Court also, either by judicial notice or direct reference in opinions rendered during the period 1843-1930, indicated that some streams and lakes floated logs on a commercial basis during the early Michigan lumbering era. The streams in the Grand River watershed that were so noted are (MDNR 1993):

Black Creek, Kent County, upstream to Flat Creek
Flat River, Montcalm County, seasonably navigable
Grand River, Kent County
Looking Glass River, Shiawassee County, meandered

During the period 1837-1907, the Michigan Legislature by local act or general statute authorized construction on certain navigable streams in order to provide for the passage of boats, canoes, rafts or other watercraft and logs. These streams should, therefore, be deemed navigable by law downstream to their mouths from the indicated Legislature-authorized dam locations. In the Grand River watershed the affected streams are (MDNR 1993):

Flat River, Section 30, T10N R8W, Montcalm County, Laws 1845
Grand River, Section 28, T1N R2W, Ingham County, Laws 1843
Looking Glass River, Section 8, T5N R3W, Clinton County, Laws 1837-38
Red Cedar River, Section 25, T4N R1W, Ingham County, Laws 1842
Thornapple River, Section 15, T4N R10W, Barry County, Laws 1837

Designated County Drains

There are over 4,400 designated county drains that make up over 5,100 miles of stream channel within the Grand River watershed. These values are estimates as a complete inventory of all designated drains is not available (Table 24). Additionally, the number and makeup of drains maintained by cities and villages throughout the watershed is unknown. Streams that are designated drains are under the authority of the Michigan Drain Code, Act 40 of the Public Acts of 1956, as amended, which is administered by an elected Drain Commissioner in each county. Among other authorities, the Drain Code grants the commissioner the authority to designate and maintain county drains. Maintenance activities include cleaning, dredging, straightening, widening, and enclosing. Many of these activities destroy instream habitats and result in impaired biological communities. Drains which were established before 1972 are largely exempt from the provisions of Part 303, Inland Lakes and Streams and Part 303, Wetland Protection, of the Michigan Natural Resources and Environmental Protection Act 451 PA 1994.

Michigan drain commissioners are also responsible for maintenance and operation of many lake-level control structures, particularly those established by the Inland Lake Level Act (PA 146 of 1961). Methods of operation are at the discretion of each Drain Commissioner. This can be a problem when riparian owners petition the Drain Commissioner to maintain unnatural lake levels. For example, it is common for riparian owners to want high water levels maintained during summer months for recreational boating and to maintain low water levels during winter and spring to prevent ice damage and flooding. Maintaining high water levels in summer can reduce or eliminate flow to an outlet, and low water levels in spring may prevent fish access to wetlands for spawning (see **Dams and Barriers**).

Parks and Natural Areas

There are numerous public conservation and recreational lands in the Grand River watershed. The MDNR is responsible for the maintenance of 28 state game areas, five state parks, four state recreation areas and one wildlife research area within the watershed (see **Recreational Uses**) (Table 25, Figure 63). Federal land holdings include the Schlee Waterfowl Production Area (WPA) near Jackson, the Edger WPA near Hastings, and approximately 1,700 acres of the Manistee National Forest in Muskegon and Newaygo Counties. There are also over 700 county and local parks, many of which provide public access to lakes or streams that would not otherwise have any access.

In addition to these public lands, several conservation groups (e.g., the Nature Conservancy, Audobon Society, Southwest Michigan Land Conservancy, etc.) have established natural areas or protected sensitive land though conservation easements. Some of these lands are quite large and are devoted to environmental education, while other, smaller tracts have been enrolled in conservation programs to restrict future development. Several of these properties are located on lakes and streams providing buffer zones between the water and adjacent developed areas. From a land and water management perspective, it should be a high priority to maintain and promote more natural riparian areas in the Grand River system.

Natural Rivers

Michigan's Natural Rivers Program was initiated in December, 1970 following passage of the Natural River Act, Part 305 of P.A. 451 of 1994 by the Michigan Legislature. This act authorizes the Department of Natural Resources, Fisheries Division, to develop a system of Natural Rivers in the interest of the people of the state and future generations. The purpose of such designation is to preserve and enhance a river's values for a variety of reasons, including; aesthetics, free-flowing condition, recreation, boating, history, water conservation, floodplain, and fisheries and wildlife habitat.

In the Grand River watershed, the Rogue and Flat rivers are designated Natural Rivers. Both are classified as country-scenic, denoting a river in an agricultural setting with narrow bands of woods or pastoral borders (MDNR 1973, 1979).

The Rogue River Natural River District is comprised of the following areas (Figure 64):

(a) Mainstem of the Rogue River from 20 Mile Road, section 14, T10N, R12W, in Kent County downstream to the confluence with the Grand River.
(b) Barkley Creek from its headwaters downstream to the Rogue River.
(c) Cedar Creek from its headwaters downstream to the Rogue River.
(d) Duke Creek from its headwaters downstream to the Rogue River.
(e) Rum Creek from its headwaters downstream to the Rogue River.
(f) Shaw Creek from its headwaters downstream to the Rogue River.
(g) Spring Creek from its headwaters downstream to the Rogue River.
(h) Stegman Creek from its headwaters downstream to the Rogue River.
(i) The lands lying within 300 feet of the edge of the waters listed in subdivisions (a) through (h).

Zoning and development restrictions in the Rogue River Natural River District require that new single family homes and associated buildings must be built on lots not less than 200 front-feet wide. On the Rogue River mainstem, the setback from the river is 150 feet from the river's edge, and on the tributaries the setback is 100 feet. New structures also must be set back 50 feet or more from the top of a bluff on both the mainstem and tributaries and no new structures can be located on land that is subject to flooding.

The boundaries of the Flat River Natural River District contain the following areas (Figure 65):

(a) Mainstem of the Flat River from the Montcalm/Ionia County line to the northern limits of the city of Lowell, excluding those portions which flow through the incorporated city limits of Belding.
(b) Dickerson Creek from the Montcalm/Ionia County line to its confluence with the Flat River.
(c) Wabasis Creek from Mills Avenue, Oakfield Township, to the Kent/Montcalm County line.
(d) Coopers Creek from Lincoln Lake Avenue, Spencer Township, to the Kent/Montcalm County line.
(e) Clear Creek from Lincoln Lake Avenue, Spencer Township, to the Kent/Montcalm County line.
(f) The lands lying within 300 feet of the river's edge which are listed in subdivisions (a) through (e).

Zoning rules in the Flat River Natural River District require new construction to be set back a minimum of 100 feet from the ordinary high-water mark or 25 feet from the 100-year floodplain, whichever is greater. In addition, new structures shall not be set back less than 50 feet from the top of a bluff, not less than 15 feet from side lot lines and not less that 25 feet from the right-of-way of a public road. New structures cannot be located on land that is subject to flooding.

Clean Water Act

The Clean Water Act is a 1977 amendment to the Federal Water Pollution Control Act of 1972. It sets the basic structure for regulating discharges of pollutants to waters of the United States. Section 404(b)(1) of this act gives the federal government authority to regulate discharges of dredged or fill materials. The State of Michigan administers Section 404 regulations for the federal government in Michigan using the Michigan Natural Resources and Environmental Code, Public Act 451, Parts 31, 301, and 303, 1994. Any dredging or filling of material within a floodplain or associated wetland within the Grand River watershed requires a permit from the Department of Environmental Quality.

In addition, the federal government retains authority to regulate dredge and fill activities under Section 10 of the Federal Rivers and Harbors Law and is administered by the U.S. Army Corps of Engineers. Section 10 regulation in the Grand River watershed includes the following areas:

- Grand River to Fulton Street bridge in Grand Rapids and all bayous in Ottawa County contiguous to the Grand River
- Crockery Creek up to I-96; T8N, R15W, Sec 23 (Ottawa Co.)
- Spring Lake to Airline Rd; T9N, R16W, Sec 36 and all contiguous bayous
- Norris Creek to upstream of Fruitport Road/Bridge Street; T9N, R16W, Sec 36

Coastal Zone Management

The Coastal Zone Management Program is administered by the Department of Environmental Quality. The Coastal Zone Management Act (CZMA), originally passed in 1972, enables coastal states, including Great Lakes states, to develop a coastal management program to improve protection of sensitive shoreline resources, to identify coastal areas appropriate for development, to designate areas hazardous to development and to improve public access to the coastline. The Coastal Zone

Management Program provides grants to local units of government and administers coastal related sections of the Natural Resource and Environmental Protection Act, 1994 PA 451 (MDEQ 2005a). The coastal zone designation for the Grand River watershed includes the Grand River, Spring Lake and Grand River bayous upstream to Robinson Township, a distance of approximately nine miles.

Critical Dunes

Critical Dune areas represent the tallest and most spectacular dunes extending along Lake Michigan's and Lake Superior's shoreline and comprise approximately 70,000 acres. These dunes are considered to be a unique, irreplaceable, and fragile resource that provides significant recreational, economic, scientific, geological, scenic, botanical, educational, agricultural, and ecological benefits to the people of Michigan. They are protected under Part 353 of NREPA PA 451 of 1994 as administered by the MDEQ. Any earthmoving, vegetation removal or construction activities with a critical dune area are regulated through a permit program (MDEQ 2005b).

Within the Grand River watershed, the critical dunes are located in Grand Haven and Spring Lake townships to the north and south of the river mouth.

Federal Energy Regulatory Commission

The Federal Energy Regulatory Commission (FERC) is authorized under the Federal Power Act of 1920, as amended, to license and regulate hydroelectric facilities that meet one or more of the following criteria pursuant to Section 23 (b) (1) of the Act: 1) the project is located on a navigable water of the United States; 2) the project occupies lands of the United States; 3) the project utilizes surplus water or water power from a government dam; or 4) the project is located on a body of water over which Congress has Commerce Clause jurisdiction, project construction occurred on or after August 26, 1935, and the project affects the interests of interstate or foreign commerce. Presently when a project is being licensed or relicensed, power and non-power aspects of a project are balanced by FERC, and the resulting license issued for the project contains specific articles to protect natural resources in the project area. Licenses are administered and enforced by FERC with MDNR Fisheries Division having a consultation role in both the licensing and enforcement proceedings (O'Neal 1997).

Tribal

There are portions of the Grand River located within the 1836 Treaty-ceded territory described by the 1836 Treaty of Washington (Figure 66). In 2007 the State of Michigan, United States government and five Michigan Indian tribes reached joint agreement which outlines and describes the extent of hunting, fishing, and gathering rights in this Treaty area. Harvest of natural resources within these boundaries is subject to the provisions and agreements contained in the 2007 Inland Consent Decree (United States *v* State of Michigan 2007).

Biological Communities

Original Fish Communities

There is a lack of information on the fish communities in the Grand River watershed prior to European settlement. Based on evidence collected from archaeological sites and historical accounts from early settlers, it is evident that lake sturgeon was an important resource to residents from the Woodland period until the 1850s.

Lake sturgeon remains are common artifacts at many archaeological sites in the valleys of the Grand, Kalamazoo, and St. Joseph rivers where they migrated upstream to riffles for spawning. Such large congregations of fish in relatively shallow water allowed them to easily be speared from shore or canoe (Martin and Brashler 2002). Harvesting of lake sturgeon has been attributed as the main reason for choosing a habitation site during the Middle Woodland period (Martin and Brashler 2002). The main food of early pioneers in the Grandville area was sturgeon, then plentiful in the river (Kent County Library Staff 1975).

Mrs. Henry Leonard, an early settler in Lyons, described how the Native Americans would form a line with their canoes across the river and advance, shouting and splashing water, to drive lake sturgeon into shallow water before spearing them. The fish were salted and smoked and then stored for winter food (Leonard 1965).

Early settlers in Ionia during a long winter lived on "corn cake and maple sugar, with a piece of smoked sturgeon, or a venison steak occasionally" (Everett 1878). Lake sturgeon were so plentiful in Stony Creek that an early settler was overheard having an imaginary conversation with his family back home remarking, "Oh, if you old folks could only know how we're living out here in Michigan (Schenck 1881).

"…the dam across the river was an obstacle to the upward passage of fish, which they had never before met. Consequently there was in this spring an unprecedented catch upon the rapids, of sturgeon, pickerel, bass, suckers, and other members of the finny tribe, to the great sport and profit of fishermen, with spears and nets" (Baxter 1891). This early documentation of a barrier to the spawning run, combined with the extensive harvest of spawning adults points to the probable causes of the decline in lake sturgeon populations in the Grand River basin.

Historical accounts also mention early settlers gathered fish from the river as a popular food source, but these references are usually limited to a few species:

"The river was fairly alive with fish, and the men caught large numbers of them. It was nothing unusual for a man to take his spear, step to the river bank, and spear a good sized bass or pickerel for his meal" (DeLand 1903).

". . .every fall father made an outing with others to Battle Point down the river and put up barrels of black bass in salt…"(Belknap 1922). Battle Point is located approximately eight miles upstream of the Lake Michigan confluence.

"While the big lakes furnished whitefish, trout, muskellunge, and even sturgeon, the settler depended most on what was near at hand. That meant black bass, sucker, and pike from the small lakes with sunfish and other small fry from the rivers and streams" (Davenport 1950).

Factors Affecting Fish Communities

The landscape of Grand River watershed changed dramatically during European settlement. These changes resulted in alterations to the physical character of the river and its tributaries and affected the composition and productivity of the fish community. Effects of point and nonpoint source pollutants, dams, agriculture and urban development, and non-native species introductions are discussed in greater depth in **Geology**, **Hydrology**, **Channel Morphology**, **Dams and Barriers, Soils and Land Use**, and **Water Quality.** The cumulative effects of these human activities have produced present day fish communities and fish distributions.

Stream fish often require different habitats for spawning, feeding, and refuge and must be able to migrate between these habitats to complete their lifecycles (Schlosser 1991). Human activities that alter spawning, feeding, or refuge habitat or that limit access to these critical habitats can negatively affect fish communities by disrupting a portion or all of a species lifecycle. In some instances these actions can result in the isolation or extirpation of a species (see **Biological Communites**, *Present Fish Communities*).

The original fish habitat was greatly altered by European settlers and their activities. Presettlement vegetation along the banks originally provided shading and bank stabilization. This vegetation consisted largely of stands of beech, sugar maple, mixed oak, and coniferous swamp forests (Comer 1996). Downed trees and logs in the presettlement era provided an abundance of fish habitat both directly and by creating undercut banks. In some portions of the mainstem, large wood accounted for much of the historical instream fish habitat, with as many as 20 large logjams per river mile (Sedell and Beschta 1991). Some of the earliest alterations to the river included the removal of large amounts of “floodwood” to open the river to unimpeded navigation. These logjam removals resulted in the loss of instream habitat both directly and through channel destabilization and sedimentation.

The logging era denuded much of the landscape, and most of the major tributaries and the main stem Grand River were used to transport logs which had major negative affects for the fish community. With the logging came removal of bank vegetation and habitat, destabilization of stream channels and banks, channel scouring from log drives, and the construction of dams and mills. These landscape scale changes resulted in mass soil erosion, increased sedimentation, and changes in stream temperatures. Due to lack of vegetative cover, flashiness of flow became more common. Negative effects on fish communities resulted from loss of critical habitat and reduced water quality.

Following the logging era, further changes to the landscape included clearing of land for agricultural development. Significant losses of functional wetlands through draining and filling reduced the storage capacity of the watershed resulting in altered stream flow patterns and increased flashiness in the river system. Altered flow regimes resulted in warmer and more variable water temperatures favoring more tolerant species. Channelization (dredging) reduced habitat diversity by removing instream cover and eliminating natural glide-riffle-run-pool sequencing and meanders of streams. The erosion that resulted from poor conservation practices and altered flows also buried gravel, cobble, and rock substrates, further reducing the biological productivity of the river.

Development of large population centers in the watershed has also negatively affected fish communities. Roads, impermeable surfaces, and storm sewer systems speed delivery of water to stream channels resulting in higher peak flows, warmer temperatures, and increased pollutant loads. Prior to the passage of the Clean Water Act, the Grand River was viewed as a convenient conveyance for municipal and industrial wastewater discharges. In 1970, a comprehensive study of the Grand River documented degraded fish and aquatic macroinvertebrate communities as a result of poor water quality (MDNR 1970). Species abundance and diversity were severely limited, and aquatic species known to be intolerant to pollution were eliminated from portions of the river. Prior to the upgrading of municipal wastewater treatment plants, fish kills resulting from low dissolved oxygen concentrations were common in areas downstream of the large urban areas. By 1978, water quality began to improve but was still lower downstream of the main metropolitan areas of Jackson, Lansing, and Grand Rapids. In 1978, it was noted that common carp were present throughout the river but were present in higher numbers below the major metropolitan areas (Nelson and Smith 1981). Discharges of untreated or partially treated sewage, toxicants, and bioaccumulative compounds have been largely controlled but continue to reduce the productivity of the biological community. Degraded habitat conditions in the large urban areas tend to favor more tolerant, less desirable fish and macroinvertebrate communities.

Dam construction has long term effects on the distribution and composition of the fish community. Unlike pollutant loadings that can be controlled through end-of-pipe treatment or implementation of

BMPs, the negative effects of dams on fish communities are typically not addressed until the structure reaches the end of its design life. These structures alter the natural flow of water and sediment, fragment the continuity of a river, isolate fish populations, block fish movements, inundate higher gradient habitats, alter thermal regimes, and degrade water quality (see **Dams and Barriers)**. These changes are responsible for reduced fish biodiversity. As a result of dam construction, fish movement from the mainstem into the Rogue, Thornapple, and Flat rivers has been largely eliminated (Figure 67). Similar to dams, improperly designed road crossings can act as barriers to the movement of fish. These crossings can eliminate access to critical habitats necessary for spawning, feeding, or refuge from harsh conditions (see **Soils and Land Use**, *Bridges, Culvert, and Stream Crossings*).

Long term hydrologic alterations affect fish and fish habitats. Intra-annual variation in hydrologic conditions is essential to the successful life-cycle completion for many aquatic and riparian species (Poff and Ward 1989; Richter et al. 1996, 1997). Seasonal high flows serve as an environmental cue to many species of fish, triggering movements to upstream spawning areas. During periods of high flow, riparian wetlands become flooded and provide nursery habitats for fish and other aquatic organisms. Changes in the timing or magnitude of these flows can reduce or eliminate access to these important habitats. Dams, channelization, levy construction, and water withdrawals can alter natural flow regimes and modify the distribution and availability of riverine habitat conditions, with adverse consequences for fish and other aquatic biota (Poff et al. 1997; Poff and Zimmerman 2010).

