



**STATE OF MICHIGAN
DEPARTMENT OF NATURAL RESOURCES**

Number 97-3

December 31, 1997

Overview of the Michigan Rivers Inventory (MRI) Project



**MICHIGAN DEPARTMENT OF NATURAL RESOURCES
FISHERIES DIVISION**

**Fisheries Technical Report No. 97-3
December 31, 1997**

OVERVIEW OF THE MICHIGAN RIVERS INVENTORY (MRI) PROJECT

**Paul W. Seelbach
and
Michael J. Wiley**



The Department of Natural Resources provides equal opportunities for employment and access to Michigan's natural resources. Both State and Federal laws prohibit discrimination on the basis of race, color, national origin, religion, disability, age, sex, height, weight or marital status under the Civil Rights Acts of 1964, as amended, (1976 MI P.A. 453 and 1976 MI P.A. 220, Title V of the Rehabilitation Act of 1973, as amended, and the Americans with Disabilities Act). If you believe that you have been discriminated against in any program, activity or facility, or if you desire additional information, please write the MDNR Office of Legal Services, P.O. Box 30028, Lansing, MI 48909; or the Michigan Department of Civil Rights, State of Michigan, Plaza Building, 1200 6th Ave., Detroit, MI 48226 or the Office of Human Resources, U. S. Fish and Wildlife Service, Washington, D.C. 20240.

For information or assistance on this publication, contact the Michigan Department of Natural Resources, Fisheries Division, Box 30446, Lansing, MI 48909, or call 517-373-1280.



*Printed under authority of Michigan Department of Natural Resources
Total number of copies printed 200 — Total cost \$394.36 — Cost per copy \$1.97*

Overview of the Michigan Rivers Inventory (MRI) Project

Paul W. Seelbach

*Institute for Fisheries Research
Michigan Department of Natural Resources
212 Museums Annex
Ann Arbor, Michigan 48109*

and

Michael J. Wiley

*School of Natural Resources and Environment
The University of Michigan
Ann Arbor, Michigan 48109*

Abstract.—The sound, scientific management of lower Michigan's expansive river systems will require a sophisticated understanding of their ecological structures and processes, and a careful evaluation of the state of these rivers as they currently exist—i.e. a comprehensive inventory. To this end we developed a partnership in 1988 between scientists at the Michigan Department of Natural Resources—Institute for Fisheries Research, and the University of Michigan—School of Natural Resources and Environment, known as the Michigan Rivers Inventory (MRI) project. Our strategy for studying the comparative ecology of Michigan rivers has four primary components: conducting an *Inventory*, developing *Descriptions and Predictive Models*, developing an *Ecological Classification System*, and developing *Management Applications*. The foundation of the inventory was a large Geographic Information System (GIS); i.e. a collection of maps and a relational, geo-referenced database containing key physical and biological characteristics for a large number (~675) of river sites representative of rivers draining the Lower Peninsula of Michigan. Data incorporated in the MRI came from a variety of sources and included (1) field measurements made by project personnel; (2) numerous existing datasets that were compiled by other State and University research groups; (3) mapped data of various origins that could be processed and related to MRI study sites by manipulation in a GIS; and (4) "synthetic" data produced by modeling site-scale variables (for example stream flows) from summaries of catchment landscape characteristics for a subset of sites. To explore linkages between different-scale habitat variables and fishes, we emphasized data development at 3 distinct spatial scales of influence: (1) the catchment landscape; (2) the local channel reach; and (3) the immediate sampling site. The temporal extent of the data covered the past 2.5 decades, providing a reasonable summary of the current nature of Michigan's rivers. We used the GIS to develop several graphical summaries and statistical models of habitat and fish community characteristics. These helped to identify broad patterns within the data, explore the underlying relationships between local ecological conditions and the larger-scale processes that drive them, and to provide predictive capabilities. We likewise developed an ecological classification for the river valley segments of Michigan's Lower Peninsula, incorporating both physical and biotic

segment attributes. The multi-scale framework of the MRI approach provides a toolbox for addressing many local river management issues. Viewing a system in its larger-scale (landscape) context helps managers to define key variables and constraints that shape site-scale problems. MRI models provide the complimentary ability to predict specific site-scale attributes for developing management expectations and targets. Comprehensive regional assessments like the MRI ultimately should provide a platform for more-informed, broader-scale thinking and communication about river ecosystems. The MRI is an ongoing project; current work includes extending geographical coverage to Michigan's Upper Peninsula and further refinement of the valley segment ecological classification system.