Several non-indigenous species have been intentionally or accidently introduced into the Grand River watershed and have also greatly affected fish communities. Introduced species influence the native fish community directly through competition or predation, or indirectly through habitat alterations (e.g., common carp). Inadvertent introductions result from discharge of ballast water, shipping canals, bait bucket releases, and unauthorized stockings. Many times introduced or colonized species tend to out-compete and displace native fish species (see also Aquatic Nuisance Species).

Present Fish Communities

Fish diversity and distributions are largely dictated by catchment size, thermal regime, hydrologic stability, and current velocity (Zorn et al. 2008; Zorn et al. 2009). Knowledge of species attributes and local fish communities is necessary for proper management of the resource. This information can guide managers in assessing the quality of the resource and making informed decisions regarding stocking or recommendations for rules governing harvest. Knowledge of species distribution is also necessary for the development of statewide and regional planning documents such as the Wildlife Action Plans and Southern Lower Peninsula Ecoregion Plan.

One hundred eight fish species representing twenty three families are currently known in the Grand River watershed (Table 26). The list includes 13 taxa that were introduced by direct and indirect human activities. Maps of current fish distributions (Appendix 1) were prepared based on previous collections by the MDNR Fisheries Division, the MDEQ Water Bureau, historical collections cataloged at the University of Michigan Museum of Zoology, and literature (Bailey et al 2004; Hubbs, Lagler, and Smith 2004; Latta 2005). Supplemental information was collected by MDNR Fisheries Division during several mainstem fish surveys from 2004-2006. Several species inhabiting Lake Michigan utilize the Grand River mainstem or its tributaries on a seasonal basis; these species were included to document this portion of their range. Many species can be found throughout the entire watershed, while others have patchy distributions. The pugnose shiner is an endangered species in Michigan, and the lake sturgeon, cisco, and river redhorse are currently listed as threatened (MDNR 2009). Several other species have been identified in the Michigan Wildlife Action Plan as Species of Greatest Conservation Need (SGCN) suggesting the need for more comprehensive monitoring of native fish populations (Eagle et al. 2005; Table 26). Fish communities are characterized more extensively within the following mainstem segments.

Headwaters

Fish community samples were collected on the mainstem and Portage River by the MDEQ Water Bureau in 1996 (Goodwin 2000). The mainstem was sampled at two locations upstream of Jackson. The stream channel was characterized as low gradient with moderate sedimentation. The survey reported the collection of 25 fish species. The collection included several centrarchid species including smallmouth bass and largemouth bass. Several intolerant species including redhorse and darters were noted in the collection. The collection also included greenside darter, a species not previously reported at this location.

The Portage River is the largest tributary in this segment. The river has been historically channelized through wetland areas and is overly, wide resulting in pool type habitat with deep accumulations of organic sediments. Violations of water quality standards in the Portage River required the development of a TMDL for dissolved oxygen (Sunday 2002). During the 1996 surveys 18 species were collected, with bluegill and pumpkinseed sunfish being the most abundant. Intolerant species were absent from the sample (Kosek 1997).

Upper

Through much of this segment, the river is low gradient with a wide, forested floodplain. Large woody material, overhanging vegetation, and deep runs are common, with submerged vegetation and pools being less common. Thirty seven fish species were reported from boomshocking surveys conducted near Eaton Rapids, Dimondale, and the Moores Impoundment during 2004 (MDNR, FD, unpublished data). The fish community is predominately warmwater although some species classified as warm-transition species are present (Lyons et al. 2009). Centrachid, cyprinid, and castostomid species are well represented in this segment of the river. Northern pike, walleye, and channel catfish were the game fishes present at most of the seven survey locations. These surveys documented the presence of greenside darter, the first report of this species in this segment. Species of Greatest Conservation Need (SGCN) collected included golden redhorse and striped shiner. Redear sunfish were collected at two locations near Eaton Rapids. This species is introduced and likely colonized this portion of the mainstem after being stocked in upstream lakes. The weed shiner is an extirpated minnow species that once occurred in the upper mainstem segment. The last report for this species in this area was 1941.

Sandstone Creek and Spring Brook are the largest tributaries in the upper segment. Sandstone Creek was surveyed at three locations by the MDEQ Water Bureau in 1996 (Rockafellow 2003f). These fish collections recorded 24 species with cyprinids composing most of the catch. The lower reach of Sandstone Creek is impounded at Minard Mill. The influence of the impoundment was indicated by the increase diversity of sunfishes immediately below the dam. Fantail darter (SGCN) was also reported in the collections.

Spring Brook was surveyed in 1984 and in one location in 2001 (MDNR unpublished data). The headwater portions of Spring Brook are in a flat wetland plateau and have been historically dredged resulting in limited habitat. Species composition in this reach is limited to brook stickleback, central mudminnow, and johnny darters. In the downstream reaches, gradient increases and substrates become coarser. The fish community in these reaches is more diverse and contains smallmouth bass, rock bass, northern pike, and several darter and minnow species.

Middle

The middle mainstem segment gains in size with the addition of two large tributaries, the Red Cedar and Looking Glass rivers. Habitat in this segment alternates between free flowing and impounded reaches as the river is blocked by six mainstem dams. The streambed substrates in this segment range from coarse sands and gravel to localized bedrock near the City of Grand Ledge. Beds of aquatic vegetation are more prominent in this reach as the channel widens and becomes less shaded. The thermal classification of the mainstem and tributaries in this segment is warm (Zorn et al. 2008). Thirty-nine fish species were collected with a boomshocker from six mainstem locations during 2005. Cyprinids, castostomids, and centrarchids accounted for the highest species diversity and abundance. Several species associated with larger water were collected at the lower reaches of the segment including silver redhorse, quillback, and flathead catfish. These species have not been reported from the mainstem at locations above the Webber Dam. Species diversity and abundance were lowest in the Lansing area. The fish community was sampled between the North Lansing and Moores Impoundment Dams, a stream reach with known water quality impairments (Table 15). Diversity and abundance were highest in the free-flowing portions of the river downstream of the Portland and former Wagar dams. The middle segment represents the upper bounds for migration of Chinook salmon, coho salmon, and steelhead. Based on fall monitoring of salmon passage, averages of 2,500-3,500 coho salmon ascend the mainstem past Webber dam (Dexter 2002; Taylor and Wesley 2009). Many of these fish continue their migrations up Carrier Creek and the Red Cedar and Looking Glass rivers.

The fish community in the Red Cedar River is relatively diverse and contains a mix of warm and warm-transition species (MDNR 1992; Zorn et al. 2008; Lyons et al. 2009). Common centrarchids include rock bass, green sunfish, bluegill, largemouth bass and smallmouth bass. Collections reported for the lower reaches include five sucker species, eight species of cyprinids, and four species of darters. Coho salmon and steelhead are present on a seasonal basis.

Twenty six species of fish were reported during recent surveys of the Looking Glass River (MDNR-FD unpublished data). The collection was dominated by rock bass, green sunfish, common shiner, and bluntnose minnow. The remaining nine minnow species accounted for approximately thirty percent of the catch. Five Species of Greatest Conservation Need, black redhorse, grass pickerel, river chub, pirate perch, and stonecat, were reported from this location. The survey also reported an isolated population of flathead catfish.

Lower

The lower mainstem segment is a large warm river and includes drainage from the Maple River, Prairie Creek, Flat River, Thornapple River, and Rogue River. In addition to these larger tributaries, several smaller cold, cold-transitional, and warm-transitional tributaries discharge to the mainstem providing a variety of thermal microhabitats. Channel form is diverse, ranging from relatively shallow riffles and runs to deep pools. In some portions, the channel is constrained in a valley and in other locations the channel meanders through a wide floodplain. The river in this segment supports a diverse fish community (MDNR-FD unpublished data). Catostomid diversity is very high with 11 of the 15 Michigan species present. Surveys conducted during 2005-2007 documented the presence of the State-threatened river redhorse throughout the entire segment. Sunfish and minnow assemblages are also diverse with nine and 16 species, respectively. This portion of the river supports good populations of channel catfish, flathead catfish, largemouth bass, smallmouth bass, and walleye. Other species of interest found in this segment include: black buffalo, black redhorse, golden redhorse, spotted sucker, river chub, striped shiner, and grass pickerel, all of which are identified as SGCN (Eagle et al. 2005). The influence of Lake Michigan on the composition of the fish community is seasonally apparent as potamodromous species including lake whitefish, round whitefish, lake trout, longnose sucker, lake sturgeon, brown trout, steelhead, Chinook salmon, coho salmon, and sea lamprey ascend the river. With the exception of the salmon and steelhead, upstream movement of these species is blocked by the Sixth Street dam. In the days of early settlement, the lake sturgeon was common in the lower and mouth segments. Due to over fishing and habitat fragmentation the species is now on the list of threatened species in Michigan. Recent surveys targeting this species reported a remnant but stable population in the river below the Sixth Street Dam (K. Smith, MDNR Fisheries Division, personal communication).

The Maple River was part of a large glacial river that drained Lake Saginaw to Lake Chicago (see **Geology**). The river is low gradient and has an especially low base flow yield. The Maple River is known for its unique fish population that includes flathead catfish, channel catfish, white crappie, black crappie, northern pike, largemouth bass, smallmouth bass, rock bass, and walleye. The river is open to migratory fish species capable of navigating the fishway at the Sixth Street dam. Quillback, Chinook salmon, coho salmon, and steelhead have been reported in the watershed. Species with limited distribution in the Grand River watershed are recorded from this drainage including redfin shiner, brassy minnow (SGCN), river redhorse (threatened), stonecat (SGCN), tadpole madtom (SGCN), pirate perch (SGCN), and least darter (SGCN),

Major tributaries to the Maple River are Stony Creek and Fish Creek. Stony Creek was most recently surveyed in 2003. Although habitat is limited as a result extensive channelization, it does have a fairly diverse fish population with smallmouth bass being the primary game fish. Fish Creek is a cold-transitional stream in its headwaters and supports self-sustaining populations of brook trout and brown trout. Further downstream, it becomes a warm-transitional stream as it receives inputs from several small, warm tributaries. The fishery in this portion of the stream is maintained with annual stockings of brown trout (see **Fisheries Management**).

The Flat River originates in southern Mecosta and northern Montcalm Counties. It gained its name from the Native American word Kau-bau-gwas-shee, flat like a belt of wampum (Augustine 1971). The Flat River supports a diverse warmwater fish community with several species of cyprinids, centrarchids, and percids (Hanshue 2002a). Sucker diversity in the Flat River is reduced, likely a result of the dam at the mouth which blocks migrations. It is best known for its smallmouth bass fishery. Some of its tributaries, like Dickerson and Wabasis creeks, also support trout populations.

Spring Brook is a coldwater tributary that flows into the mainstem near the City of Lowell. This stream was historically managed for trout and was stocked with brook trout from 1938 through 1951. Recent fisheries surveys report Spring Brook contains a naturalized population of brook trout and is utilized to some extent by spawning steelhead. Other species present in this tributary include mottled sculpin and creek chub.

Similar to the Flat River, the Thornapple River contains a diversity of warmwater fish species (MDNR-FD unpublished data; Hanshue 2002c). The headwaters of the Thornapple River drain primarily agricultural lands in Eaton County. The channel in this location is characterized as low gradient and quality riffle/run habitats are limited. As the river begins to cut through glacial moraines, gradient increases and coarser substrates (gravel, cobble) become more prevalent. The river supports good populations of smallmouth bass, northern pike, walleye, and various panfish species. Habitats in the lower segment are highly fragmented by five dams. An isolated population of the threatened river redhorse was recently reported in the river reach near the Cascade and Ada dams (MDNR-Fisheries Division, unpublished data). Several tributaries to the Thornapple River are classified as cold- or cold-transitional streams and are managed for brown trout fisheries.

The Rogue River is a medium-sized system that changes from a warm-transitional to cold-transitional as localized groundwater inputs increase. The Rogue River supports a popular stocked brown trout and rainbow trout fishery above the dam at Rockford. Downstream of the dam the river is known as a good steelhead fishery. Several of its tributaries, including Duke, Cedar, Stegman, Shaw, and Rum creeks have self-sustaining brook trout and brown trout populations.

Several tributaries join the mainstem in the vicinity of Grand Rapids. Honey, Egypt, Bear, Scott, Sunny, Mill, and Strawberry creeks are relatively small cold- and cold-transitional streams that were historically stocked. These streams currently support small self-sustaining populations of brown trout. York Creek was stocked with brook trout during 1933-1941 and once supported a popular fishery. In the past 20 years the stream has changed dramatically. In the mid-1980s land use was a mix of agricultural and low density residential. A large golf course was located in the central portion of the watershed. Since that time, the golf course was sold and developed into retail stores and housing complexes. The conversion of permeable soils to imperious surfaces, and rapid routing of storm water to the creek resulted in unstable hydrology and channel morphology. As the habitat quality lessened, the brook trout population declined. Brook trout were last reported in York Creek in 1991.

Limited historical information is available for Plaster Creek. It has long been an urbanized watershed with severe flooding and storm water control problems. The available information indicates the creek contains a warmwater fish community (e.g., bluegill, green sunfish, rock bass, black bullhead, and various minnow species).

Buck Creek begins as a cold-transitional stream and changes to a warm-transitional stream in the lower half of the watershed. The stream flows through an urban environment and is the receiving water for relatively large amounts of storm water runoff. Water temperature data for this stream is limited and indicates that mean temperatures are at the upper thermal limits for supporting trout populations. The stream is stocked annually with brown trout. Other fish species reported in the watershed include black crappie, bluegill, green sunfish, largemouth bass, and yellow perch.

Sand Creek has a predominately agricultural watershed with some residential land use in the lower section. A few brown trout were stocked in the early 1970s, but it does not have an extensive management history.

Mouth

The fish community composition of the mouth segment reflects the large channel size and open connection to Lake Michigan. Largemouth bass, bluegill, freshwater drum, gizzard shad, and several species of redhorse suckers and minnows are common. Several Lake Michigan species enter the lower river on a seasonal basis. Recent observations indicate that lake sturgeon are successfully spawning in the mouth segment (K. Smith, MDNR Fisheries Division, personal communication). The shallow habitats in the braided section of the channel provide nursery habitat for juvenile lake sturgeon and other fish species.

Crockery Creek originates in Newaygo County and flows in a southerly direction to join the Grand River mainstem west of the Bass River. Crockery Creek and some of its tributaries are cold-transitional streams and are stocked with brown trout and steelhead (see **Fishery Management**).

Aquatic Invertebrates

Invertebrates are an important and diverse component of lakes and streams. Organisms in this grouping include sponges, moss animals, worms, arthropods (scuds, sowbugs, spiders, and crayfish), insects (mayflies, stoneflies, caddisflies, dragonflies, beetles, etc.) and mollusks (snails. clams, and mussels). They are an important food source for fish and other animals including birds, mammals, reptiles, and amphibians. Although invertebrates play a significant role in the ecology of river systems, as a group their value is largely overlooked by the public. The general public tends to view most invertebrates with aversion and avoidance (Kellert 1993). Recent national assessments on the conservation status of invertebrates have revealed some alarming trends (Master et al. 2000). These assessments noted a disproportionate number of aquatic organisms in need of conservation attention when compared to those of the terrestrial environment. This is especially true of freshwater mussels (Williams et al. 1993; Strayer 2008) and crayfishes (Taylor et al. 1996, 2007). These assessments have increased awareness regarding the plight of these imperiled groups. More ambitious educational programs are needed to enhance public recognition of the positive values of these organisms.

Invertebrates are less mobile than fish and are often used to assess water and habitat quality (Statzner and Higler 1986; Loeb and Spacie 1994; Hauer and Lamberti 1996; Rosenburg and Resh 1996). For example, most mayfly, caddisfly, and stonefly species are sensitive to degraded water quality and therefore are excellent indicator organisms. Several surveys of aquatic invertebrates have been conducted on major tributaries within the Grand River basin. Aquatic biologists with the MDEQ, Water Resources Division inventory invertebrates as part of the State of Michigan water quality surveillance program. Beginning in 1991, the Water Bureau implemented qualitative multi-metric bioassessment protocols (Procedure No. 51 MDEQ 1990) to evaluate the relative biological integrity of wadeable streams throughout the State of Michigan (see **Water Quality)**. The underlying premise is that better stream quality is normally indicated by greater macroinvertebrate diversity and a greater abundance of pollution-sensitive organisms (e.g., mayfly, stonefly, caddisfly). Conversely, streams with degraded water quality or limited habitat would support overall lower diversity and an abundance of pollution-tolerant organisms (isopods, leeches, surface dependent taxa) would indicate persistent, degraded stream quality (Lenat and Barbour 1994; Davies and Jackson 2006). These data were compiled for the mainstem and select tributaries by valley segment (Tables 27-31). Because these bioassessment protocols were developed for wadeable streams, information regarding the distribution of aquatic insects is limited for the Grand River mainstem in the lower and mouth valley segments.

Freshwater Mussels

Freshwater mussels are an important component of the biodiversity of Michigan's aquatic ecosystems. They have a unique ecological role in both rivers and lakes and are valuable indicators of ecosystem integrity. The diversity and distribution of freshwater mussels in Michigan were greatly influenced by the connection of southern Michigan waters to the headwaters of the Mississippi River during glacial recession. As a result of this connection, the majority of the species present in the state are found in the southern half of the Lower Peninsula or below the Saginaw-Grand Valley region (van der Schalie 1941). A total of 45 species have been reported in Michigan lakes and rivers, with 32 of them present in the Grand River watershed (van der Schalie 1941 and 1948; Goforth et al. 2000; Badra and Goforth 2002).

Mussels are of significant value to the health of aquatic ecosystems. They are a food source for some fish (e.g., river redhorse) and terrestrial predators (e.g., muskrat, raccoon, river otter) and often comprise a significant amount of the total biomass of all benthic invertebrates (Strayer et al. 1994, Strayer 2008). The spent shells also serve as physical habitat and are often colonized by a variety of aquatic insects and other macroinvertebrates. Since they are important filter feeders, they may play an important role in nutrient uptake and increasing water clarity. Freshwater mussels are comparatively sensitive to declines in habitat and water quality. Because mussels are generally long-lived, are relatively immobile, and are reliant on fish host for both reproduction and dispersal, their community status can provide an integrative view of physical, chemical, and biological changes in the watershed (Grabarkiewicz and Davis 2008).

In North America, freshwater mussels have been identified as the most imperiled of any major group of animals (Williams et al. 1993; Master et al. 2000; Strayer 2008). Of the 45 mussel species found in Michigan, 19 (42%) are listed as either endangered or threatened pursuant to Part 365, Endangered and Threatened Species, of NREPA (1994 PA 451) (MDNR 2009). An additional eight species are in decline and are identified as Species of Special Concern (http://web4.msue.msu.edu/Mnfi/). The primary reasons for decline of unionid mussels include habitat loss as a result of dam and road construction, stream channelization, water quality degradation, siltation, alterations to natural streamflow, over harvest, and the introduction of non-indigenous species such as zebra mussels (Williams et al. 1993; Watters 2000; Strayer 2008). In some instances these human actions can result in immediate population reductions (e.g., poaching, discharge of a toxicant), whereas other anthropogenic impacts may take decades to be fully expressed. For example, dam construction and operation may limit mussel reproduction by blocking necessary host-fish species or may suppress reproduction as a consequence of discharging cold-hypolimnetic waters. Because mussels are long-lived, the loss of recruitment as a result of the dam may not be manifested as a localized extirpation for decades.

Humans have long utilized the vast mussel beds in the Grand River valley. Native Americans utilized the meat of mussels for food and the shells as spoons, hoes, and scraping tools (Griffin et al. 1970; Martin 1993). In the early part of the 20th century, mussels were harvested from the Grand River for the production of buttons (see **History)**.

In 1922, a report by the U.S. Bureau of Fisheries listed 4,825,170 pounds of shell were taken from Michigan streams with a value of $196,026, but by 1935, the then Conservation Department reported that 479,952 pounds of shell were taken with an estimated value of $8,942 (van der Schalie 1938). Grand River mussel populations had declined so dramatically by the late 1930s that the Michigan Conservation Commission declared a closed period of five years beginning January 1, 1944 with the hope that mussel populations would rebound (van der Schalie 1948). In 1945, a survey of the Grand River was conducted to determine if mussel populations had recovered from over-harvest. A total of 17 species were found, seven fewer than had been reported by earlier surveys (Coker et al. 1921). Although fewer species were collected, it was apparent that some of the mussel populations had seen some significant recovery (van der Schalie 1948). Near the end of the 1940s the demand for mussel shells declined due to the increased use of plastics to manufacture buttons. The river was never re-opened for commercial harvest.

Interest in freshwater mussel shells remained virtually nonexistent for the next few decades until the rise of the cultured pearl industry. Cultured pearls begin as beads or seed pearls made from thick-shelled mussel species such as the three-ridge and mapleleaf which are inserted into oysters. The oysters then form additional layers of shell material called nacre over the beads, resulting in cultured pearls. Commercial mussel harvest is legal in some parts of the country, and in some areas populations of commercial species have been so depleted that new harvest areas are being investigated. Michigan law prohibits the take of freshwater mussels or parts of any freshwater mussels whether living or dead (Fisheries Order 228.03; Part 487 of 1994 PA 451). In 1995, as the result of an extensive investigation, two people were arrested for poaching mussels from the Grand River for the cultured pearl industry (Badra and Goforth 2003).

Comparison of current surveys to observations made by early researchers in the late 19th and early 20th centuries shows some interesting and rather disturbing changes to mussel populations in the Grand River (Table 32). For example, the mucket is a large, thick-shelled species that was extensively harvested for pearl buttons. Coker et al. (1921) state that at Lyons, muckets comprised 80% of the collection of mussels, although the three-ridge, pocketbook, spike, and black sandshell were also quite common and could be readily collected by hand from shallow water. In 1945, the number of muckets in the Lyons area was down to less than 1% of the total catch (van der Schalie 1948). The decline in the mucket population may have been the result of unstable flows associated with dam operations (peaking) at the time of the survey (van der Schalie 1948). Unfortunately, no current surveys have been conducted in this area, but the catch of muckets in recent surveys throughout the lower segment of the Grand River was less in 1999 than in 1945 (Gorforth et al. 2000). The spike is another mussel species that has had a precipitous decline. Coker et al. (1921) and van der Schalie (1948) both listed this noncommercial species as common, yet only one live specimen was found in surveys from 1999 through 2002 (Goforth et al. 2000; Badra and Goforth 2002; Badra and Goforth 2003).

Although the relative abundance of several other species was unchanged, the decline of what were formerly abundant species raises concerns about the overall health of mussel fauna in the Grand River watershed. The spike and mucket use a variety of host fish (e.g., bluegill, black crappie, central stoneroller, flathead catfish, and smallmouth bass) that are relatively common in the watershed (Fuller and Brynildson 1985; Cummings and Watters 2004). Thus, their decline may be indicative of a decline in habitat and/or water quality. Temperature stress, particularly during the summer reproductive season when river levels are low, has been implicated in both mortality and failed reproduction of mussels (Watters and O'Dee 2000). The mucket has a lower thermal threshold than other species and has been recommended as an indicator species to monitor the health of mussel beds in the Kiamichi River in Oklahoma (Spooner et al. 2005). Temperature stress coupled with fluctuating river levels may be partially responsible for the inability of the mucket population to recover below the Lyons Dam

Given the conservation status of several species of freshwater mussels in the Grand River watershed, additional surveys to determine their distribution and abundance are needed. Further information regarding physical habitat preferences, streamflow needs, host fish relationships, and sensitivities to environmental contaminants is needed to develop a comprehensive recovery plan for these species.

Snails

Freshwater snails (gastropods) in the Great Lakes region have been studied since early in the 19th century. However, many early studies emphasized species composition and taxonomy rather than research on ecology. Freshwater snails have an important ecological role in the aquatic food web and contribute greatly in nutrient exchange processes. Primarily by controlling algae growth, they also maintain water quality and clean substrates utilized by other bottom-dwelling organisms such as aquatic insects. Freshwater snails are also an important food source for fish, turtles, and other species of wildlife. Finally, because many species are pollution-intolerant, they are excellent indicators of water quality.

Freshwater snails, like many other river species across North America, are in decline. The abundance and diversity has dramatically decreased over the past 80 years (Johnson 2009). This rapid decline is attributed to habitat degradation associated with dams and impoundments, channelization and dredging, sedimentation and channel instability, and water quality degradation. Vegetation control and dumping of wastes was cited as probable causes for a decline in snail populations as early as 1936 (Goodrich and van der Schalie 1939).

Targeted surveys for freshwater snails have not been conducted in the Grand River watershed; therefore, knowledge of diversity and distribution is limited. Species potentially present in the Grand River watershed are listed in Table 33. Freshwater snails of conservation interest that are present in the watershed include spindle lymnaea, and watercress snail (Eagle et al. 2005).

Crayfish

Crayfish represent one of the most diverse faunal groups in North America with 363 known species (Taylor 2007). The status of crayfish in North America is declining with nearly 48% of the known species listed as endangered, threatened, or vulnerable (Taylor 2007). Crayfish habitats are diverse and include rivers and streams, lakes, ponds, and wetlands. Crayfish are ecologically important omnivores consuming benthic invertebrates, algae, macrophytes, detritus, and decaying organisms. They are important food sources for a variety of fish and other aquatic and terrestrial predators. Several species of crayfish in the family Cambaridae have unique life history characteristics including the ability to burrow. Burrows are typically created in riparian wetlands and extend below the groundwater table. Crayfish burrows allow numerous species to colonize seasonally wet habitats

(Welsh and Eversole 2006). Crayfish burrows serve as hibernacula for eastern massassaga rattlesnakes and are a critical habitat component in their conservation (USFWS 2009).

Crayfish are susceptible to habitat damage caused by impoundments, stream channelization, pollution, and sedimentation. Probably the biggest threat is nonnative crayfish introduced as fishing bait. Introduced crayfish may compete with natives for shelter, hybridize with them, and destroy vegetation beds used by native crayfish and other organisms for foraging, nesting, and shelter. One introduced species in particular, the rusty crayfish, has displaced native species in many areas.

The crayfish fauna of Michigan includes seven native species and the exotic rusty crayfish (Table 34). Although native species populations are considered stable, the devil crayfish and the digger crayfish, are identified as Species of Greatest Conservation Need in the Michigan Wildlife Action Plan. These species are considered to be at elevated risk due to a lack of knowledge of their distribution and abundance. Experts suggest these species are in decline as a result of urbanization and the associated loss of wooded areas with ephemeral wetlands (Eagle et al. 2005).

Amphibians and Reptiles

Amphibians and reptiles are integral components of the watershed and inhabit a variety of aquatic habitats. They are valued consumers of a variety of plant and animal materials and are an important food source for other species including fish, mammals, and birds. Unfortunately negative attitudes toward amphibians and reptiles persist and as a group they are often feared and persecuted (Czech et al. 1998; Eagle et al. 2005).

The degradation, fragmentation, and destruction of natural habitats due to watershed development are undoubtedly the greatest threats to amphibian and reptile populations (Harding 1997). Populations have become restricted to smaller habitats making them more vulnerable to disease, mortality, and exploitation. Effects of watershed development have favored adaptable species with broad habitat tolerance.

Forty-three species of amphibians and reptiles have been found in the Grand River watershed (Table 35). Information on the distribution and abundance of amphibians and reptiles in the basin is limited (Holman 1989; Harding and Holman 1990; Harding and Holman 1992). Several species are of conservation interest.

The Grand River watershed is home to nine species of turtles. Three of these species, Blanding’s turtle, wood turtle, and eastern box turtle, are species of special concern. The spotted turtle is listed as threatened. These populations are threatened by habitat fragmentation, conversion of forest and wetland habitats to agriculture and urban land uses, and collection as pets.

Two species of frogs, Blanchard’s cricket frog and northern leopard frog, are listed as threatened and special concern, respectively. These species were once common but have declined in number over most of their range in the state. In addition, eight species of amphibians are identified as species of greatest conservation need (Table 35). These species are considered to be in decline as a result of habitat fragmentation, land use changes, altered hydrologic regime, and toxic chemicals (Eagle et al. 2005).

Sixteen species of snakes are found in the Grand River watershed, nine of which are of conservation interest (Table 35). The most imperiled is the copperbelly water snake which is state listed as endangered and federally listed as threatened. Kirkland’s snake is listed state endangered. Eastern massasauga and queen snake are identified as special concern. Eastern massasauga has also been identified as a candidate species for listing on the Federal Endangered Species List. (USFWS 2009).

An additional five species are identified as species of greatest conservation need (Eagle et al. 2005; Tables 38a and 38b).

Birds

Many birds use rivers and river corridors in the Grand River basin as nesting, feeding, and resting areas. Some species are year-long residents, and many others are migratory or occasional visitors. Birds are an integral component of the watershed's biodiversity. Many recreational birders appreciate the aesthetics of their sight and sound. Other bird species also provide hunting opportunities and table fare for humans. MDNR, Wildlife Division has successfully reintroduced wild turkeys into several areas of the basin.

As part of the Mississippi Flyway, Canada geese, many species of dabbling and diving ducks, and trumpeter and mute swans use the Grand River watershed. This area encompasses both the northern and southern ranges of Michigan warblers. Riparian floodplain forests offer critical habitat to many of these species. There are over 218 breeding and regular migrant bird species found in the watershed (Table 36). Historically, northern goshawk, short-eared owl, barn owl, common raven, black-throated blue warbler, and pine warbler also bred in the watershed but were not reported during the Michigan breeding bird survey conducted from 1983 to 1988 (Brewer et al. 1991). Endangered species found in the watershed include the king rail, prairie warbler, short-eared owl, and migratory loggerhead shrike. Threatened species include the common loon, osprey, least bittern, trumpeter swan, red-shouldered hawk, Caspian tern, common tern, long-eared owl, cerulean warbler, and Henslow's sparrow. The bald eagle and osprey are identified as species of Special Concern.

Mammals

The Grand River basin is home to a diverse assemblage of mammals. The riparian corridors of the mainstem and tributaries provide food, water, cover and travel routes for many mammalian species. Watershed development has reduced, fragmented, and degraded natural habitat, requiring mammals to adapt in order to coexistence with humans (see **Soils and Land Use).** As populations increase, management of game species (e.g., white-tail deer) is necessary to avoid conflicts with humans and maintain balanced assemblages in limited habitat.

There have been no comprehensive inventories of mammals in Grand River watershed. There are at least 50 species known to use the area and evidence of several others that have been locally extirpated (Baker 1983; Table 37). Several fur-bearing species, such as American beaver, river otter, muskrat, mink, coyote, red fox, grey fox, and raccoon are present. Popular game species include white-tailed deer, eastern cottontail, gray squirrel, and fox squirrel. Black bear are rare but have been reported with increasing frequency within the various State Game Areas throughout the watershed. The woodland vole is listed as special concern; the least shrew is threatened; and the Indiana bat is listed as endangered (Table 38b).

Other natural features of concern

The Michigan Natural Features Inventory maintains a list of endangered, threatened, or otherwise significant plant and animal species, plant communities, and other natural features (Tables 38a and 38b). Vascular plants are the most commonly listed group of threatened and endangered species in the basin. Many are wetland plants or are found in floodplains and river corridors. Significant plant communities include southern swamps, prairie fens, coastal plain marshes, tall grass prairies, bogs, Great Lakes marshes, interdunal wetlands, open dunes, submergent and emergent marshes, wet and mesic prairies, hard-wood conifer swamps, intermittent wetlands and Southern floodplain forests.

Aquatic Nuisance Species

Aquatic nuisance species are waterborne nonnative organisms that have been intentionally or accidentally introduced and pose a significant threat to native species or their habitat. Many species identified as threatened or endangered are considered to be at elevated risk because of competition with nonindigenous species. Negative ecological consequences on aquatic ecosystems include dramatic modifications to food webs, alterations of biogeochemical cycles, and declines in native biodiversity. In aquatic ecosystems, nonindigenous species are transported through vectors such as shipping, intentional release, migration through man-made canals, escape from aquaculture, and baitfish release (Holeck et al. 2004). More than 184 nonindigenous species have become established in the Great Lakes though these vectors (Ricciardi 2001). During the past four decades, shipping has been the primary mechanism responsible for these introductions.

Pest fish species in the Grand River basin include: sea lamprey, goldfish, round goby, and common carp. The recent range expansion of the exotic round goby into tributaries in the mouth segment from Lake Michigan is of concern. It is likely that round goby are direct competitors with native benthic fishes such as darters and sculpins. (Jude and Smith 1992). Common carp are found in high densities within impoundments and bayous and in some of the inland lakes. Carp are noted for increasing turbidity as they forage, stirring up the bottom and causing reduced water clarity.

The sea lamprey became established in the upper Great Lakes between 1936 and 1946, and in a very short period developed a large population (Scott and Crossman 1973). The parasitic adults quickly decimated, or contributed significantly to the decline of several commercially important fishes such as lake trout and lake whitefish. It is estimated that adult sea lampreys can kill up to 40 pounds of fish per year (Coscarelli and Bankard 1999). Sea lampreys are potamodromous and migrate upstream to spawn. Lampreys spawn on gravel riffles in the lower Grand River and tributaries. Juvenile lampreys, called ammocoetes, create burrows in sand and silt areas and feed on detritus and small organisms. The ammocoetes remain in the burrows for a period of three to eight years, at which time they transform into the parasitic adult phase and migrate downstream to Lake Michigan.

Efforts to control lamprey parasitism of Great Lakes fish populations have been ongoing since the late-1940s. The U.S. Fish and Wildlife Service routinely surveys tributaries accessible to sea lampreys. Streams with high densities of sea lamprey ammocoetes are treated with the lampricide TFM (3-trifluoromethyl-4-nitrophenol) to eliminate or reduce lamprey populations. Treatments are scheduled every three to four years, or as often as necessary to ensure no lampreys older than age three will be in a stream. Historically, sea lamprey distribution was limited to the streams below the Sixth Street Dam. However, recent surveys located a population upstream of the dam in the Rogue River. Because this population was large enough to warrant management, the Rogue River was treated with lampricide for the first time in 2009.

The lampricide TFM can negatively affect local aquatic communities. Studies have found temporary reductions of burrowing mayfly populations after treatments. Tadpoles and salamanders are susceptible, but most amphibians have left the water for terrestrial habitats during treatment time. Mudpuppies, a permanently aquatic salamander, are sensitive to TFM (Harding and Holman 1992). Limited fish kills as a result of lampricide treatments do happen on occasion. TFM may affect fish that are already stressed from pollutants, low dissolved oxygen levels, increased water temperatures, or spawning. Although most fish are not affected by lampricides, native lamprey species, channel catfish, stonecat, mudpuppy, rainbow trout, and juvenile lake sturgeon are known to be sensitive to TFM (GLFC 1985; Hay-Chmielewski and Whelan 1997).

The zebra mussel is native to the Baltic Sea and was introduced to the Great Lakes through the discharge of ballast water from ocean-going cargo ships. The zebra mussel has rapidly colonized the

Great Lakes, inland lakes and rivers and has caused significant ecological and economic harm to the region (Pimentel et al. 2000). The zebra mussel is established in Lake Michigan and found in the lower Grand River near the mouth and in the bayous. The Flat River, lower Thornapple River, and many inland lakes within the basin have also been invaded. Larval zebra mussels, or veligers, suspend in the water column and have the potential to colonize other waters through downstream drift. Dispersal through human activities, such as the discharge of bilge or live-well waters containing veligers, has likely hastened the spread of mussels throughout the basin. Zebra mussels are notorious for their biofouling capabilities by colonizing water intake pipes of power plants, public water supply plants, and industrial facilities. They colonize pipes constricting flow, therefore reducing water intake in heat exchangers and cooling systems. Zebra mussels attach to any hard surface and can become a nuisance on docks, piers, navigational buoys, and boats.

Zebra mussels can have profound effects on the ecosystems they invade. They are filter feeders and primarily consume phytoplankton, but other suspended material is filtered from the water column including bacteria, protozoans, and other zooplankton. Large populations of zebra mussels in the Great Lakes reduced the biomass of phytoplankton significantly following invasion (Benson and Raikow 2010). Survival rates of native unionid mussels have been shown to decline significantly with the increase in zebra mussel colonization (Hart et al. 2001a, 2001b). Through epizootic colonization and competition, extirpation of native unionid clams has occurred in Lake St. Clair and western Lake Erie (Nelepa 1994; Schloesser et al. 1996; Baker and Hornbach 1997). Zebra mussel colonization of larval dragonflies resulted in decreased mobility, increased mortality through predation, and reduced rates of emergence (McCauley and Wehrly 2007; Fincke et al. 2009).

The rusty crayfish is a nonindigenous species that has colonized the harbors along the eastern Lake Michigan shore, including the mouth of the Grand River (Lodge and Feder 2001). This species is endemic to the Ohio River basin, and its establishment in Michigan is likely the result of a bait bucket introduction. Rusty crayfish inhabit inland lakes, ponds, and streams. They prefer areas that offer rocks, logs, or other structure as cover. Bottom substrates may be clay, silt, sand, gravel, or rock. Rusty crayfish can be found in riffle and pool habitats. Unlike native crayfish, they are generally not a burrowing species. Rusty crayfish are opportunistic feeders and consume a variety of aquatic plants, benthic invertebrates, detritus, fish eggs, and small fish.