Hundreds of permanently-flowing streams drain Michigan's Lower Peninsula. These form about 20 major river ecosystems, and scores of smaller, coastal systems. Managed wisely these fluvial resources can provide a rich suite of ecological, water supply, recreational, and aesthetic benefits for years to come. Sound scientific management of these expansive systems will require a sophisticated understanding of their ecological structures and processes, and a careful evaluation of the state of these rivers as they currently exist-- i.e. a comprehensive inventory. Extensive historical data sets on many aspects of Michigan's rivers already exist. In Appendix 1 we provide a guide to key references that illustrate both the disciplinary breadth and the impressive histories of earlier Michigan river survey efforts. But as is commonly observed (Chamberlin 1984), most of these studies have been carried out by separate agencies, were purposefully narrow in focus, and the results of many are difficult to locate and utilize. Despite the fact that large amounts of detailed information have been collected (often through routine government monitoring), available data are not well integrated, nor have they been examined from a holistic perspective. There is a pressing need to gather and synthesize the wealth of relevant information on Michigan's rivers.

To this end we developed a partnership in 1988 between scientists at the Michigan Department of Natural Resources--Institute for Fisheries Research, and the University of Michigan--School of Natural Resources and Environment, known as the Michigan Rivers Inventory (MRI) project. This collaboration has been largely informal, built initially around the project "Inventory and classification of

Michigan rivers" (funded primarily by Federal Sportfish Restoration monies and several small university grants). The combined platform of the state agency and the university has consistently provided many logistic and technical resources. More recently, MRI work has been developed further through a series of more specifically-focused, externally-funded research projects (Table 1).

The overall purpose of the MRI has been to study the comparative ecology of Michigan rivers. Though interested in the full spectrum of rivers found in Michigan, we felt the Lower Peninsula represented a natural study unit of a scale consistent with our logistical abilities to conduct field sampling from our operating base in Ann Arbor (located in southeast MI). Lower Peninsula rivers also represent an interesting, very hydrologically-diverse set; some rivers are nearly entirely runoff-driven, while others are nearly entirely groundwater-driven.

Conceptually, we view rivers as large-scale hydrologic, geomorphic, and biological systems, rather than as aggregations of distinct sites (Wiley and Seelbach 1997). As rivers are expansive, landscape-scale systems, we have also drawn upon the fundamental principles of the discipline of Landscape Ecology (Risser et al. 1983; Ricklefs 1987; Levin 1992; Pickett and Cadenasso 1995). For example: (1) River system dynamics involve the transfer of water and sediment downslope across complex mosaics of landscape units; in the MRI we focused on hydrology as a key discipline linking landscape, channel, and ecological processes. (2) Large-scale patterns in ecosystem structure and dynamics exist within and among rivers; in the MRI, we searched for patterns in ecological characteristics of rivers that could be quantified

both within and across systems, and for relationships among variables that might suggest mechanisms behind the observed patterns (Levin 1992). And finally, (3) human-modified landscapes are integral to the study of rivers; in the MRI we studied river systems as they presently exist, often radically-modified by human activities. Landuse variables were explicitly included in many of our descriptions and models.

The goals of the MRI project were:

- To assemble selected data on important aspects of Michigan's watershed landscapes, river channels, and associated fishes.
- To describe the broad-scale spatial variation and patterns observed in these river ecosystems and their fish assemblages.
- To develop a set of models that suggest mechanisms behind the patterns observed in river ecosystems; both for comparison with existing theories of river organization and to provide predictive capabilities to river managers.
- To develop a system for the classification of ecological units within Michigan rivers.
- To develop decision-making tools for river management.

This report is the underlying reference document for the MRI project. In it we document both our conceptual approach and some of the fundamental methods. Hopefully it can also serve as a guide to others involved in developing regional inventory programs.

The objectives of this report were:

- To provide an overview of the conceptual and functional approach used in the MRI.
- To describe the MRI GIS (map and database system) structure.
- To describe development of primary datasets.
- To provide a guide to current and expected products.