Rusty crayfish may cause a variety of negative environmental and economic impacts when introduced to new waters. This aggressive species often displaces native or existing crayfish species (Lodge et al. 2000; Klocker and Strayer 2004). Rusty crayfish have been shown to reduce aquatic plant abundance and species diversity by overgrazing. As rusty crayfish populations increase, declines in macroinvertebrate populations were noted (McCarthy et al. 2006). Rusty crayfish can harm fish populations by eating fish eggs and fry, through direct competition for food resources, and habitat loss through the destruction of submersed aquatic plants (Gunderson 2008). They are known nest predators and will attack the nests of bluegill, pumpkinseed, and largemouth bass.

Rusty crayfish are not readily controlled, although evidence suggests restrictive fishing regulations protective of crayfish predators (e.g., smallmouth bass) may be an effective management strategy. Preventing future introductions by educating anglers and bait dealers is likely the best method of control.

Purple loosestrife is a serious plant pest in the watershed. It can be found in most wetlands and in some areas, it dominates wetland vegetation. Purple loosestrife spreads quickly. Due to its attractive purple flower, humans have spread it through transplantation to gardens and lakeshores. Wind, flowing water, and animals disperse seeds. Purple loosestrife will out-compete more beneficial native plants for space. It provides little cover for wildlife, and is not used as a food source (Eggers and Reed 1987). Because of its ability to form monotypic stands, it has the potential to destroy the wildlife value of wetlands. Purple loosestrife thrives on moist soils, often invading after some type of disturbance. Eradicating an established stand is difficult because mature plants produce an enormous number of seeds, and plants can reestablish from root fragments and broken stems. Biological control of purple loosestrife has been accomplished through the introduction of a root-boring weevil and two leaf eating beetles. The plant can also be controlled through the application of selective herbicides (MSUE 1997).

Common reed is a perennial, wetland grass that can grow to 15 feet in height. Although phragmites is native to Michigan, an invasive, non-native form is becoming widespread and is threatening the ecological health of wetlands and the Great Lakes coastal shoreline. Invasive phragmites creates tall, dense stands which degrade wetlands and coastal areas by crowding out native plants and animals. Phragmites can be controlled using an integrated pest management approach which includes herbicide treatments followed by either mechanical removal (e.g., cutting, mowing) or prescribed burning

Eurasian water milfoil and curly leaf pondweed are two widespread nuisance plants found in lakes and impoundments throughout the watershed. These nuisance plants can out-compete native plants and form dense monotypic stands. These dense beds cause a loss of plant diversity, degrade water quality, and can reduce habitat for fish, invertebrates, and wildlife. In shallow areas, these plants can interfere with water recreation such as boating, fishing, and swimming. These plants are readily moved between waterways on recreational equipment. Plant fragments should be removed from boats, trailers, and other equipment prior to transport. Control of these invasive aquatic species is best accomplished through early detection. New colonies can be removed through hand pulling and raking. Larger stands may be controlled through the MDEQ-permitted use of selective herbicides. Biological control methods, such as the release of weevils, provide an alternative to chemical herbicides. Because most lake-dwelling fish and invertebrate species are dependent on submersed aquatic vegetation for habitat, whole-lake chemical treatments should be avoided. Significant biological risks associated with large-scale aquatic plant treatments include a loss of sensitive plants, declines in fish populations, and declines in water quality (Valley et al. 2004).

Nuisance aquatic organisms also include fish pathogens and parasites. Outbreaks of fish diseases such as largemouth bass virus and viral hemorrhagic septicemia have resulted in large-scale fish die-offs in affected waters. Infected waters cannot be treated; therefore, prevention through the implementation of best management practices is the only means of control. To prevent or slow the spread of VHS and other diseases, MDNR Fish Disease Control Order (FO-245) was issued to restrict movement of live and frozen baitfish and fish eggs (roe), movement of live game fish, and movement of water in any container (e.g., bait buckets, live wells and bilges) from water body to water body.

Fishery Management

Fisheries management in the Grand River watershed began in the late 1800s when the Michigan Fish Commission began to inventory fish populations in inland waters. Management to improve the recreational fishery has generally concentrated on specific tributaries and lakes. Fisheries management includes the manipulation of fish populations through the introduction of desired species (e.g., walleye, brown trout) or control of undesirable species (e.g., common carp, sea lamprey). Fisheries management also involves aquatic habitat protection through environmental regulations, and habitat improvement and restoration (e.g., installation of instream fish cover, dam removals). The entire watershed is subject to fishing regulations (e.g., size, possession limits, and gear restrictions), as prescribed by law. Laws and regulations are forms of fisheries management aimed at protecting, preserving, and enhancing a fishery resource. The following is a description of fisheries management of the Grand River watershed. Emphasis is placed on historical and current fisheries management, fisheries management limitations, and potential fisheries enhancement.

Headwaters

Mainstem

Fisheries management in the headwaters dates back to the 1870s when American eel, Chinook salmon, Atlantic salmon, and channel catfish were stocked (Table 39). Following these early introductions, management efforts included supplemental stocking of smallmouth bass in 1944. Fish communities in this segment were limited by degraded water quality caused by several inadequately treated industrial and municipal discharges in and near the City of Jackson. Since the enactment of the Clean Water Act, these discharges have either been terminated or currently receive proper treatment resulting in much-improved water quality. Portions of the mainstem channel in the headwaters segment have been highly modified by channelization, relocation, and in some locations-enclosure. Currently, the mainstem receives annual stocking of spring fingerling walleye as a result of a walleye culture program on the grounds of the Jackson State prison. Channel catfish, walleye, and panfish provide angling opportunities.

Tributaries

Past fisheries management in the headwater tributaries involved stocking brook trout and brown trout in Willow and Portage creeks. These were primarily put-and-take fisheries as both water quality and temperature are marginal for sustained trout management. These streams are no longer stocked and are now managed for native species. All other tributaries are managed for self-sustaining native fishes.

Lakes

Most lakes were stocked by Fisheries Division during the 1930s through the 1950s. Species stocked during this period included bluegill, largemouth bass, smallmouth bass, yellow perch, and in some instances, tiger muskellunge and walleye. These management actions ceased when Fisheries Division determined that stocking of fish species in waters where they are already present does not enhance the populations or fishery (Cooper 1948).

Recent management has included the introduction of redear sunfish to Gilletts Lake, Pleasant Lake, and Grass Lake. Channel catfish are stocked in Gilletts Lake on an annual basis. Future management of lakes in this segment will concentrate on habitat protection to maintain self sustaining populations of native game fish.

Upper Segment

Mainstem

Past fisheries management in this mainstem segment included stocking American eel, walleye, and smallmouth bass (Table 39). Recent surveys of the Grand River have documented good populations of walleye, smallmouth bass, northern pike, and channel catfish. Several good access points provide diverse angling opportunities. Due to spawning habitat limitations, natural recruitment of walleye is not anticipated. Future fisheries management will focus on maintaining the walleye fishery through supplemental stocking, and maintaining self sustaining populations of native species through habitat protection. Additional dam removals and other habitat improvement opportunities should be considered in the Eaton Rapids vicinity. Where dam removal is not an option, installation of fish passage structures should be considered where feasible.

Tributaries

Mackey Brook and Sandstone Creek are coldwater resources that have been managed for trout since the 1930s. However, because public access could no longer be secured, these stockings were discontinued in 2007.

Spring Brook and Columbia Creek are high-quality, warm-transitional streams that historically were managed for trout. After several failed attempts to establish trout fisheries, these management strategies were discontinued. Currently these waters are managed for native species.

Lakes

The three managed lakes in the upper valley segment are manmade and include Lake Delta, Lake Interstate, and Moores Park Impoundment. Lake Delta is a cooling-water reservoir for the Lansing Board of Water and Light, Erickson generating station. The lake has been stocked with bluegill, black crappie, largemouth bass, channel catfish, and walleye. Lake Interstate was created from sand and gravel mining operations during the construction of Interstate Highway 69. Ownership of the lake and adjacent lands was transferred to the Department of Natural Resources as partial mitigation for the loss of aquatic and wetland habitats during highway construction. Initially, the lake was stocked with rainbow trout, largemouth bass, and redear sunfish and provided a popular fishery. Due to poor survival, rainbow trout management has been discontinued. Lake Interstate is now managed for warmwater fish including sunfishes, largemouth bass, and stocked channel catfish. The Grand River impoundment formed by the Moores Park Dam contains a variety of game fish species including northern pike, smallmouth and largemouth bass, channel catfish, walleye, and panfish species. The current management strategy includes alternate year stocking of spring fingerling walleye.

Middle Segment

Mainstem

Following the successful introduction of Chinook and coho salmon to the Great Lakes in the mid-1960s, fish ladders (or fishways) were built on the Grand River mainstem to allow these fish to migrate upstream from Lake Michigan to the City of Lansing (See **Dams and Barriers)**. The first ladder was constructed in 1975 at the Sixth Street Dam in the lower mainstem segment. Five other fishways, located at the middle segment dams (Lyons, Webber, Portland, Grand Ledge, and North Lansing), were completed in 1981 (Ryckman 1986). The objective of these projects was to allow salmon and steelhead to ascend the river and to diversify inland angling opportunities.

To maintain the Lake Michigan and Grand River fisheries, coho salmon and steelhead have been stocked in the City of Lansing since the early 1980s. These fish are released at this location to imprint and improve upstream returns during the spawning migrations. An average of 300,000 coho salmon yearlings and 25,000 steelhead yearlings are released upstream of the North Lansing Dam on an annual basis. After the coho salmon and steelhead are stocked, they must migrate downstream approximately 185 river miles and negotiate the six mainstem dams to reach Lake Michigan. The costs associated with these high stocking densities make Lansing one of the most expensive stocking sites in the state, therefore; estimates of the number of returning fish and angler harvest are necessary to evaluate the effectiveness of this management.

Currently, accurate estimates of total salmon and steelhead returns to the Grand River cannot be made. This is due to the lack of counting facilities at the Sixth Street Dam and the many coldwater tributaries that provide some natural reproduction of these species. Partial estimates have been developed for the upper segment using data collected at the Webber Dam fish ladder. The fishway at the Webber Dam is the only facility constructed with an underground viewing chamber. The chamber contains a window and video monitoring equipment that allow for the identification and counting of fish ascending the ladder during the spring and fall migration periods. Counts of coho salmon passage at the Webber ladder for 2001, 2002, and 2008 were 3,573, 2,173, and 1,575, respectively. Based on mean stocking numbers, the counts translate into return estimates of 0.9%, 0.6%, and 0.7%, respectively (Taylor and Wesley 2009). Total counts (spring and fall) of steelhead passage were also modest at 1,695, and 163; for 2001 and 2002, respectively. Extremely low spring flows during 2002 resulted in reduced spring migrations. Steelhead passage in fall 2008 was estimated to be 164 fish, which is low compared to other Michigan rivers and previous fall numbers recorded at the Webber ladder (Dexter 2002; Taylor and Wesley 2009).

Estimates of angling effort and harvest were developed for the upper segment through creel surveys in 2003 and 2004. The surveyed portions of the river included the greater Lansing area (Moores Park to Grand Ledge) and from the City of Portland to the Village of Lyons. Angling effort was estimated at 6,717 angler trips (17,996 angler hours) in 2003 and 21,635 trips (64,143 angler hours) in 2004. Warmwater fish species (e.g., smallmouth bass, bluegill, and channel catfish) comprised the majority of the catch. The estimated steelhead catch during the 2003-2004 creel period (harvest and released) was 860, the majority of which were returned to the river. The estimated coho salmon catch (harvest and released) between Lansing and Lyons totaled 432 for 2003 and 318 for 2004. Based on the 2002-2004 coho stocking rates, the return to creel was estimated to be 0.1% (Taylor and Wesley 2009). The creel estimates and low numbers of coho salmon observed in the Webber ladder suggest the high stocking rates in Lansing are not producing significant returns; therefore, further evaluation of the coho salmon stocking strategy is warranted (see **Management Options**).

Combined angling effort from the 2003 and 2004 creel surveys, estimated at 28,352 trips, reveals the recreational value the Grand River fishery provides the greater Lansing area. From an economic perspective, data generated from the 2000 U.S. Census estimates the average daily trip expenditure per angler in Michigan is $24 (U.S. Department of Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau 2006). Based on this estimate, the combined value of the 2003 and 2004 angling trips in this portion of the Grand River was approximately $680,450.

Other fisheries management actions in the middle mainstem segment include alternate year walleye stocking and periodic fisheries surveys to monitor fish populations. Future management should be focused on maintaining diverse angling opportunities through the continued stocking of salmonids and walleye. Efforts that improve habitat (e.g., dam removal) and improve water quality in the mainstem, including eliminating combined sewer overflows in the greater Lansing area, should be promoted.

Tributaries

Fish communities in the Red Cedar and Looking Glass rivers are not actively managed through supplemental stocking. Both rivers have diverse resident warmwater fish communities and offer angling opportunities for northern pike, largemouth bass, and smallmouth bass and are popular during the spring sucker runs. The rivers also provide modest fisheries for salmon and steelhead. In addition to periodic fisheries surveys, one location on the Looking Glass River is identified as a long-term fixed monitoring location and is sampled at regular intervals as part of Fisheries Division's Status and Trends Program. Future management of these rivers should focus on self-sustaining populations of native fish species. Habitat improvement should target wetland restoration and rehabilitation of channelized tributaries with the goal of restoring subwatershed hydrology.

Sebewa Creek is the only designated trout stream in the middle valley segment. The creek was managed for brown trout and stocked on an annual basis from 1969 to 1990 when public access became an issue. Although the stream has been highly modified by dredging, it has good stream temperatures and water quality. Due to public interest and the willingness of riparian land owners to grant public access, the brown trout stocking program was reinitiated in 2010. Future management should focus on maintaining the fishery through stocking and restoring instream habitat.

Lakes

There are relatively few public access lakes in the middle valley segment. Those with active fishery management include Lake Lansing (Ingham County) and Park Lake (Clinton County). Past management of Lake Lansing included stocking of channel catfish and tiger muskellunge. The lake in now managed for native fish species. Park Lake is being stocked with channel catfish as a means to control bluegills. Redear sunfish were also introduced to provide a faster growing panfish that utilizes a different niche and food resources.

Lower Segment

Mainstem

Fisheries management in the lower mainstem segment began in the 1880s with stocking American eel, salmon, and channel catfish. Walleye population management has continued since the supplemental stocking program began in the 1930s. Although historical management efforts included salmon stocking, the present day coho and Chinook salmon fisheries did not become established until the late 1960s. For decades, the fish community in the lower river was limited as a result of uncontrolled municipal and industrial wastewater discharges. In the 1970s standing stocks of game fish species were greatly diminished, and the fish population was dominated by common carp and white suckers (MDNR 1970; Nelson and Smith 1981). Fish population recovery began with the passage and implementation of the Clean Water Act of 1973 (see **Water quality).** The lower segment now supports diverse populations of fishes and a significant recreational fishery. In addition to the popular spring and fall runs of potamodromous fishes, river fisheries include channel catfish, flathead catfish, smallmouth bass, largemouth bass, walleye, northern pike, and sunfishes.

Angler surveys in the Grand Rapids metropolitan area were conducted in the spring and fall of 2003 and 2004. Survey statistics estimated a combined total 46,164 angler trips to the river with a catch of 1,228 coho salmon, 5,948 Chinook salmon, 15,852 rainbow trout (steelhead), 791 brown trout, 80 lake trout, 2,473 walleye, and 2,880 smallmouth bass (MDNR Fisheries Division, unpublished data). At a value of $24 per angler trip (U.S. Department of Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau 2006) the combined economic value of angler trips was slightly less than 1.11 million dollars. This value would be significantly higher if the angler survey would have included other popular mainstem fishing sites such as the area from Ionia to Saranac, and the confluences of the Flat and Thornapple rivers.

Future river management decisions in the Grand Rapids area will need to consider the fate of the Sixth Street Dam. According to MDEQ records, the current structure has been in place since 1917, long past the anticipated 50-year design lifespan of most dams (Lane 2008). The dam is not currently used for power generation and offers limited potential for hydroelectric power development (Black and Veatch 1988). Given the age of the dam, significant capital expenditures can be expected to maintain structural integrity. Many Michigan communities are facing similar liability and financial decisions associated with aging and deteriorating dam structures (Michigan River Partnership 2007). Costs of dam removal are often less expensive than the costs of repair and long-term maintenance, and removal can provide significant local economic benefits (Graber 2003). Funding is also available for selective dam removal but not for dam repair, replacement, or maintenance. When faced with similar decisions, the Villages of Dimondale and Nashville opted for dam removal.

The Sixth Street Dam has a significant influence on fish populations in the Grand River and in Lake Michigan. The structure is a barrier to the movement of several Lake Michigan fish species that ascend the river to spawn. Although the ladder provides upstream passage for coho salmon, Chinook salmon, and steelhead, other migratory species (e.g., lake sturgeon, walleye, longnose sucker, redhorses) do not successfully pass upstream through the ladder. Failure to reach upstream spawning areas limits the productivity of these populations. Natural salmon and steelhead recruitment is also negatively affected, as not all adults successfully pass. A major obstacle to lake sturgeon rehabilitation is its inability to ascend to upstream spawning habitats (Hay-Chmielewski and Whelan 1997). Conversely, the dam also has a positive influence on the Lake Michigan fishery in its control of sea lamprey populations. The tailwater hydraulic created at the face of the dam prevents most adult sea lamprey from reaching upstream spawning areas. When the Sixth Street fish ladder was constructed in 1975, the pool-weir configuration was selected because a sea lamprey barrier could be readily incorporated into the design. Future management of the dam and fishway will need to consider management of this and other pest species.

Ultimately, the decision to maintain or remove the Sixth Street Dam must be made by the owner, the City of Grand Rapids. The decision-making process should consider the social, economic, and environmental costs and benefits associated with dam retention or removal. This decision will have significant implications regarding future management of the Grand River and Lake Michigan fishery resources. Removal of the Sixth Street Dam would be supported as consistent with Fisheries Division policies. However, due to the potential for adverse effects to the Lake Michigan fisheries, this support would be contingent on the identification and implementation of alternative sea lamprey control strategies (e.g., integrated pest management, adjustable-crest barrier, etc.). If the City chooses to maintain the dam, design modifications to the existing ladder including construction of a viewing room equipped with fish counting equipment should be included in any renovation or major modification of the structure. Alternatively, construction of rock arch rapids (Aadland 2010) immediately in front of dam would allow for the passage of nearly all fish species, would eliminate the dangerous hydraulic undertow, and would restore habitat similar to the natural rapids that were once found at this location.