Overview of the MRI

Our strategy for studying the comparative ecology of Michigan rivers had four primary components (Figure 1):

- 1) We conducted an *Inventory* to assemble data (existing and new) on characteristics of river sites, their catchments, and associated fishes.
- 2) We used these data and appropriate hydrologic, geomorphic, and ecologic theory to develop *Descriptions and Predictive Models* of both physical habitats and fish communities; these both describe patterns and help clarify causal hypotheses. Model outputs were incorporated into the inventory database as site attributes.
- 3) We developed an *Ecological Classification System* to allow generalization of the complexity found in river ecosystems. Again, classification attributes were incorporated into the inventory database.
- 4) We developed *Management Applications* for specific projects to demonstrate how MRI tools could be used to aid local decision-making.

Inventory

We developed a rivers inventory by building a large Geographic Information System (GIS); i.e. a collection of maps and a relational, geo-referenced database containing key physical and biological characteristics for a large number (~675) of river sites representative of rivers draining the Lower Peninsula of Michigan. This GIS provided us with extensive capabilities for both map- and table-based storage, query, display, and analysis of data. Data incorporated in the MRI came from a variety of sources (Figure 1) and included: (1) field measurements made by project personnel; (2) numerous existing datasets that were compiled by other state and university research groups; (3) mapped data of various origins that could be processed and related to MRI study sites by manipulation in a GIS; and (4) "synthetic" data produced by modeling site-scale variables (for example, flow duration curves, see Modeling below) from

summaries of catchment landscape characteristics for a subset of sites.

Spatial coverage

About 675 MRI study sites have been established in the Lower Peninsula to date. These sites constitute the sampling framework upon which the MRI GIS has been built and their unique site numbers act as the shared “common field” in the relational database. Data from these sites were used to construct an overall picture of the spatial structure and organization of Michigan's river ecosystems. Because site selection was based in part on a desire to incorporate existing data collections, it is important to emphasize that this group of sampling sites does not constitute a true random sample of Michigan streams. However, we believe that the MRI sampling sites as a group are: (1) representative of the major types of fluvial ecosystems that occur in lower Michigan (Figure 2; though this shows that MRI sites likely under-represent the smallest streams [tabulated by site and segment numbers, not by stream miles]); and (2) sufficiently dispersed to provide a basis for large-scale description of spatial patterns across the Lower Peninsula (Figure 3).

Spatial Scales

Linking the multi-scale dynamics of geo-climatic, catchment-level driving variables, local river channel habitats, and fish populations has often been identified as an important goal of fishery scientists (Dewberry 1980; Imhof et al. 1996; Rabeni and Sowa 1996). To explore these linkages we emphasized data development at 3 distinct spatial scales of influence: (1) the catchment landscape; (2) the local channel reach bracketing each site (about 5-10 km long); and (3) the immediate sampling site (about 100-300 m long). First, catchment landscapes determine the extent and timing of water, sediment, and nutrient deliveries to a local site (Dunne and Leopold 1978; Newson 1994). The nature of these deliveries defines much of the ecological character of a site. We therefore focused on the

development of catchment-landscape data sets which could be used to describe and model hydrology at each site. Catchment-specific climatic, geologic, soil, and landcover data (measured from GIS maps) comprise the basic MRI data sets at this larger scale (Wiley and Seelbach 1997).

Second, some ecological conditions of a site are determined or constrained by the unique geology and morphology of the valley through which a reach runs (Cupp 1989; Rosgen 1994). For example, a reach that lies in a clayey, former glacial lake bed might have a low gradient, high sinuosity, fine substrates, high turbidity, and broad floodplain wetlands regardless of hydrologic sources upriver. As another example--channel meanders and floodplain morphology will typically be restricted, gradients will be higher, and substrates rockier, when a stream flows within a fairly narrow valley through a resistant, rocky morainal area.

Third, local ecological conditions may be even further shaped by unusual site-specific characteristics. The presence of a bedrock outcrop, waterfall, or glacial gravel deposit; as well as local variations in channel gradient all influence the development of substrates, pools, and riffles. Similarly, local water temperatures are affected by the presence of upstream impoundment or lake.

An important assumption of the MRI approach was that factors shaping riverine biology operate at some larger-than-site or -reach scale (such as river segment or perhaps multiple segments). Throughout their life cycles, many riverine biota undergo extensive movements among multiple, distinct habitats (for example fishes; Schlosser 1991; Gowan et al. 1994); suggesting that some mid-scale unit (at least) is needed for population-level studies (Bayley and Li 1992). So we conceptually viewed site data as samples of some larger ecological units (Seelbach et al. 1997).