At the time of European settlement, the most significant physical and ecologically important feature of the Grand River was the former rapids. “ The rapids are not the nature of an abrupt leap or cataract, but have nearly uniform descent for the distance of a little more than a mile, through the central part of the city, amounting to a fall of about eighteen feet, over a limestone bed, the western outcrop of the limestone rock in this part of Michigan” (Baxter 1891). Prior to their destruction, the rapids provided substantial rocky spawning habitat for several Lake Michigan species, including cisco, lake whitefish, lake trout, and lake sturgeon. Although lake-run populations of cisco, lake whitefish and lake trout are no longer extant, restoring the rapids in Grand Rapids would greatly benefit lake sturgeon recovery efforts (Hay-Chmielewski and Whelan 1997, Aadland 2010). In addition to improving fish habitat, restoration of the rapids downstream of Sixth Street Dam would improve river aesthetics and would be an attraction to paddling enthusiasts.

Future fisheries management of the lower mainstem segment should continue to focus on maintaining the potamodromous fishery. The diverse warmwater fishery that includes northern pike, walleye, smallmouth bass, largemouth bass, channel catfish, and flathead catfish should be promoted. Future river management should recognize the diverse mussel populations distributed throughout the lower segment and insure that actions are protective of critical habitats and host fish populations.

Tributaries

Fisheries inventories of the Maple River were completed in 1974 (Lincoln 1974) and 1989 (MDNR unpublished data). The Maple River is a unique northern river in that it has many characteristics (flow pattern, terrain, and fish community) that are more typical of rivers located in the southern United States (P. Seelbach, Fisheries Division, personal communication). With the exception of the fisheries surveys, active fisheries management of the Maple River has been limited to stocking channel catfish and walleye during the 1980s. The river also receives a modest run of steelhead as a result of the stocking site located on Fish Creek. Returning steelhead stray upstream to the Elsie Dam, which is a barrier to further upstream movement. Despite the lack of fisheries management, the river supports as significant fishery for channel catfish, flathead catfish, black crappie, and white crappie. A 1973 angler survey estimated 18,990 angler days were spent on the river. On a per acre basis, this estimate of angler effort was higher than any other warmwater river in the state (Lincoln 1974). Future fisheries management of this unique warmwater fishery should focus on habitat protection and maintaining self-sustaining populations of native fish species. The removal of the Elsie Dam has been advocated by Fisheries Division since 1974. Removal of this structure would result in expanded fishing opportunities and restore fish migration in the upper watershed.

The Maple River has two main tributaries with fisheries potential: Stony Creek and Fish Creek. Stony Creek is a warmwater tributary that supports a seasonal population of smallmouth bass. Extensive channelization in the Stony Creek watershed has altered the hydrology and channel morphology and significantly reduced fisheries management options. Future management in this watershed should focus on restoration of the stream channels and riparian corridors. In many locations, a two-staged channel design could be utilized to restore connectivity with the floodplain. Restoration of headwater wetlands should be promoted to benefit watershed hydrology and provide wildlife habitat.

Fish Creek begins as a small coldwater stream that receives ample groundwater inputs and supports a brook trout and brown trout fishery. Further downstream the thermal classification becomes warm-transitional as several warmwater tributaries join the mainstem. At this point the stream is too warm for brook trout but still cool enough to support a stocked brown trout fishery. The damming of the creek at Hubbardston further increases stream temperature, creating conditions unsuitable for brown trout management. In addition to annual stocking of brown trout, fisheries management has included habitat improvement projects which were completed by the Lansing Chapter of Trout Unlimited in the late 1990s. Approximately five thousand steelhead yearlings are stocked in Fish Creek near Matherton on an annual basis. This stocking creates a fairly popular steelhead fishery below the Hubbardston Dam and in the Maple River. Future management of Fish Creek should focus on maintaining the trout fisheries through stocking and protection of the coldwater habitats. Operations at the Hubbardston Dam should be monitored to assess compliance with FERC license provisions.

Prairie Creek originates in Montcalm County and flows south through Ionia County, joining the Grand River at the city of Ionia. Although Prairie Creek is classified as warm-transitional (Zorn et al. 2008), groundwater yield increases as the stream descends into the Grand River valley and is sufficient to support managed coldwater fisheries in the lower portion of the watershed. Prairie Creek has been actively managed through annual stocking of brown trout since 1966. Annual stocking of steelhead in the lower portion of creek began shortly after the construction of the Sixth Street ladder in 1975. Although access is limited, Prairie Creek is a popular fishing destination because of its proximity to Lansing and Grand Rapids. Fisheries surveys have documented natural recruitment of steelhead from Prairie Creek. However, further studies are needed to determine the extent of the natural production and whether this is supported by wild or hatchery-produced fish. Currently upstream migration of steelhead is hampered by an unnamed lowhead dam in the lower watershed. Although a steep-pass fishway was installed, the structure is easily blocked, preventing upstream passage to suitable spawning habitat. Improved passage, either through dam removal or installation of rock arch rapids, would likely increase natural recruitment of steelhead and would allow for a reduction in stocking rates. Future management will focus on maintaining the trout fisheries through stocking and protection of the coldwater habitats.

Bellamy Creek also begins as a warm stream, changing to a cold-transitional stream as it drops into the Grand River valley. Although only one historical stocking of brown trout in 1953 is recorded, the population appears to be self-sustaining. Adult steelhead stray into Bellamy Creek, and limited natural recruitment has been documented.

Lake Creek is also a self-sustaining brown trout stream. It originates from Morrison Lake but gains sufficient gradient and groundwater to support trout. It was stocked with brown trout periodically from the 1940s through the 1970s and currently supports itself through natural reproduction.

Other small streams in Ionia County that were once stocked with brook and/or brown trout include: Cannon, Hawns, Tibbets, and Timberline creeks. Current models suggest these streams are warm-transitional (Zorn et al. 2008) and should be managed for self-sustaining native fish species. Most of these are in need of surveys to determine the composition of the current fish populations.

The Flat River is a large, warmwater river that joins the Grand River south of the City of Lowell. Although the river was once polluted, it now has excellent water quality and is known for its quality smallmouth bass fishery. The river also supports a diverse fish community and a rich assemblage of freshwater mussels, including several species of conservation interest. Past fisheries management has included limited stockings of largemouth bass and smallmouth bass, but this practice was discontinued as these species are typically self-sustaining. Current fisheries management includes the annual stocking of approximately 5,000 steelhead yearlings downstream of the King Mill Dam in Lowell. Returns of these fish provide a popular fishery during the spring and fall runs.

Management of the aquatic resources of the Flat River is complicated by the presence of several mainstem dams. These dams block the fish movements, resulting in several populations that are isolated between dams. In addition to reducing the overall productivity of the fish community, these dams have a negative effect on the dispersal and distribution of several species of fish and freshwater mussels. In fact, the upstream distributions of several Flat River mussel species are bound by the presence of a dam. Additionally, several species of fish that migrate from the Grand River are prevented from reaching upstream habitats by the King Mill Dam in Lowell. During migrations these fish congregate below the dam and become more susceptible to predation and harvest. The river redhorse, a State-threatened fish species, typically returns to the Flat River to spawn during May and June. This large sucker species is particularly vulnerable to bow and spearfishing as it congregates below the dam. Special regulations, such as gear restrictions, or spawning closures may be required for conservation of this species.

Several tributaries of the Flat River were historically managed for trout. Curtis, West Branch, and Dickerson creeks were once stocked with trout on a regular basis. These creeks now support naturalized trout populations and are no longer stocked. Current inventories of the fish populations in Flat River tributaries are needed to better evaluate management goals and potential.

Future management of the Flat River will concentrate on maintaining self-sustaining populations of native fish species through habitat protection and the implementation of the Flat River Natural River Plan. The potamodromous fishery in the lower river should be maintained through continued stocking. Opportunities to improve river connectivity, such as dam removal or construction of natural fishways, should be promoted. The river downstream of the Fallasburg Dam will be monitored at regular intervals as part of the Fisheries Division Status and Trends Program. Recovery plans for the several threatened and endangered aquatic species that remain in the river should be developed and implemented.

Between the confluences of the Flat and Thornapple rivers, there are several small cold- and cold-transitional streams that enter the Grand River in the vicinity of Lowell and Ada. Many of these tributaries were stocked with trout in the 1930s and 1940s. Fisheries surveys conducted in the 1990s documented that naturalized trout populations are supported in several of these tributaries. Active fisheries management in most of these streams is limited to periodic surveys. Spring Brook is a long-term fixed monitoring location that is sampled at regular intervals as part of Fisheries Division's Status and Trends Program (Wills et al. 2005).

The Thornapple River enters the Grand at the Village of Ada. The Thornapple River watershed contains a diversity of warmwater and coldwater habitats and is the focus of several fishery management actions. The fish community in the headwaters consists of largely nongame species but does provide some fishing opportunities for northern pike. The Thornapple River near Nashville is generally more navigable and provides angling for northern pike, largemouth bass, smallmouth bass, and walleye. The Village of Nashville Dam was a barrier to upstream fish movement for several species of game and nongame fish species (MDNR Fisheries Division, unpublished data). The structure was removed and replaced with a series of arch rock rapids in 2009. The project resulted in restored fish passage to approximately 60 mainstem river miles, 105 tributary miles, and five inland lakes in the headwater reaches of the Thornapple River. Future fisheries management in this portion of watershed will include stocking walleye and maintaining self-sustaining populations of warmwater fish species.

Thornapple Lake is a natural water body, 409 acres in size and up to 30 feet deep. The lake has a long management history and has been stocked since the late 1800's. Current fisheries management includes stocking walleye, and northern muskellunge. Thornapple Lake also offers angling opportunities for other sport fish including northern pike, smallmouth bass, channel catfish, and panfish (Wesley 2000). The lake is managed for trophy northern muskellunge and serves as a broodstock lake to support the State's northern muskellunge rearing program. Special harvest regulations apply to the lake to protect the muskellunge fishery. These regulations include gear restrictions and limited harvest through a 50-inch minimum size limit and a reduced season. Thornapple Lake will continue to be managed as a top-quality warmwater fishery. Stocking of northern muskellunge and walleye will be continued to ensure the fishery will be maintained.

There are several coldwater and cold-transitional tributaries to the Thornapple River many of which are designated trout streams (Zorn et al. 2008; Table 13). Active trout management in some of these tributaries has been discontinued due to channelization (e.g., Quaker Brook) or because trout populations have become self-sustaining (e.g., Hill Creek). The trout fisheries in Highbanks, Cedar, Glass, Duck, and Tyler creeks are currently managed through stocking. Although natural recruitment has been documented in some of these tributaries, it is not sufficient to maintain the fisheries.

The Coldwater River is the largest tributary to the Thornapple River and is classified as a cold-transitional small river (Zorn et al. 2008; Lyons et al. 2009). Trout management in the Coldwater River dates back to the initial stocking of brook trout in 1884. Since the mid-1970s the river has been stocked with various strains of rainbow trout and brown trout. Management has also included chemical reclamation and several successful habitat improvement projects. Because the river is in a rural setting near high population centers, it is a relatively popular brown trout fishery. An angler survey conducted during the 2002 trout season estimated 2,144 angler trips were made on the river with a catch of 9,025 brown trout.

Future management of the coldwater streams in the Thornapple River watershed will focus on maintaining the existing fisheries through annual stockings of yearling trout. The trout fisheries in Quaker Brook, Duck Creek, Tyler Creek, and the Coldwater River would benefit from additional stream corridor and channel rehabilitation projects.

The Thornapple River downstream of the City of Hastings is fragmented by five mainstem hydroelectric dams, and the lack of fish passage at these structures limits fisheries management options. The fish populations between the dams are isolated and are either self-sustaining or reliant on recruitment from upstream locations. Although a fish ladder was constructed at the Ada Dam, it is not functional. As a result, several native fish species (e.g., smallmouth bass, northern pike, walleye, and redhorse) that would historically have utilized the Thornapple River on a seasonal basis are blocked from these habitats. The lack of fish passage also prevents the further development of the Grand River steelhead and salmon fisheries. Because public access to the lower impoundments is limited, no active management of these fisheries is planned. Future management of the lower portion of the Thornapple River should include the development of a comprehensive fish passage program.

Several small cold- and cold-transitional tributaries join Grand River mainstem between the confluences of the Thornapple and Rogue Rivers. Honey, Egypt, Sunny, and Bear creeks were historically managed trout streams and now support naturalized populations of brook trout and brown trout. Urban development in these small subwatersheds has the potential to negatively affect trout populations through increased delivery of storm water runoff and increased sediment loadings. Habitat protection through the implementation of storm water best management practices and protection of the riparian corridors is critical to the continued existence of these urban trout populations.

The Rogue River is a large, cold-transitional tributary that has a long history of trout management. Initial management actions included the stocking of brook trout in 1884. The river has been managed through annual stockings of both brown trout and rainbow trout since 1933. Although limited natural recruitment of brown trout occurs, the trout fishery is maintained through annual stockings of approximately 16,500 yearling rainbow trout and 16,500 yearling brown trout. The mainstem also supports a significant steelhead fishery from the confluence with the Grand River upstream to the Rockford Dam. This fishery is maintained by stocking 30,000 steelhead yearlings on an annual basis. Due to its close proximity to the City of Grand Rapids, the Rogue River receives a high amount of angling pressure. Spring and fall angler surveys were conducted above and below the Rockford Dam during 2002-2004. Total catch estimates (harvest and released) for the three year survey period were 13,683 brown trout and 28,672 rainbow trout (including steelhead). The survey estimated a total combined effort of 60,559 trips during the 2002-2004 trout seasons (MDNR Fisheries Division, unpublished data). At a value of $24 per angler trip per day, the combined value of spring and fall angling trips to the Rogue River was 1.45 million dollars or approximately $485,000 per year (U.S. Department of Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau 2006) .

The Rogue River has several cold, cold-transitional, and warm-transitional tributaries which were actively managed in the past. Many of the tributaries (i.e., Spring, Duke, Cedar, Stegman, Becker, Shaw, and Rum Creeks) were stocked with brook trout and brown trout from 1933 until the mid 1960s (Table 39). These tributaries now support self-sustaining trout populations and are no longer stocked. Groundwater yield to these tributaries is significant, providing stable coldwater rearing habitat for juvenile trout and summer thermal refuge for adult trout inhabiting the warmer mainstem. Implementation of the Rogue River Natural River Plan to protect riparian corridors and coldwater habitats associated with these tributaries is critical to maintaining the coldwater fishery in the Rogue River mainstem. Future fisheries management of the Rogue River and tributaries will continue stocking brown trout, rainbow trout, and steelhead, to maintain the current recreational fisheries. The potential removal of the Rockford Dam should be explored. If dam removal is not a feasible option, then fish passage in the form of a constructed rock arch rapids or other natural fishway should be considered. The thermal effects of the dam should also be evaluated and mitigated for as necessary. Additional habitat protection measures, such as the development of comprehensive storm water management plan to protect the hydrology and thermal quality of the watershed, should be a priority.

Buck Creek is currently managed for brown trout and is stocked on an annual basis. Although the lower portion of the watershed is a warm-transitional stream (Lyons et al. 2009), temperature data indicate that the stream is on the upper thermal limits for supporting trout. An angler survey was conducted on Buck Creek during the 2002 trout season. The survey estimated 46 angler trips and reported no trout in the catch. Land use in the Buck Creek watershed is predominantly urban, and the stream receives significant storm water inputs. It is possible the stream quality has declined and can no longer sustain a brown trout fishery; further evaluation of this management strategy should be conducted.

Lakes

There are 254 lakes greater than 20 acres in the lower segment of the Grand River watershed. Although the majority of these lakes contain warmwater fish communities (e.g., largemouth bass, bluegill), some are coldwater and support populations of cisco and rainbow trout. Inland lakes are popular angling destinations and receive a considerable amount of fishing pressure. Creel census statistics (i.e. angler hours per acre) vary widely between lakes, region, and years. A 1985 statewide summary of on-site creel surveys reported that larger lakes tend to have lower average catches and catch rates (Ryckman and Lockwood 1985). Angler surveys conducted on nine southern Michigan inland lakes from 125 to 2050 acres in size, estimated summer angling effort at 9.5 to 68.3 angler hours/acre (Waybrant and Thomas 1988; MDNR Fisheries Division, unpublished data). Using a mean value of 31.9 angler hours per acre, total summer angling effort on 49 inland lakes within this size range in the lower segment is estimated at approximately 403,000 angler hours. At an estimated 3,352 angler trips/lake and $24 expenditure /trip, the economic benefit derived from angling on these lakes is estimated at 3.9 million dollars.

Many of these lakes were once stocked by Fisheries Division but are no longer managed due to a lack of public access. Historically, fish stocking was the primary means of lake management in the lower segment (Table 39). Inland lake management methods also included the use of rotenone and other chemicals to control fish populations, population reductions through netting, and harvest restrictions through special fishing regulations. Currently, fish populations in the majority of the inland lakes located in the lower segment are protected by general fishing regulations, and fisheries management on these waters is directed toward habitat protection to promote self-sustaining populations of native fish. Some publicly-accessible inland lakes are still stocked by Fisheries Division to create unique fishing opportunities.

There are four lakes in the lower segment that are currently managed for muskellunge fisheries: Lake Ovid (Clinton County), Thornapple Lake (Barry County), and Murray and Campau Lakes (Kent County). These lakes are currently stocked with fall fingerling northern muskellunge at a density of 2-3 fish per surface acre. Although harvest is limited to one fish per day, angler surveys conducted on Murray and Campau lakes during the 2005 season indicate these fisheries are primarily catch and release fishing. The surveys estimated that during 9,284 trips (31,651 angler hours) 621 northern muskellunge were caught and released, and none were harvested.

Walleye are inexpensive and relatively easy to grow in rearing ponds. In southern Michigan, fisheries biologists have attempted to plant walleye in various locations that were thought to be suitable in order to provide a diverse fishery. Lakes are initially stocked for three years annually and then on alternate years. Population evaluations are conducted with a combination of trap netting for adults and electrofishing in the fall to evaluate fall fingerlings stocked the previous spring. Not all lakes stocked with walleye have established a fishery. Wabasis, Bass, and Reeds lakes, all in Kent County, are examples of lakes that had been stocked and did not establish a viable fishery. Lakes in the lower segment that are currently stocked with walleye include: Sessions (Ionia), Crystal and Clifford (Montcalm County), Thornapple Lake (Barry), and Lincoln (Kent County). Additionally, several lake associations have received approval from Fisheries Division to purchase and stock fall fingerling walleye in their lakes. Walleye have also been stocked by fisheries managers as additional predators to restore population levels of prey fish. Woodard Lake (Ionia County) and Long Lake (Kent County) have both been stocked with walleye in an effort to control stunted bluegill populations.

In southern Michigan, there are a few lakes that are deep, well oxygenated, and cold enough to support a trout fishery. These lakes are often referred to as “two-story lakes”, having a good bluegill and largemouth bass fishery in the shallower waters and a trout fishery in deeper waters. These lakes require annual trout stocking in order to maintain the fishery since most of the trout stocked are harvested in their first year in the lake. Unfortunately, when northern pike become established in these lakes, the trout stocking program often has to be discontinued since pike are notorious predators of trout. This, combined with the relative scarcity of lakes with management potential for a two story fishery means there are very few of these lakes. In the lower segment, Nevins Lake (Montcalm County) and Lime Lake (Kent County) are currently stocked with rainbow trout. Deep Lake in Barry County and Derby and Half Moon lakes in Montcalm County are no longer stocked with trout due to poor survival or overabundant northern pike populations.

Rainbow Lake in Montcalm County was stocked with redear sunfish from 1991 through 1993. This was an experiment to determine if redear sunfish would survive and establish a breeding population so far north of their natural range and to provide an alternative species that could potentially grow larger than the native bluegills. In addition, the lake association has purchased and stocked channel catfish under permit. The catfish are growing well and providing a fishery. The redear sunfish have established a self-sustaining population based on a 1999 survey that caught fish from 4 to 11 inches in size.

Mouth Segment

Mainstem

The Grand River mainstem in Ottawa County has a very diverse fishery for walleye, flathead catfish, channel catfish, largemouth bass, northern pike, and several species of suckers. It also has seasonal fisheries for coho and Chinook salmon, steelhead, brown trout and lake trout during spawning runs.

Although this portion of the river is not stocked, walleye fry stocked in upstream areas drift downstream into the mouth segment. Recent electrofishing surveys of the spring walleye run up to the Sixth Street Dam have shown an alternate year pattern in ages of walleye present that corresponds to the years that fry are stocked upstream in Ionia and Kent counties.

Approximately 170,000 Chinook salmon and 16,000 brown trout are planted annually at the river mouth in Grand Haven. Chinook salmon are stocked in net pens in Grand Haven to improve acclimation and imprinting to the Grand River. Brown trout are stocked at the mouth to provide a near-shore Lake Michigan fishery (Table 39).

Early records show that the Great Lakes form of muskellunge was known from the coastal and inland waters of southern Michigan, including the Grand River and some of its larger tributaries such as the Thornapple River. Presently, none of the original southern inland populations remain, presumably as a result of habitat fragmentation and poor water quality (Seelbach 1988). Present day conditions (i.e. habitat, water quality, forage base) in the mouth segment are suitable for muskellunge and provide an opportunity to reintroduce a large predator to the river. Although Fisheries Division currently stocks the northern strain of muskellunge in select inland waters, Seelbach (1988) recommended that Great Lakes muskellunge should receive primary consideration for stocking in southern Michigan rivers. The Great Lakes form is native to these waters and represents the lowest risk of genetic contamination to existing Great Lakes populations. A rehabilitation plan for Great Lakes muskellunge, including the establishment of a broodstock population, is being developed by Fisheries Division. Future fisheries management should include stocking of the Great Lakes strain of muskellunge when the rehabilitation plan is implemented.

A small remnant population of lake sturgeon is still present in the Grand River downstream of the Sixth Street Dam. Biologists report several adult and juvenile individuals have been captured, tagged, and released. Incidental catches of lake sturgeon occur below the Sixth Street Dam, downstream near Walker, and at the river mouth in Grand Haven. Evidence suggests high annual variation in the numbers of adults returning to the river to spawn (Kregg Smith, MDNR Fisheries Division, personal communication). Open-population capture–recapture models have been used to evaluate population status and estimate survival and the relative importance of survival and recruitment in influencing population trends. The rate of population change (λ) indicates that the population is barely maintaining itself (average λ across years = 0.67; 95% confidence interval [CI] = 0.86–0.54). Annual population estimates have ranged from about 66 fish to almost 130 fish but had wide confidence intervals. Estimates of new lake sturgeon entering the population each year are low, with the current population age structure comprised of fish older than 36 years. Growth is similar to other populations along the eastern Lake Michigan shoreline. Ongoing studies suggest that the population is essentially maintaining itself through a combination of episodic recruitment and relatively constant survival of adults. The likely impact of recent illegal harvest on survival of adults underscores the importance of compliance with the closed fishery.

Physical habitat characteristics were measured at juvenile lake sturgeon capture locations and areas where tagged individuals were tracked through radio telemetry. These data indicate that shallow areas of the river with sand substrates and moderate flows are critical nursery habitat for juvenile lake sturgeon. These areas are typically found along braided-channel margins or along shorelines that are away from the high-velocity areas associated with the main channel. Habitat areas with finer substrates are of secondary importance and may be critical during active movement periods (September to December) when juvenile lake sturgeon forage for small benthic prey. Evidence of recruitment during recent fall gill net surveys may be due to improvements in water quality.

Management of the Grand River lake sturgeon population is limited by the lack of historic information on the population to compare to the assessed current status. In order to protect and rehabilitate this population, additional study is needed. Maintaining closure of the recreational fishery still appears necessary. Bolstering of recruitment through streamside rearing may be needed to increase the population. Full recovery will require persistence and long-term commitment to restoration for this long-lived, late-maturing, infrequently reproducing species.

Tributaries

Crockery Creek was first stocked with brook trout in the 1930s and has been managed for brown trout and steelhead since 1971. Although the stream has limited habitat, stream temperatures are acceptable, and it does provide a modest trout fishery. A 2003 creel survey from May through August estimated 711 angler trips and a catch of 109 steelhead and 38 brown trout. Future management will focus on habitat protection and maintaining the brown trout population through stocking. To maintain the potamodromous fishery, approximately 5,000 steelhead yearlings will be stocked on an annual basis.

Deer Creek and the Bass River are warmwater tributaries that currently receive no active fisheries management. These catchments are predominantly agricultural lands and have been channelized to promote drainage. Biological assessment indicates degraded macroinvertebrate communities and moderately impaired habitat (Rockafellow 2005). Future management of these streams should include further inventories of the fish communities and assessment of management potential. Habitat projects, such as restoration of headwater wetlands, in these watersheds should be promoted.

Norris Creek, a tributary of Spring Lake, was stocked with brown trout plants from 1993 through 1998. However, trout management was discontinued due to poor survival. Water temperatures are suitable for trout survival, but habitat tends to be very poor. Future management should focus on habitat protection and rehabilitation. If these efforts are successful, low-level stocking of brown trout could be reinitiated.

Lakes

Publically accessible lakes in the mouth segment are limited. The bayous along the Grand River, including Spring Lake, provide the most opportunity for fishing lakes in this segment. The bayous are well known for their good bluegill, largemouth bass and northern pike fishing. In recent years, bow fishing for common carp and black buffalo has also become popular along the lower Grand River and its bayous.

Half Moon Lake in Muskegon County is managed as a two-story fishery and is stocked with approximately 7,500 rainbow trout on an annual basis. A 2003 creel survey conducted from June through August estimated nearly 2,400 angler trips (6,100 angler hours) were made to the lake with a catch of 101 rainbow trout and 9,200 bluegills. Assuming rainbow trout survival remains high, the stocking program in Half Moon Lake will continue

Recreational Uses

The Grand River watershed offers a variety of water-based recreational uses. Opportunities for hunting, fishing, swimming, camping, picnicking, boating, and wildlife viewing exist at numerous locations throughout the watershed (Table 25; Figure 63). Public access is provided by lands administered by federal, state, county, township, city, and village governments. Privately held marinas and boat launches are also numerous in the watershed.

Historical estimates of fishing pressure and harvest are available from angler surveys conducted by Conservation Officers from 1928 to 1964 (Appendices 2 and 3). These records indicate preferred fish species, most heavily fished waters, and species abundance. More recent (2002-2005) angler surveys have been conducted on the mainstem, inland lakes, and streams throughout the watershed. These surveys typically follow traditional roving-count and access interview protocols of both boat and shore anglers to develop estimates of angling effort and harvest (see **Fisheries Management**).

There are 140 boating access sites and boat launches (Figure 68) advertised within the watershed, as well as, several unmarked sites on lakes and streams, such as road crossings and road endings, that are commonly used for public access. There are 29 access sites on the Grand River mainstem, many of which are limited to shallow draft boats, kayaks or canoes. The Grand River is navigable from the headwaters to the mouth; however, several dams and road crossings would require portage (see **Dams and Barriers**). Additional public boating access sites are needed on the mainstem and larger tributaries such as the Maple, Looking Glass and Red Cedar rivers. Specific information regarding boating access designs and amenities can be found at http://www.mcgi.state.mi.us/MRBIS/. Fisheries Division continues to work toward acquiring additional access on rivers, streams, and inland lakes throughout the watershed.

The numerous State Game Areas in the watershed contain a large variety of upland, wetland, lake, floodplain, and stream habitats. These areas were purchased to provide hunting opportunities for small game, waterfowl and upland birds, and whitetail deer but are also open to fishing, hiking and wildlife viewing. There are significant amounts of public lands in the headwaters, middle, lower, and mouth segments (Figure 63). Future land acquisitions should target floodplains and adjacent uplands to establish greenways and restore connectivity along riverine corridors.

Headwaters

Canoeing and kayaking are popular in the headwaters. Due to shallow waters and numerous log jams, boating is limited. Public access to the mainstem is provided at Maple Grove Road and Center Lake outlet. Additional canoe/kayak access sites are needed upstream of the City of Jackson. Although there are only eleven boating access sites on inland lakes within this valley segment, many are located on lake chains and provide access to multiple waters. Carefully planned log jam removal would improve river access and promote recreational use.

Upper

The Grand River in this valley segment is large enough to provide recreational opportunities throughout the year and can be navigated with canoes and small boats. There are eight mainstem boating access sites providing access to both free flowing portions of the river and the impounded reaches near Eaton Rapids and Lansing. Public lands are limited to county, city, and township parks.

Middle

The middle segment offers a variety of recreational opportunities, due largely, to the park systems of Eaton and Ingham counties. Although canoe/kayak access is somewhat limited on the tributaries (e.g., Red Cedar and Looking Glass rivers), good access is provided to the mainstem. The local units of government are working to develop extensive river walks connecting various neighborhoods along the Grand River mainstem, Red Cedar River and Sycamore Creek. Major state-owned recreational lands in the middle segment include the Portland State Game Area and Rose Lake Wildlife Research Area.

Lower

Due to its large size and diverse geology, the lower segment offers more variety in recreational opportunities than the other segments. Camping, hiking, mountain biking, skiing, wildlife viewing, hunting, and fishing are available on public lands at a variety of State Game Areas, State Parks and Recreation Areas, and numerous County, Township, and City parks. Information detailing the recreation opportunities on State-owned lands can be found at http://www.michigan.gov/dnr. Significant state-owned lands protecting river corridors and providing public access include the Maple River, Stanton, Langston, Flat River, Barry, and Rogue River state game areas, and the Yankee Springs and Ionia state recreation areas. Additionally, significant park lands are administered by the Kent County Parks and Recreation Department. Ten boating access sites are found on the mainstem and an additional eighty sites are located on tributaries and inland lakes

Mouth

This mainstem segment is also heavily used for recreation. Fishing, hunting, and other recreational opportunities are provided at the Grand Haven State Game Area, Bass River State Recreation Area, and Grand Haven State Park. The Ottawa County Parks and Recreation Commission is developing the Grand River Greenway and has acquired over nine miles of frontage on the mainstem and bayous. The Port of Grand Haven is the home to a large fleet of charter boats offering trips for Lake Michigan salmon, steelhead, brown trout and lake trout. Numerous marinas catering to pleasure boaters operate in the Grand Haven-Spring Lake area.

Citizen Involvement

Citizen involvement is a critical component in the management of the natural resources of the Grand River watershed. The overall mission of Fisheries Division is “to protect and enhance fish stocks and other forms of aquatic life and aquatic habitat, and to promote optimum use of these resources for the benefit of the people of Michigan”. To achieve this mission, and the goal of sustainable fisheries resources, Fisheries Division supports collaborative efforts and open dialog with the public and many stakeholder groups representing a variety of watershed interests. As current trends point toward smaller government, these collaborative and cooperative partnerships are of increasing importance and will be invaluable in the future management of the Grand River watershed.

Citizen involvement occurs in many forms, from letter writing and meeting attendance to membership in watershed councils or angling groups. Many diverse groups are involved in efforts to protect and restore the quality of natural resources in the Grand River watershed (Table 40).

Several of these citizen groups were established as a community response to local watershed issues or to promote recreational uses within the watershed. Many are the recipients of funding grants from federal Clean Water Act funds or other funding initiatives (e.g., Inland Fisheries Grants, Clean Michigan Initiative). These grants have enabled them to develop land use planning tools, foster education and outreach activities, improve habitat, and implement best management practices in their adopted watersheds. Their involvement in management of the Grand River watershed is not limited to interactions with various government agencies charged with the administration of environmental laws and policies. Many of these groups sponsor or participate in annual river cleans-ups, and volunteer water quality monitoring networks such as the Michigan Clean Water Corps (MiCorps).

Grand River Environmental Action Team (G.R.E.A.T.) - The mission of the Grand River Environmental Action Team is “to promote, through activities and educational programs, public awareness for the need to protect and preserve the Grand River, including its watershed and surrounding wetlands in Jackson County, Michigan”. GREAT was founded in 1989 and is a local nonprofit organization. Activities include: river cleanups to pull trash from the river, labeling of storm drains to remind citizens that the drains lead directly to the Grand River, maintenance of an inventory of the rare plants and animals that line the Grand River, and recreational canoe trips along the river to promote an understanding and appreciation of Grand River natural resources.

Upper Grand River Watershed Council - This is a coalition of townships from the upper segment and part of the middle segment. Their goal is to educate residents on ways they, as individuals, can help improve water quality in the Upper Grand River watershed.

Michigan State University Watershed Action Through Education and Research (MSU-WATER) - Initiated in 2000, this project is led by faculty, staff and students from various colleges, departments and support units at MSU. This project integrates research, teaching, and outreach activities within the Red Cedar River watershed. Their goals are: to determine the University’s ecological footprint on the Red Cedar River; enhance MSU’s reputation in water resources research, teaching and outreach; develop a comprehensive watershed plan that includes practical management alternatives; and meet storm water management objectives as required by Phase II of the Clean Water Act.

Friends of the Looking Glass River - The mission of Friends of the Looking Glass is “to promote the enjoyment of and responsibility for the river and to maintain and improve the watershed”. Their goals and objectives are to: promote responsible land use and environmental practice within the watershed; communicate watershed information to managers, decision makers and the general public; develop networks with stakeholders in the Looking Glass Watershed, and; promote responsible recreational use of the Looking Glass River.

Greater Lansing Regional Committee - This committee is comprised of the communities participating within Phase II of the Clean Water Act. Their goal is to guide the implementation of the Phase II program for communities within the Lansing area watersheds of the Grand River, Red Cedar River and Looking Glass River.

Lansing “Perrin” Chapter of Trout Unlimited – This chapter embraces the national Trout Unlimited mission “to conserve, protect, and restore North America’s Trout and Salmon fisheries and their watersheds”. They work to accomplish this through: education of our members and the public on important mission issues; conservation/improvement of specific cold water habitat watershed projects; participation in Trout Unlimited meetings and initiatives to legislative reform; cooperative fund raising activities to allow financial grants to be selectively awarded for activities in agreement with the chapter’s mission: “to preserve, protect and restore Michigan’s watersheds which support wild trout and salmon”.

Friends of the Maple River - The mission of Friends of the Maple River is to preserve, improve and promote through education, the wise use of the Maple River and the Maple River Watershed. They are working toward the following goals: develop an inventory and monitoring program for the water resources, flora and fauna within the Maple River and the Maple River watershed; develop a watershed restoration and management plan; develop educational materials and presentations to educate the public on issues related to the Maple River and the Maple River watershed.

Lower Grand River Organization of Watersheds (LGROW) – A multidisciplinary watershed organization to oversee restoration, protection and enhancement activities in the lower Grand River drainage basin that encompasses more than 3,000 square miles starting at the confluence of the Grand and Looking Glass Rivers in downtown Portland in Ionia County through Metro Grand Rapids to Lake Michigan. The watershed covers ten counties and includes the Thornapple River, Flat River, and Rogue River Watersheds.

Coldwater River Watershed Council - The mission of the Coldwater River Watershed Council is: "Working together to protect, rehabilitate and sustain the ecological and cultural communities that make up the Coldwater River Watershed." They have developed both a management plan and an atlas available at their website to identify non-point source pollutants and to find ways to prevent those pollutants from entering the waterways.

Thornapple River Watershed Council - The goal of the Thornapple River Watershed Council is for the Thornapple River to regain its reputation as some of the best fishing in the mid-west. Their goals and objectives are as follows: to provide a regional vision for the Thornapple River watershed; to promote responsible land use and environmental practices within the watershed and coordinate multiple interests within the watershed; communicate watershed information to managers, decision-makers and the general public; speak with a collective voice and secure state and federal resources for the watershed; develop networks among stakeholders within the Thornapple River watershed.

Kalamazoo Valley Chapter of Trout Unlimited - This chapter of Trout Unlimited has over 500 members. Chapter members have participated in various projects on trout streams throughout southwestern Michigan. In the Grand River watershed, they have been involved in projects on the Coldwater River and Tyler Creek.

West Michigan "Schrems" Chapter of Trout Unlimited - The mission of the West Michigan Chapter of Trout Unlimited is "to conserve, protect and restore west Michigan's coldwater fisheries and their watersheds and to provide a forum for the exchange of information concerning coldwater fisheries and the techniques and the sport of trout fishing". They have been involved in many activities including river clean-ups, stream monitoring, bank erosion control, and fly fishing clinics. In the Grand River watershed, most of their work has been associated with the Rogue and the Coldwater rivers.

West Michigan Walleye Club - The mission of the West Michigan Walleye Club is "to promote the sport of walleye fishing through the education of its members, involvement of youth, and conservation, in a fun and friendly environment". This club assists Fisheries Division with walleye rearing pond management. Spring fingerlings from this partnership are stocked throughout the watershed.

It is evident that there are many concerned and motivated citizens supporting the goals of water quality improvement and the protection of aquatic resources in the Grand River watershed. Citizen involvement is critical for the long-term protection and enhancement of the Grand River watershed.

MANAGEMENT OPTIONS

The Grand River watershed is a fairly healthy system, with habitats that range from cold to cool to warm water in tributaries to predominately warm water in the mainstem. However, fish populations and habitat are degraded in many areas and in need of attention. The management options presented in this assessment are meant to address the most important problems that are now understood and to establish priorities for further investigation. Some management options will be pursued by MDNR Fisheries Division. However, many of the identified options are beyond the scope of MDNR authority and will require the cooperation of private entities and collaboration with many partners.