Temporal extent

Our inventory has incorporated data on the status of Michigan rivers from the past 2.5 decades (roughly 1970 to present). Data for many parameters of interest are available for this

index period and they provide a reasonable summary of the current nature of Michigan's rivers.

Climatic and landscape variables controlling river geomorphology change slowly, on the order of 100-10,000 year time scales (Knighton 1989). On the other hand, hydrologic variables are characterized by exceptionally-high, short-term (daily, seasonal) temporal variance (Poff and Ward 1989). We believe that index periods of several decades provide both a current view of stable, geomorphic controls and a sufficient period for statistical summarization of higher-frequency, hydrologic and biological variables (Hakanson 1996). In the MRI project, we have focused on an intermediate time-scale set by the scale of variation seen in biological communities. Although the abundance of component fish populations certainly varies both seasonally and annually; in most river species, persistence and rough community composition are fairly stable over a longer time frame of multiple generations (Vannote et al. 1980; Imhof et al. 1996; Maxwell et al. 1995; Wiley et al. 1996); generally comparable to the decadal scale of the MRI.

MRI databases include data in two formats: data-series and data summaries. In both data are referenced to specific MRI site locations. Data series files contain measurements at individual MRI sites repeated over some period of time. Data summaries typically contain but one value for each MRI site (e.g., one measure for late summer discharge, channel width, or abundance of smallmouth bass). Some data summaries (such as temperature or discharge values) are statistical summaries of data series. When necessary data (such as late summer fish abundance) were single collections. Recognizing that annual variation occurs and adds considerable "noise" to our data, we nonetheless used such single values to represent the average condition at a site over the study time period. In landscape-scale studies the scale of observation is always limited at some point by technical or logistical constraints (Levin 1992). Noisy data are, however, often entirely adequate to answer many important questions. We proceeded under the assumption that such data were appropriate to examine, at the least, the

larger-scale spatial variation in the structure of Michigan's river ecosystems.

The MRI Geographic Information System (GIS)

The MRI GIS provides a powerful analytical environment. It contains a collection of maps and a relational, geo-referenced database. Its capabilities include data storage, spatial or tabular queries, and spatial display and analyses. This GIS is a flexible system that can be refined and expanded upon. Study regions, sampling sites, data types, or temporal components can be added as they are needed or available (geographic expansion into Michigan's Upper Peninsula is already underway). The MRI GIS consists of three general components, presently residing in two separate hardware environments:

1. A collection of digital map data layers for Michigan's Lower Peninsula. These include (a) map layers representing numerous landscape characteristics useful for catchment description (e.g., surficial geology and land use), and (b) map layers containing locations of study sites and their catchment and major watershed boundaries. These map data are maintained in a Unix environment, and were developed and managed using ARC/INFO and ArcView (ESRI, Inc.) and IMAGINE (ERDAS, Inc.) GIS software.
2. A collection of data files containing data summaries for a wide variety of pertinent physical and biological variables (Figure 4). Each data summary is referenced by a common "site number" datafield, allowing both relational use of the multiple files and geo-referencing of these data to mapped site locations.
3. A series of data files that contain data collected on multiple dates (series data) and are similarly geo-referenced to the site locations. Data file types 2 and 3 are stored in a Windows NT environment and managed using Microsoft Excel and Microsoft Access (Microsoft Corporation) database software. Copies of the type-2 datafiles are also maintained on the Unix platform for use within the Unix GIS environment. Users

often access this Unix environment from a remote Windows-based PC terminal, using an x-windows client software (that emulates the Unix operating system). And some users are operating the GIS solely within a Windows PC environment, using Arcview software.

Map layers and geographic analyses

The MRI GIS currently contains numerous maps that describe the landscapes of lower Michigan (Table 2). Most maps were obtained from other agencies, and some were developed or modified within the MRI project. Maps are in both raster and vector formats, and generally represent the best-available (statewide) scale of resolution. Raster-format maps are at either the 1-km² or 1-ha² scale. Vector-format maps are generally at either 1:100,000 or 1:24,000 scale; and data include catchment boundaries for each major river basin, location and catchment boundaries for each site, and statewide coverages of stream channel networks. All maps were georeferenced to the following coordinate systems: UTM Zone 16, Clarkeson 1866 spheroid, rad 27 datum.

We characterized the catchment landscape for each of the 675 MRI study sites using the GIS. The entire boundary for the catchment upstream of each site was digitized to create a digital map layer for each site-specific catchment. Surficial catchment boundaries were delineated as the divides between stream channels based initially on subwatershed boundaries developed by MDNR from 1:24,000 maps and locally modified according to the 3 arc-second USGS Digital Elevation Map. A digital map layer depicting major watershed boundaries was also created. Buffer outlines of radius 1 km, 2 km, and 4 km were made for each site; and of 1 km for the stream network upstream of each site. We used the catchment, major watershed, site buffer, and stream buffer boundaries to "clip" and summarize descriptive data from various map layers (e.g. soil textures or land covers) for each site and major watershed. Catchment summaries were either of the form "percent coverage" (e.g. categories of soil textures) or "mean value" (e.g. mean annual

rainfall). Summaries were saved in the MRI relational database.

Data files

We compiled data from sources including MRI field measurements (Appendix 2), existing agency and university datasets, summaries of map information, and site-specific model outputs. Databases were stored in database format (as "*.dbf" files) and were relational according to a "site number" variable common to all databases. Table 3 provides a general overview of the MRI databases.

Descriptions and Predictive Models

We developed a number of graphical summaries and statistical models of habitat and fish community characteristics. These helped to identify broad patterns within the data, explore the underlying relationships between local ecological conditions and the larger-scale processes that drive them, and to provide predictive capabilities. Simple graphical summaries provided a first-cut description of particular ecological resources and of some relationships between variables; as illustrated in Figures 6 and 7.

Our general approach to modeling these processes was to search for statistical relationships among datasets (an empirical and inferential approach). This was appropriate given (1) some inherent randomness in river systems, (2) the considerable sampling error inherent in our datasets, and (3) a need for simplification and abstraction in modeling complex river ecosystems (Schumm 1977; Knighton 1989; Levin 1992; Hakanson 1996). But we also consciously tried to incorporate logical causal structure (a deductive approach) whenever possible (Hakanson 1996). For example, linear regression equations predicting various discharge exceedence frequencies were based on the commonly-accepted hydraulic geometry relationship:

$$Q = a DA^s \times b P^t \times c M^u \dots \quad \text{EQ. 1.}$$

where Q = discharge; DA = drainage area; P = precipitation; M = hydrologic modifiers such as slope or urban land use; "a", "b", "c", "s", "t", and "u" are derived coefficients (Dunne and Leopold 1978; Holtshlag and Crosky 1984). As another example, models of the July water temperature regime included independent variables that represented important elements of a heat-balance model; eg. travel time, water volume, local groundwater inputs, and upstream shading (Wehrly et al. 1997).

Ecological Classification System

Like modeling, developing a classification is another way to simplify, and generalize about, complex information sets. The classification process of grouping and separating is a valuable one, helping us refine our understanding of interrelationships among entities and of hierarchical systems organization.

River classification schemes have been proposed using many different kinds of variables (e.g. aquatic plants, fish fauna, chemistry, or geomorphology) across scales of examination ranging from whole watersheds; through valley segments, reaches, and channel units, down to microhabitats (e.g Frissel et al. 1986; Hawkins et al. 1993; Maxwell et al. 1995). To balance the goal of simplification with the retention of information, we chose to focus our classification work on an intermediate spatial scale, the valley segment.

We developed an ecological classification for the river valley segments of Michigan's Lower Peninsula, incorporating both physical and biotic segment attributes (Seelbach et al. 1997). Using MRI data; and model-derived knowledge of the relationships among catchment landscapes, local geomorphology, and local riverine conditions, we interpreted from GIS maps:

- 1) The boundaries of ecologically-distinct river valley segments. Segment boundaries are usually associated with abrupt changes in geomorphology or major river confluences. The biota and physical character within each ecological valley segment are relatively

homogeneous and segments are often fairly large, roughly 2-40 miles in length.

- 2) a number of component ecological attributes for each segment, including discharge regime, July temperature regime, nutrient chemistry, slope, valley character, and fish assemblage.

Management Applications

The multi-scale framework of the MRI approach provides a toolbox for both 1) providing statewide perspectives on aspects of the riverine resource, and 2) addressing many local river management issues. Viewing a system in its larger-scale (landscape) context helps managers to define key variables and constraints that shape site-scale problems. MRI models provide a complimentary ability to predict specific site-scale attributes for developing management expectations and evaluating current status (Biggs et al. 1990).