The options follow recommendations of Dewberry (1992), who outlined measures necessary to protect the health of river ecosystems. Dewberry stressed protection and rehabilitation of headwater streams, riparian areas, and floodplains. Streams and floodplains need to be reconnected where possible. A river system must be viewed as a whole, for many important elements of fish habitat are driven by whole system processes.

The identified options are consistent with the mission statement of Fisheries Division “to protect and enhance fish stocks and other forms of aquatic life and aquatic habitat, and to promote optimum use of these resources for the benefit of the people of Michigan”. In particular, the division seeks to: protect and maintain healthy aquatic environments and fish communities and rehabilitate those that are degraded; provide diverse public fishing opportunities to maximize the value of recreational fishing to anglers; and foster and contribute to public stewardship of natural resources through a scientific understanding of fish, fishing, and fisheries management.

Four types of options for correcting problems in the watershed are presented: 1) options to protect and preserve existing resources; 2) options requiring additional surveys; 3) opportunities for rehabilitation of degraded resources; and lastly, 4) opportunities to improve an area or resources, above and beyond the original condition, are listed last.

History

Archaeologists are interested in the recent past as well as more ancient times. Pioneer homesteads, mills, logging camps, trading posts, and Native American villages can teach us much that was not recorded in written records.

Archaeological and other historic sites can be damaged or destroyed by any activity that disturbs the soil. Most artifacts lie in the upper foot of soil; a few are more deeply buried. The Office of the State Archaeologist and the State Historic Preservation Office maintain records on archaeological sites and other historic sites and can advise on management. Archaeological artifacts cannot be removed without the permission of the land owner. Permits are required for investigation of sites on federal or state lands. There are guidelines to follow while working near archaeological sites (Mead 1985), but the overriding principle is to avoid disturbing soil.

Option: Protect existing and future archaeological and historical sites by contacting the Office of the State Archaeologist and the State Historic Preservation Office before any major earth moving or river restoration projects.

Option: Survey for and identify animal artifacts at archaeological sites to further our understanding of the historical presence of animals within the watershed.

Geology and Hydrology

The mainstem of the Grand River exhibits relatively stable annual flow patterns. However, some reaches and many tributaries have flows that are less stable than expected based on their surrounding geology. Poor land use, channelization and extensive drainage, irrigation practices, and dams cause most of these flow problems.

Option: Protect all existing cold water and cold-transitional, stable streams from effects of land use changes (e.g., increases in impervious surfaces from development practices), channelization, surface and groundwater withdrawals, and construction of dams and other activities that may disrupt the hydrologic cycle by educating and working with planners, zoning boards, developers, drain commissioners, and land owners.

Option: Protect critical groundwater recharge areas by identifying these and developing state and local strategies to protect them. Identify existing large quantity removals of groundwater (e.g., irrigation, industrial, and municipal withdrawals). Promote development and implementation of ecologically-based water withdrawal standards protective of river and stream, inland lakes, and wetlands.

Option: Protect and rehabilitate the function of wetlands and floodplains as water retention structures for high flow conditions. Develop an inventory of existing and potential areas for creation or protection of wetlands, with emphasis on riparian areas.

Option: Protect remaining natural lake outlets by opposing the establishment of new legal-lake levels and the associated construction of lake-level control structures. This would allow for natural variation of water levels in lakes and associated riparian wetlands, and maintain flow in outlet streams.

Option: Protect and rehabilitate flow stability by developing a hydrologic routing model for the entire river system that describes both ground and surface water routes in response to changes on the landscape. Such a model would allow various alternatives to be examined and drive future planning processes by providing fundamental information critical for proactive landscape and storm water management planning. It could also be used to identify critical tributary watersheds.

Option: Protect nearshore habitats and floodplain connectivity of both lakes and streams by encouraging and requiring natural methods of bank and shoreline stabilization (e.g. rock riprap, log or whole tree revetments, and vegetative plantings) rather than seawalls through permitting processes, zoning procedures, and education.

Option: Inventory surface and groundwater withdrawals and establish minimum flow regime standards for the mainstem and all tributaries. Support implementation of the Michigan Water Withdrawal Assessment Tool and other programs that promote water conservation and regulate surface and groundwater withdrawals.

Option: Survey flows and water quality below mainstem and tributary dams and lake-level control structures to determine if minimum flow or run-of-river flow requirements are necessary.

Option: Partner with state and federal hydrologist to identify needs for additional streamflow gauges or miscellaneous flow measurements. Identify funding resources needed to improve collections of streamflow data.

Option: Rehabilitate mainstem and tributary run-of-river flows by operating dams and lake-level control structures as fixed-crest structures rather than by opening and closing gates.

Option: Rehabilitate mainstem and tributary run-of-river flows by removing dams and lake-level control structures where possible.

Option: Rehabilitate summer base flows on mainstem and tributaries by establishing natural flow regime standards downstream of all dams and lake-level control structures. These could be established through administrative or legal processes. This could also be accomplished through maintenance of run-of-river conditions.

Option: Rehabilitate mainstem and tributary flow stability by working with county drain commissioners to incorporate annual and seasonal flow patterns into criteria for drain design and storm water management.

Option: Rehabilitate flow stability and storage capacity through wetland restoration by removing or plugging agricultural drain tiles that are no longer critical for land drainage.

Option: Rehabilitate flow stability by reducing runoff in agricultural catchments through implementation of conservation programs (e.g., Conservation Reserve Program (CRP), Wetland Reserve Program (WRP)). Partner with state and federal Departments of Agriculture and county conservation districts to identify priority areas for restoration.

Option: Rehabilitate developed floodplains by supporting policies that regulate land use activities and reconstruction of roads, homes, and other structures in floodplains after large floods.

Option: Rehabilitate developed floodplains by supporting mitigation that targets removal of flood walls and other structures.

Soils and Land Use

Agricultural and urban land uses have altered large portions of the Grand River system. The basin has gone from a predominately forested landscape to a predominately agricultural and urban landscape. Undeveloped land within the watershed has buffered some changes. However, projected urban sprawl and intensive, high acreage farming threaten the integrity of the buffer and will alter the water budget, routing more water along a surface path. There are 8,639 known road crossings in the watershed; adverse effects attributable to these sources are significant. In addition, pipelines and other submerged crossings affect streams during placement and can cause erosion and barrier problems when exposed in the streambed.

Option: Protect undeveloped landscapes through property tax incentives, transportation policies, integrated land use planning, conservation easements, and policies to encourage redevelopment of urban areas.

Option: Protect water quality and stream hydrology in agricultural catchments through the enrollment of marginal lands into Farm Bill conservation programs (e.g., CRP, WRP). Identify the Grand River as a priority watershed for inclusion in the Conservation Reserve Enhancement Program (CREP) to assist agricultural producers to protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard groundwater and surface water.

Option: Protect pervious open spaces by preserving agricultural landscapes through best management practices and agricultural zoning plans.

Option: Protect developed and undeveloped lands through land use planning and zoning guidelines that emphasize protecting critical areas, minimizing impervious surfaces, and improving storm water management for quality and quantity, and maximizing use of groundwater infiltration systems.

Option: Protect remaining wetlands, especially small, "unregulated" wetlands, by working with local governments and planners, zoning boards, agricultural agencies, and conservation groups to preserve them.

Option: Protect riparian wetlands near the river mouth from additional marina development. Encourage new marinas to utilize off-river basins, with single outlets to the river.

Option: Protect and rehabilitate forested corridors along the river and its tributaries. Encourage additional tree planting and reforestation throughout the watershed.

Option: Protect and rehabilitate critical areas through maintenance of current storm water management systems and retrofitting areas that are in need of storm water management systems.

Option: Protect existing streams from sedimentation and flow constrictions by routing new roads to avoid streams rather than crossing, where feasible. Use MESBOAC design guidelines to review crossing construction and reconstruction proposals to ensure adequate stream protection.

Option: Protect streams from degradation by promoting bore and jack or flume methods of pipeline stream crossings as an alternative to open trench construction.

Option: Protect the functionality of the watershed through legislation that preserves rural lands by controlling urban sprawl and industrial development.

Option: Protect natural river functionality through the purchase of flooding rights within the floodplain (i.e., similar to conservation easements by public and private organizations).

Option: Survey watershed to locate crossings that are degrading streams through sedimentation, disruption of stream flow, or creation of barriers to fish passage.

Option: Survey watershed and create map of all known submerged pipelines. Identify pipelines that are exposed and causing bank erosion or barriers to fish movement and notify the appropriate company for repairs.

Option: Rehabilitate any crossings identified above through erosion control measures, reconstruction of poorly placed crossings, replacing perched culverts, and replacing undersized culverts and bridges.

Option: Survey watershed to identify sources of sediment in runoff from gravel and other secondary roads and rehabilitate through implementation of best management practices.

Channel Morphology

The Grand River channel ranges from normal to degraded for habitat diversity and natural form. Most high-gradient areas have been impounded, covering sections that formerly provided good hydraulic diversity. Dredging, straightening, and high sediment loads have created channels that are homogenous, over wide, shallow, lacking diversity, and lacking woody structure, which has adversely affected both the mainstem and tributaries.

Option: Protect tributaries from further channelization by developing and promoting alternatives to current dredging practices for drainage improvements.

Option: Protect riparian greenbelts through adoption and enforcement of zoning standards. Encourage development of linear parks as a means to protect riparian corridors.

Option: Survey to identify and map all floodplains. Protect existing floodplains and restore historical floodplains to control storm water runoff, stabilize flows, increase infiltration, reduce erosion, preserve natural areas, and prevent flood damage.

Option: Survey channel cross-sections throughout the watershed and further investigate streams that deviate from an expected channel form.

Option: Rehabilitate rare, high-gradient habitats by removing dams no longer used for their original purpose (e.g., Liberty Mill, Putnam Mill, Leoni Mill, Minard Mill, Sixth Street, Lyons, Grand Ledge, Carson City, Rockford, Greenville, North Lansing, and others). Failed dams should be thoroughly evaluated on the basis of environmental and social factors to determine whether reconstruction is appropriate (e.g., Greenville dam). Existing hydroelectric dams should evaluate options for removal or modification at the close of their license term (e.g. Smithville, Mix, Moores Park, Portland, Webber, Hubbardston, Belding, Whites Bridge, Fallasburg, King Mill, Irving, Middleville, Labarge, Cascade, Ada, and several others).

Option: Rehabilitate recruitment of woody structure by developing and managing wooded greenbelts on riparian lands and managing amounts of wood in a channel (e.g., river clean-ups should be carefully planned and carried out to ensure that most structure remains).

Option: Rehabilitate natural channel morphology in the Grand River mainstem and tributaries (e.g., Maple, Flat, Thornapple, Rogue rivers; Prairie and Fish creeks; Quaker Brook; and others) to enhance existing habitat diversity

Option: Rehabilitate stream banks by replacing artificial flood wall structures with more natural banks made of vegetation or field stone (e.g., cities of Jackson, Lansing, and Grand Rapids).

Option: Rehabilitate stream banks by providing a minimum width for vegetated buffer strips and eliminating livestock access.

Dams and Barriers

There are 231 dams in the Grand River watershed, and many have significant negative effects on aquatic resources. Dams fragment habitat for resident fish, impede fish movements, impound high gradient areas, trap sediments and woody structure, cause flow fluctuations, cause fish mortalities (entrainment with hydroelectric dams), and block navigation. Lake-level control structures alter natural water regimes and can severely impair downstream aquatic habitat. Some dams, however, provide impoundments with existing and future potential for fisheries and other recreational uses not provided by flowing water.

Option: Protect and improve biological communities by providing upstream and downstream fish and large woody structure passage at dams to mitigate for habitat fragmentation (e.g., Smithville, Mix, Moores Park Hubbardston, Prairie Creek, Greenville, Belding, Whites Bridge, Fallasburg, King Mill, Irving, Middleville, Labarge, Cascade, Ada, Rockford and several others).

Option: Protect fishery resources by recommending screened turbine intakes at operating hydroelectric dams (e.g., Moores Park).

Option: Protect remaining connectivity of the river system by opposing construction of dams and within-stream-channel storm water detention basins.

Option: Protect fishery habitat and river functionality through active opposition to hydroelectric facilities development within the Grand River basin. Encourage the use of turbine technology that does not require damming of the river. If hydroelectric development cannot be avoided, the Department of Natural Resources should forcefully pursue mitigation of all project effects on the resource. Such mitigation would include, but not be limited to, passage of all fish species.

Option: Survey and develop an inventory of barriers to fish passage, such as perched or misaligned culverts, and explore options to correct any problems.

Options: Survey and develop a list of the most environmentally damaging dams and barriers to fish passage in the river, with recommendations to mitigate damage.

Option: Survey to determine the number of small unregistered dams in the basin.

Option: Rehabilitate free-flowing river conditions by encouraging dam owners to make appropriate financial provisions for future dam removal, and seek legislation to require dam owners to establish such funds.

Option: Rehabilitate free-flowing river conditions by removing dams, requiring dam owners to operate at run-of-river, and modifying all possible dams to fixed-crest structures (e.g., Smithville, Mix, Moores Park Hubbardston, Greenville, Belding, Whites Bridge, Fallasburg, King Mill, Irving, Middleville, Labarge, Cascade, Ada, Rockford and several others).

Option: Rehabilitate river navigability by constructing canoe portages and upstream and downstream access sites at dam locations on the mainstem and major tributaries (e.g., Ada, Cascade).

Option: Rehabilitate natural water levels by requiring all lake-level control structures to be operated to maintain existing seasonal water level fluctuations. Lake-level control structures could be removed or converted to fixed-crest structures to accomplish this.

Option: Rehabilitate river functionality through foundation support and appropriations to create a dam removal fund that local communities (e.g., Eaton Rapids, Lyons, Grand Ledge, Grand Rapids, Greenville, Rockford, and others) can use to help remove their unwanted dams.

Options: Promote benefits of river restoration through alternative proposals that provide an attractive waterfront in communities where dam removal may be an option (e.g., Eaton Rapids, Lyons, Grand Ledge, Grand Rapids, Greenville, Rockford, and others).

Special Jurisdictions

Natural resources and environmental quality are managed directly by the State of Michigan through the Department of Natural Resources and Department of Environmental Quality. The Federal Energy Regulatory Commission licenses active hydropower facilities within this watershed. County drain commissioners have authority over designated drains and many lake-level control structures. Township and city officials control zoning and ordinances that can affect the quality of the river system.

Option: Protect recreational access to streams by continuing to advocate and work toward legislative adoption of the recreational definition of navigability (e.g., a stream is legally navigable if it can be navigated by a canoe or small boat).

Option: Protect and rehabilitate the river system by supporting cooperative planning and decision-making. Develop a Geographic Information System that could be used in these processes (e.g., the Watershed Interactive Mapping initiative that was developed as part of the 319 project for the lower Grand River watershed, could be expanded both in content and geographic extent to the entire watershed).

Option: Protect cold water tributaries by designating appropriate reaches as trout streams to ensure proper management and environmental protection.

Option: Protect the quality of wetlands, streams, and lakes through rigorous enforcement of Parts 31, 91, 301, and 303 of the Natural Resources and Environmental Protection Act, PA 451 of 1994.

Option: Survey and identify river reaches for Country-Scenic designation pursuant to the Natural Rivers Act, Part 305 of the Natural Resources and Environmental Protection Act, PA 451 of 1994 (e.g., Grand, Maple, and Thornapple rivers).

Option: Rehabilitate designated drains by encouraging drain commissioners to use stream management approaches that protect and rehabilitate natural processes rather than traditional deepening, straightening, and widening practices that emphasize moving water away quickly with little consideration for the effect on the stream or biota.

Option: Rehabilitate designated drains to natural stream status where drain designation is no longer appropriate or where past drainage modifications have been excessive and permanently altered stream channels (e.g., Coldwater River, Stony Creek, Maple River, Thornapple River).

Option: Rehabilitate designated drains by supporting efforts to amend the Drain, Code, PA 40 of 1956, to include provisions for the protection and enhancement of fish and wildlife resources.

Option: Rehabilitate lake outlet streams by encouraging run-of-river management at lake-level control structures. Support establishment of natural flow regime standards through amendments to Part 307, Inland Lake Levels, of the Natural Resources and Environmental Protection Act, PA 451 of 1994.

Option: Protect surface water and groundwater resources from over-exploitation through the support of the Michigan Water Withdrawal Assessment Program. Support future refinements including the development of index of flow alterations for Michigan streams.

Water Quality

The Grand River basin has historically suffered from poor water quality due to unregulated discharges from municipal and industrial point source discharges. Water quality in the basin has steadily improved, and virtually all point source discharges are now regulated through the National Pollutant Discharge Elimination System (NPDES) permitting program administered by the MDEQ

Water Bureau. Contemporary causes for non-attainment of water quality standards include poorly-designed sanitary sewer systems that allow for combined sewer overflows (CSO) and sanitary sewer overflows (SSO), nonpoint source pollution from the lack of best management practices in the uplands, deposition of airborne pollutants, and localized degradation from contaminated sediments and venting contaminated groundwater. The Grand River watershed is a significant source of nitrogen, mercury, and atrazine loadings to Lake Michigan. It is sixth overall in total PCB loads to Lake Michigan.

Option: Partner with federal, state, and local agencies to identify high quality river and stream segments and ensure protection of these areas through full implementation of Parts 31, 301, 303, of the Natural Resources and Environmental Protection Act, PA 451 0f 1994.

Option: Partner with federal, state, and local agencies to establish a network of fixed monitoring stations to develop long-term trends of water and sediment quality, biological diversity, and attainment of designated uses.

Option: Protect and rehabilitate water quality through infrastructure redevelopment projects to identify and eliminate discharges from combined sewer overflows and sanitary sewer overflows.

Option: Protect and rehabilitate water quality by implementing improved storm water and nonpoint source best management practices. These projects are needed in urban and agricultural areas throughout the entire watershed.

Option: Protect and rehabilitate water quality by supporting the development and implementation of total maximum daily load (TMDL) limits for pollutants in the watershed (e.g., mercury, PCBs, pathogens, etc.).

Option: Protect water quality and fish habitat by ensuring enforcement and compliance of erosion control permits under Part 91 of the Michigan Natural Resources and Environmental Quality Protection Act (1994 PA 451).

Option: Protect water quality by conserving existing wetlands and riparian corridors, rehabilitating former wetlands, and maximizing use of constructed wetlands as natural filters. Promote use of low impact development technologies.

Option: Protect river quality by supporting educational and other pollution prevention programs targeting the agricultural industry, land developers, and other resource users who teach land and water management practices that prevent further degradation of aquatic resources.

Option: Protect groundwater and stream flows through implementation of the water withdrawal assessment process pursuant to PA 34 of 2006.

Option: Protect major aquifers in the watershed by promoting hydrogeologic studies to characterize groundwater and programs to protect groundwater from contamination.