For example, MRI models are currently being used to assess ecological status and potentials for rehabilitation on several Michigan rivers. We first use the regional models to develop predicted (or expected or reference) ecological conditions specific to selected sites and catchments. Current ecological status is assessed by comparing these expected conditions with historical and current observed conditions. Mechanisms controlling current status are suggested by the model structures. This compilation of site-specific data provides a basis for interpreting how a particular system is currently working and how it may have changed over time; and provides an ecological basis for the identification of management opportunities and priorities. Very similar comparative, modeling approaches to ecological assessment have been recently developed for other aquatic systems (Wright 1995; Ladle and Westlake 1996; Hakanson 1996; Imhof et al. 1996). Preliminary results have been encouraging, in that information derived at moderate-to-fairly large scales, seems to be appropriate for answering both segment-specific and regional management questions.

Specifically, we have developed rehabilitation targets for fish communities, discharge regimes, and

water temperatures for specific segments of the heavily-degraded, Rouge River near Detroit. The MRI models have provided regionally- and catchment-appropriate summaries of what a similar-sized, unurbanized river in southeast Michigan, with similar discharge patterns, would be like ecologically. These summaries are being used by the Rouge River National Wetweather Demonstration Project as a vision for developing a rehabilitation strategy for the river.

Similar landscape-based modeling results are helping local watershed councils to assess stream conditions and develop management strategies for habitat and fisheries restoration. On Mill Creek (Huron River system): we assessed the potentials for fishery developments resulting from the proposed removal of a barrier dam and riparian wetland enhancements. On the Pigeon River, models were used to assess the potential for development of a coldwater fishery, following resolution of water quality problems.

A product of the models, the MRI valley segment ecological classification (VSEC) system provides a basis for the development of additional management tools. We are building an ecologically-supported, segment-based inventory of the coldwater (or trout-supporting) streams of lower Michigan; this will be an important foundation for both state trout and water-quality management programs. (Water quality regulations are more stringent for coldwater streams). We are likewise beginning the development of a set of statewide, segment-specific standards for environmental integrity. This involves an expansion of the modeling done for the Rouge River, Mill Creek, and the Pigeon River; to provide a range of expected values of ecological (physical and biotic) traits for each unique river segment. The Nature Conservancy is building upon this classification framework to develop a segment-based system for prioritizing regional and national aquatic conservation programs. And the U.S. Forest Service is considering using ecological segments as the basis for their aquatic habitat protection programs within Michigan.

Finally, a comprehensive, regional GIS-based inventory like the MRI should ultimately serve as a platform for broader, more-informed communications among those interested in river ecosystems. Many such regional river

assessments are being conducted—some at state or multi-state scales (Rankin et al. 1996, Beard et al. 1998), some for large watersheds (Lammert et al. 1997; Myers and Finnegan 1995; Bain 1996), and even for nations (Biggs et al. 1990; Wright 1995). These are typically done using somewhat different approaches but improving computer technologies should allow for increasing sharing of information and broad-scale comparative study.

Products and future directions

A number of theses and reports have been, or are currently being, completed (Table 4); those that are Michigan Department of Natural Resources, Fisheries Division reports will be available as Adobe Acrobat documents through the web site of the Institute for Fisheries Research: <http://www.dnr.state.mi.us/www/ifr/ifrilibra/ifrilibra.htm>.

We expect the MRI project to be ongoing. Current work includes:

- Extending the GIS, modeling, and classification work to Michigan's Upper Peninsula (in cooperation with E. Baker, Michigan Department of Natural Resources, Marquette, MI; The Nature Conservancy, Chicago Regional Office; and the U.S. Forest Service, Region 5 Office, Milwaukee, WI)
- Additional sampling of streams within the Lower Peninsula (in cooperation with The Nature Conservancy, Chicago Regional Office; and The U.S. Environmental Protection Agency, Chicago Regional Office; and others).
- Testing, refining, and expanding the valley segment ecological classification system throughout Michigan (in cooperation with The Nature Conservancy, Chicago Regional Office; and The U.S. Forest Service, North Central Forest Experiment Station, Rhinelander, WI).
- Developing an inventory and ecological classification for riparian ecosystems, and exploring the linkages between terrestrial and stream classification systems (in cooperation with The Michigan Natural Features Inventory).

- Exploring the uses of catchment modeling or valley segment classifications for development of reach- or valley-specific ecological (e.g., biological, hydrologic, and thermal) standards (this is as an alternative to regionalization; in cooperation with the U.S. Environmental Protection Agency, Chicago Regional Office, The U.S. Fish and Wildlife Service, The Wisconsin Department of Natural Resources, and the Minnesota Department of Natural Resources).
- Applying MRI concepts and models to local case studies; specifically developing ecological stream assessments for local watershed councils that describe ecological history and status, and management options for specific stream segments (in cooperation with The Rouge River National Wet-weather Demonstration Project, Wayne Co., MI; the Huron River Watershed Council, Washtenaw Co., MI; and the Timberlands Resource Conservation and Development Area Council, Sparta, MI).

Acknowledgments

The Michigan Department of Natural Resources, Fisheries Division, Institute for Fisheries Research; and the University of Michigan, School of Natural Resources and Environment have provided commitment to, and continuous facilities support for, this long-term effort.

Funding for component projects has come from Federal Sportfish Restoration Funds, small grants administered by The University of Michigan, School of Natural Resources and Environment, The Michigan Coastal Zone Management Program, The Nature Conservancy–Great Lakes Office, and the Environmental Protection Agency–Region 5 Office.

Our GIS was built and managed with the assistance and considerable efforts of John Fay,

Jennifer Kotanchik, Bill Whipps, Dave Zaber, and Sarah Zorn (GIS Lab, School of Natural Resources and Environment, University of Michigan, Ann Arbor); Dr. John Bartholic and Yung-Sung Kang (Institute of Water Research, Michigan State University, East Lansing); Gary Taylor and others (Michigan Department of Natural Resources, Michigan Resource Information System, Real Estate Division), and Matt Krogulecki (Database Graphics, East Lansing, MI). GIS maps for Indiana waters of the St. Joseph basin were provided by Dr. J.C. Randolph (School of Public and Environmental Affairs, Indiana University, Bloomington).

Influential early insights and guidance regarding large-scale patterning and processes in Michigan rivers were drawn from an unpublished manuscript – Classification of midwestern rivers-- by T.C. Dewberry (Pacific Rivers Council, Eugene, OR); and discussions with L.L. Osborne and S.L. Kohler (Illinois Natural History Survey, Champaign, IL).

Assistance in developing hydrologic databases was received from Dave Hamilton, Jerry Fulcher and Richard Popp (Land and Water Management Division, Michigan Department of Environmental Quality, Lansing) and Steve Blumer (U.S. Geological Service, Lansing, MI). Michigan Department of Natural Resources, District Fisheries staff have collaborated extensively on collections of field data on water temperatures, site habitats, and fish communities.

And the horsepower driving the MRI has been, of course, the many University of Michigan, School of Natural Resources, graduate students who have taken the lead on component research projects: Matthew Baker, Steven Bowler, Leon Hinz, Richard Kleiman, Jennifer Kotanchik, Kathrine Reising, Kevin Wehrly, David Zaber, and Troy Zorn.

We appreciate the critiques of reviewers Dave Fielder and Jim Diana towards the preparation of this document.