Option: Measure of nutrient and sediment loading to the river and develop strategies to reduce nonpoint source pollution problems by working with federal, state and local partners.

Option: Survey groundwater use to determine resource availability and potential for overuse.

Option: Survey water quality to determine the effects of water withdrawal.

Option: Survey thermal effects of dams to determine where effects are greatest.

Option: Rehabilitate and protect water quality by supporting remediation of environmental contamination sites.

Option: Rehabilitate water quality (reduce nonpoint source pollution) by encouraging communities to implement best management practices that reduce contributions of refuse, sediment, and pollutants to the river.

Biological Communities

The biological communities of the Grand River have improved significantly since the 1970s due to water quality improvements. However, certain problems still require consideration. There has been a decline in species that require clean gravel substrates. This habitat has been lost to sediment deposition, impoundments of high gradient areas from dams, and channelization. There has also been a loss of potamodromous species that historically used the river for spawning (e.g., lake sturgeon). These species have been cut off from spawning habitats by dams on the mainstem and tributaries. Channelization and stream clearing have degraded channel morphology and removed woody structure used for habitat and raised stream temperature. Mussel and aquatic invertebrate species have declined from poor water quality, sedimentation, and loss of free-flowing river and gravel habitats due to impoundments. Amphibians and reptiles have been on the decline presumably from wetland loss. Introduction of exotic species has harmed native biodiversity through direct competition or indirectly through habitat impairment.

Option: Protect remaining stream margin habitats, including floodplains and wetlands, by encouraging setbacks and vegetated buffer strips in zoning regulations, controlling development in the stream corridor, and acquiring additional greenbelts through agricultural conservation programs, conservation easements, or direct purchases by conservation organizations or government agencies.

Option: Protect remaining high gradient and naturally-graveled habitats, especially the area downstream of the City of Grand Rapids, which contains lake sturgeon spawning habitat potential. Other natural stretches on the mainstem and tributaries should also be protected (e.g., mainstem in the Portland State Game Area).

Option: Protect native biological communities from the spread of nonindigenous species through education and public awareness. Encourage rigorous enforcement of laws prohibiting possession and/or release of banned species.

Option: Protect native mussels through channel restoration (e.g., dam removal) and through survey and translocation requirements for all in-stream construction projects (e.g., bridge, pipelines, and other crossings).

Option: Protect and rehabilitate cold, cold-transitional, and warm-transitional thermal habitat areas and their unique biological communities. Examples include: Rogue River and tributaries, Flat River and tributaries, Thornapple River and tributaries and most of the small tributaries of the mainstem in Ionia and Kent Counties.

Option: Protect and rehabilitate upland habitats for native plant and wildlife diversity.

Option: Survey and map biological community distributions in the watershed using advanced technology including global positioning and geographic information systems. Identify measures to protect areas with unique biological communities and locations supporting significant aquatic biodiversity.

Option: Survey distribution and status of aquatic invertebrates (crayfish, mussels, snails, and insects) and fish fauna.

Option: Survey distribution and status of amphibians and reptiles within the watershed and protect critical habitats.

Option: Survey distribution and status of other species of conservation interest (e.g., endangered, threatened, special concern, and species of greatest conservation need), develop protection and recovery strategies for those species, and explore options to protect critical habitat and maintain biodiversity (e.g., Michigan Wildlife Action Plan, southern Michigan ecoregional planning process).

Option: Develop a lake sturgeon management plan for the Grand River. Continue survey efforts to strengthen population estimates and determine distribution and status in the mouth and lower mainstem segments. Identify and map critical spawning and juvenile rearing habitats and develop protection plans for these areas.

Option: Survey distribution and status of river redhorse and other redhorse species identified as species with the greatest conservation need throughout the watershed but primarily in the lower mainstem segment and lower segment tributaries such as the Flat, Thornapple and Rogue Rivers. Develop and implement a redhorse management plan.

Option: Survey distribution and status of cisco throughout the watershed. Complete and implement a cisco management plan.

Option: Rehabilitate rare, high-gradient areas and fragmented habitats by removal of dams where feasible, as described above.

Option: Rehabilitate and improve populations of fish and native mussel species by installing upstream and downstream passage at dams and barriers where removal is not feasible (e.g., rock arch rapids, rock ramps). Structures should restore fish passage for all species during all seasons and flows. Since fish serve as hosts and vectors of distribution for mussels, passage for all fish species benefits mussels as well. Existing passage facilities that currently pass only salmonids need to be redesigned and constructed to accommodate all species (e.g., Sixth Street, Lyons, Webber, Portland, Grand Ledge, and North Lansing).

Option: Rehabilitate fish diversity by re-establishing the extirpated weed shiner to the watershed.

Option: Increase public awareness regarding the detrimental ecological effects of spreading aquatic pest species. Promote education through signage at all water access sites, bait shops, boat dealers. Promote education and outreach programs through local outlets (e.g., MSU Extension, SeaGrant, and Conservation Districts). Encourage Department of Agriculture to notify aquarium and pet trade of restricted and banned species lists.

Fishery Management

The Grand River watershed has the potential to support substantial populations of cold, cool and warmwater fish along much of its length. Angling is good, particularly in the lower and mouth segments. Yet, angling pressure is generally low, except during the spawning runs of potamodromous species and the trout fishery in some of the tributaries. Angling opportunities could be expanded through more concerted management and careful review of existing management practices.

Option: Protect aquatic habitats through technical review of environmental permit applications. Make recommendations to mitigate unavoidable habitat impacts.

Option: Survey fish populations and inventory habitat in waters where data is limited or lacking (e.g., Maple and Flat rivers).

Option: Conduct inland creel surveys to assess fishing pressure, and understand angler behaviors, interests, values, attitudes, and knowledge.

Option: Evaluate alternative sea lamprey barrier technologies in the mouth segment to allow for removal or modification of the Sixth Street Dam and fish ladder and restore fish passage for all species.

Option: Survey water temperatures and trout survival in managed waters (e.g., Buck Creek, Sand Creek, etc.) to determine if trout stocking is prudent (e.g., summer temperatures too marginal, natural reproduction can sustain fishery, adjust strains, or continue stocking).

Option: Survey and evaluate fish and invertebrate species of conservation interest (e.g., lake sturgeon, cisco, redhorse suckers, freshwater unionid mussels, and crayfish).

Option: Survey and evaluate existing walleye, channel catfish, and flathead catfish populations in the lower and mouth segments.

Option: Rehabilitate habitat continuity by removing unnecessary dams. Require upstream and downstream fish passage of all fish species on those dams that remain.

Option: Rehabilitate lake sturgeon spawning activity in the lower mainstem segment by removing or providing adequate fish passage at Sixth Street, Lyons, Webber, and Portland dams.

Option: Rehabilitate historical populations of Great Lakes muskellunge in the mouth and lower mainstem segments by initiating stocking programs and providing fish passage or removing dams.

Option: Improve angling opportunities by continued improvement and acquisition of public access property (e.g., Bear Creek, Prairie Creek, and others).

Option: Maintain fishing opportunities through existing stocking programs (e.g., walleye, brown trout, cohos salmon, Chinook salmon, and steelhead). Stocked waters should continue to be surveyed to evaluate fish populations and angler use to justify future stocking.

Option: Survey and evaluate need for special regulations to protect species (e.g., river redhorse), to provide unique fishing opportunities (e.g., muskellunge management), or provide trophy fisheries through catch and release angling.

Recreational Use

The watershed provides great recreational opportunities in public-owned areas. The river and tributaries are used frequently for fishing, hunting, canoeing, and nature watching, especially through state recreation and game areas. These recreational opportunities would be enhanced by increased public access (e.g., more boat and canoe launches) to the river and its tributaries. Navigation is impeded by poorly designed and maintained portages around some mainstem and tributary dams. Recreational use would also significantly increase once the stigma of combined sewer overflows is removed.

Option: Protect, encourage, and support existing parks and promote responsible management for riparian areas in public ownership.

Option: Protect recreational (fishing, canoeing, hunting, wildlife viewing etc.) use of small tributaries by supporting establishment of a “recreational” definition of legal navigability as opposed to the “commercial” definition.

Option: Protect angler access by considering development of a stream public right-of-way by purchasing easements for angler access from private land owners.

Option: Survey and quantify recreational user groups within the river system, and identify programs to enhance compatible use of resources (e.g., educate liveries of the importance of woody structure in streams; educate pleasure boaters and personal watercraft users of proper operational etiquette near shorelines, wildlife, swimmers, and anglers).

Option: Survey recreational users to assess access needs (e.g., locations, facilities).

Option: Survey and promote recreational areas through more efficient use of media outlets and publications.

Option: Rehabilitate canoe portages and boat launches at all dams along the mainstem and on the Flat, Thornapple and Rogue rivers. These sites can be maintained by hydropower facilities under FERC re-licensing agreements where applicable.

Option: Rehabilitate small-scale public access where lacking through MDNR, county, township, and other municipal recreation departments, as well as private organizations.

Option: Rehabilitate access through funding support for fishing piers, river walkways, and other facilities to provide recreational use of the river. Allow these grant monies to be used for maintenance needs.

Citizen Involvement

Citizen involvement in the watershed is increasing. Several groups have developed with specific goals for the watershed. It is important that all interest groups communicate with each other as well as with other groups around the state to develop educated and effective management strategies toward watershed improvements.

Option: Protect the natural landscape by supporting local land conservancies, and conservation districts in identifying lands for acquisition and conservation easements.

Option: Improve communication between interest groups in the Grand River watershed.

Option: Maintain and expand Fisheries Division's partnerships with continued involvement with citizen groups by attending meetings, reviewing project proposals, and providing information about the watershed.

Option: Maintain and improve strategies to educate the community to the benefits of river ecosystems, wetlands, and floodplains by supporting local conservation organizations.

Option: Rehabilitate and improve river habitat by encouraging and supporting habitat improvement projects conducted by sport and/or watershed groups.

Option: Improve citizen use of the river by supporting programs that encourage use and contact with the river and its tributaries.

GLOSSARY

aggradation - the accumulation of bed materials

ammocetes - juvenile lampreys that burrow in the substrate of streams for 3 to 6 years before transforming and migrating downstream to Lake Michigan

base flow - groundwater discharge to a stream system

basin - a complete drainage including both land and water from which water flows to a central collector such as a stream or lake at a lower level elevation, synonymous with watershed

bedrock outcrop - emergence of early geologic rock at the soils surface

benthic - plants and animals living on, or associated with, the bottom of a water body

biological integrity - the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region

biological oxygen demand - the measure of the consumption of oxygen in an ecosystem within a fixed period of time

biota - animal and plant life

BP - before present

cfs - cubic feet per second

channelize - to straighten and clean a streambed or waterway to enhance land drainage

channelization - a process of altering natural stream channels by straightening, widening, and deepening to improve water movement

channel morphology - the study of the structure and form of stream and river channels including pattern (sinuosity), dimension (width, depth), profile (slope) and bed materials.

cobble - naturally rounded stones larger than pebbles and smaller than boulders arbitrarily limited to a size of two to ten inches in diameter

confluence - the joining or convergence of two streams

CSOs – Combined Sewer Overflows

draft – the depth of water that a ship requires, particularly when loaded with cargo

drawdown - removal of stop logs, or similar retaining structure, resulting in the lowering of water levels in an impoundment

drought flow - water flow during a prolonged period of dry weather

ecological - the relations between living organisms and their environment

ecosystem - a biological community considered together with the non-living factors of its environment as a unit

effluent - the outflow of a sewer, septic tank, municipality, industry etc.

electrofishing - the process of putting an electric current, either AC or DC, through water for the purpose of stunning and capturing fish

end moraine - an arch-shaped ridge of moraine found near the end of a glacier

entrainment - to trap an object during a given mechanical process (e.g. fish in hydropower turbine)

erosion - the process of moving soil particles by wind or rain

evapotranspiration - the loss of water from plant material to the atmosphere

exceedence flow - the probability of a discharge exceeding a given value

exotic species - successfully reproducing organisms introduced by human action into regions where they did not previously exist

extirpate - to make extinct by removing

fauna - the animals of a specific region or time

FCMP - Fish Contaminant Monitoring Program

FD - Fisheries Division

FERC - Federal Energy Regulatory Commission

flashy - streams and rivers characterized by rapid and substantial fluctuations in stream flow

floodplain - a relatively flat valley floor formed by floods which extends to the valley walls

forage – a group of fish that provide food for piscivorous fish

game fish - fish species that are commonly sought by anglers; also called sport fish

glacial outwash - gravel and sand carried by running water from the melting ice of a glacier and deposited in stratified layers.

GLFC - Great Lakes Fishery Commission

gorge - a primitive fishing device made of a sliver of copper or bone that is pointed at both ends with a line attached at mid-shank and then baited. When a fish swallowed it, it was pulled so that it became lodged in the mouth of the fish

gradient - rate of decent of a stream usually expressed in feet per mile

gradient class - an index of hydraulic diversity in streams

ground moraine – continuous layer of till near the edge or underneath a steadily retreating glacier

groundwater - water that contained in subsurface aquifers.

heterogeneity - having composition of dissimilar parts: diversity or variety

hydraulic diversity - the variability of water depths and velocities in a stream or river channel

hydrograph - a graph of the water level or rate of flow of a stream as a function of time, showing seasonal change

hydrology - the science of water

hyporheic zone – Subsurface zone in streams where surface water and groundwater exchanges occur (*hypo* = under; *rheo* = flow)

ice contact - pervious glacial material (gravel) found in moraines that is associated with groundwater recharge

impermeable - will not permit fluids to pass through

impervious - not permitting penetration or passage

impingement – a process of physically capturing juvenile and adult fishes on screens designed to prevent debris from entering a power plant along with process cooling water

impoundment - water of a river system that has been held up by a dam, creating an artificial lake

indigenous - a species that is native to particular area

infiltration – a process of water moving through soil particles

interlobate – between lobes of a glacial moraine formation

invertebrate – an animal having no backbone or internal skeleton

lacustrine - pertaining to lakes

lake plain - land once covered by a lake that is now elevated above the water table

lake-level control structure - a low head dam placed at the outlet of a lake to control the lake level

land cover - primary character or use of an area of land (e.g. forest, wetland, agriculture, urban, barrens, water, etc.)

large woody structure – trees, logs, and logjams that are in a stream or lake

lentic - pertaining to or living in still water

loam - a soil consisting of an easily crumbled mixture containing from 7 to 27% clay, 28 to 50 % silt, and less than 52% sand

macroinvertebrates - animals without a backbone that are visible to the naked eye

mainstem - the primary branch of a river or stream, sometimes referred to as mainstream

mainstem segment – reach of a river with similar ecological characteristics

MDCH - Michigan Department of Community Health

MDEQ - Michigan Department of Environmental Quality

MDNR - Michigan Department of Natural Resources

meander - a winding, curving stream segment

mitigation - action required to be taken to compensate for adverse effects of an activity

moraine - a mass of rocks, gravel, sand, clay, etc. carried and deposited directly by a glacier

morphology - pertaining to form or structure of a river or organism

moss animals - taxa belonging to the Bryozoa phylum

niche - the position or function of an organism in a community of plants and animals

NOAA - National Oceanic and Atmospheric Administration

NPDES - National Pollution Discharge Elimination System

nonpoint source pollution - pollution to a water course that is not attributable to a single, well-defined source, e.g., sediment resulting from poor agricultural practices

outwash - sand and gravel washed from a glacier by the action of meltwater

P.A. - Public Act

panfish - fish in the centrarchid family commonly harvested by anglers to eat. Species include bluegill, black crappie, pumpkinseed sunfish, and rock bass

PCB - polychlorinated biphenyl

peaking mode - operational mode for a hydroelectric project that maximizes economic return by operating at maximum possible capacity during peak demand periods (generally 8 am to 8 pm) and reducing operations and discharge during non-peak periods

perched culvert - an improperly placed culvert that fragments habitat by creating a significant drop between the culvert outlet and stream surface

permeable - soils with coarse particles that allow passage of water

pestilent - noxious species that out compete native or more socially valuable species

phytoplankton - minute, free-floating aquatic plants

piscivorous - fish eating

plankton - floating or drifting organisms in a body of water

Pleistocene Epoch - also known as the Ice Age; period from 1,600,000 - 10,000 BP

point source pollution - pollution to a water course that is attributable to a single, well-defined source, e.g., outfall of a wastewater treatment plant

potamodromous - fish that migrate from fresh water lakes up fresh water rivers to spawn; in the context of this report it refers to fish that migrate into the Grand River from Lake Michigan

reach - a section of river

retention time - the amount of time it takes for the total volume of water in an impoundment to be replaced by incoming stream flow; also referred to as the reservoir's flushing rate

riffle - a shallow area extending across the bed of a stream where water flows swiftly so that the surface is broken in waves

riparian - adjacent to or living on the bank of a river; also refers to the owner of stream or lakefront property

riverine - of or pertaining to a river

rotenone - a natural substance found in roots of plants in the pea family; it is used as a toxicant to gill breathing animals and often as a home garden insecticide

run habitat - fast non-turbulent water

run-of-river - instantaneous inflow of water equals instantaneous outflow of water; this flow regime mimics the natural flow of a river on impounded systems

salmonids - collective group of all trout and salmon in the family Salmonidae

savanna - a treeless plain or grassland with scattered trees

sedimentation - a process of depositing silt, sand, and gravel on a stream or river bed

side-wheeler - a ship that has a paddle wheel on each side for propulsion

sinuosity - the degree of bending, winding, and curving of a river system

specific stream power - rate at which potential energy is supplied to a stream channel bed and banks; primarily a function of discharge and slope

sport fish - fish valued by anglers

surficial - referring to something on or at the surface

TFM - 3-trifluoromethyl-4-nitrophenol, A chemical toxicant used in the control of sea lamprey populations

tile - an underground enclosed drainage system generally installed for draining farmland

till - a mix of glacial clay, sand, boulders, and gravel

TMDL - total maximum daily loading

topography - the configuration of the earth's surface including its relief and the position of its natural features

tributary - a smaller stream feeding into a larger stream, river, or lake

turbidity - the measure of suspended sediments in the water column

USDA - United States Department of Agriculture

USGS - United States Geological Survey

valley segment - reaches of a river with similar ecological characteristics

veliger - the free-swimming larval stage of zebra mussels

watershed - the drainage area of basin, both land and water, from where water flows toward a central collector such as a stream, river, or lake at a lower elevation; synonymous with basin

wastewater treatment - the treatment of sewage

WD - Water Division of the Department of Environmental Quality

wetland - those areas inundated or saturated by surface or groundwater at a frequency and duration enough to support types of vegetation typically adapted to life in saturated soil; includes swamps, marshes, fens, and bogs

zooplankton - small, usually microscopic animals suspended in water

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