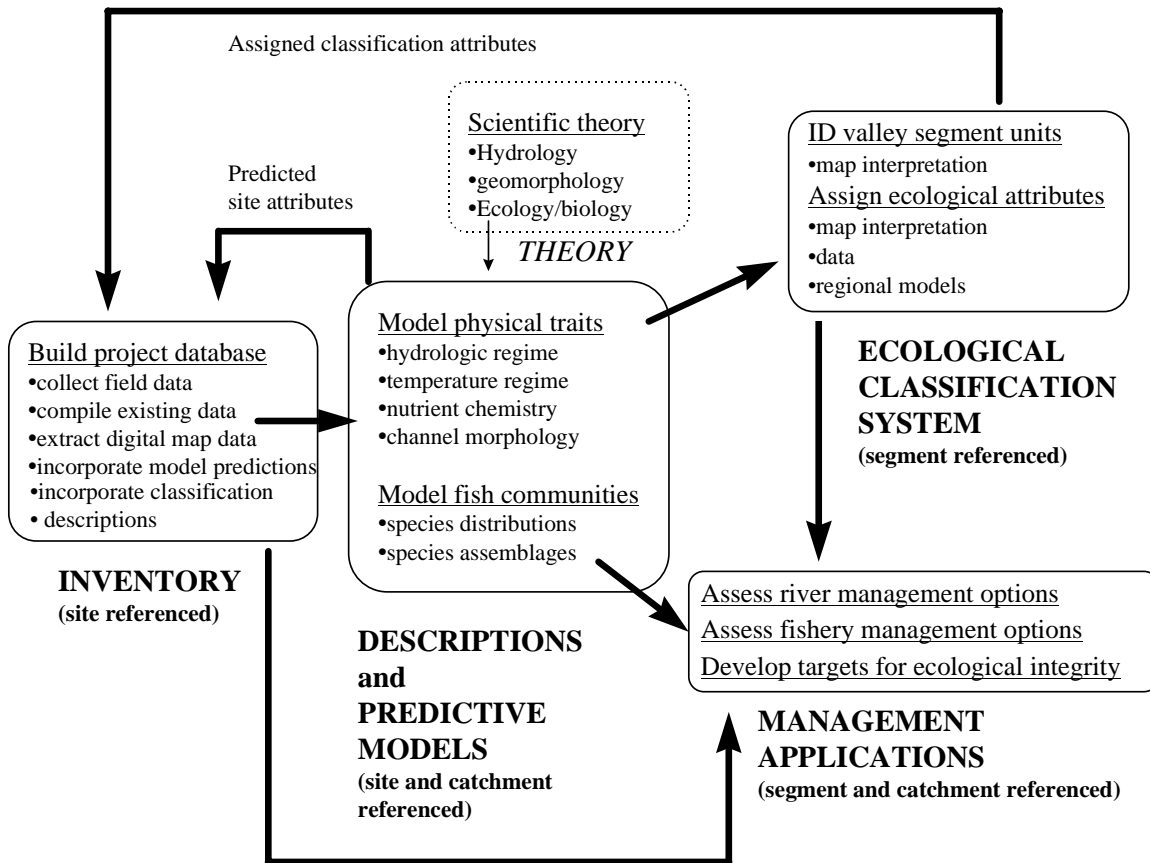


Figure 1.–Strategic components of the MRI project.

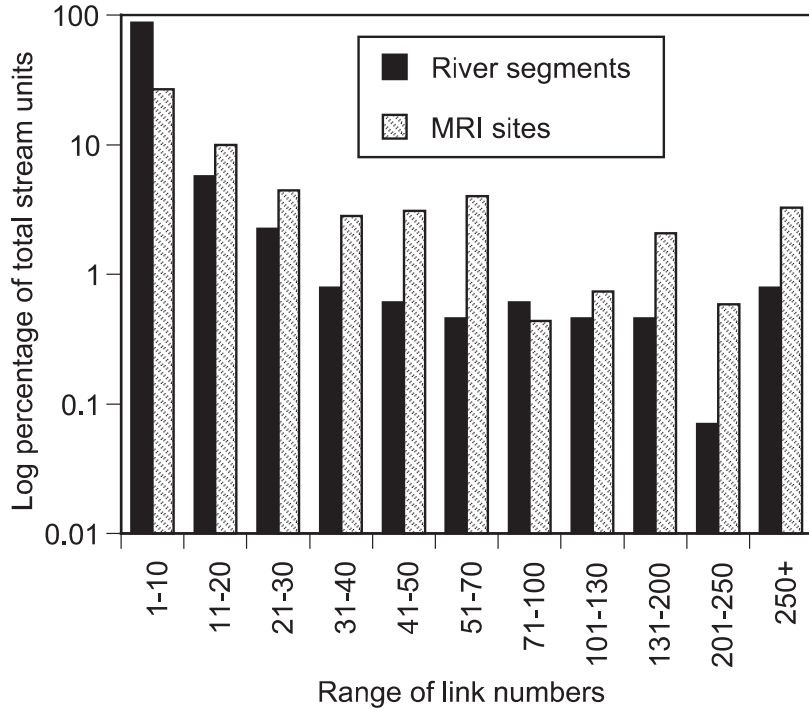


Figure 2.—Comparison of size-class frequencies (as indicated by link numbers) between MRI study sites and the total number of lower Michigan river valley segments (Seelbach et al. 1997; M. Lammert, personal communication, The Nature Conservancy, Great Lakes Regional Office, Chicago, IL). The link number at a point on a stream is the sum of the upstream first-order streams.



Figure 3.—Spatial distribution of 672 MRI study sites, within major watershed boundaries.

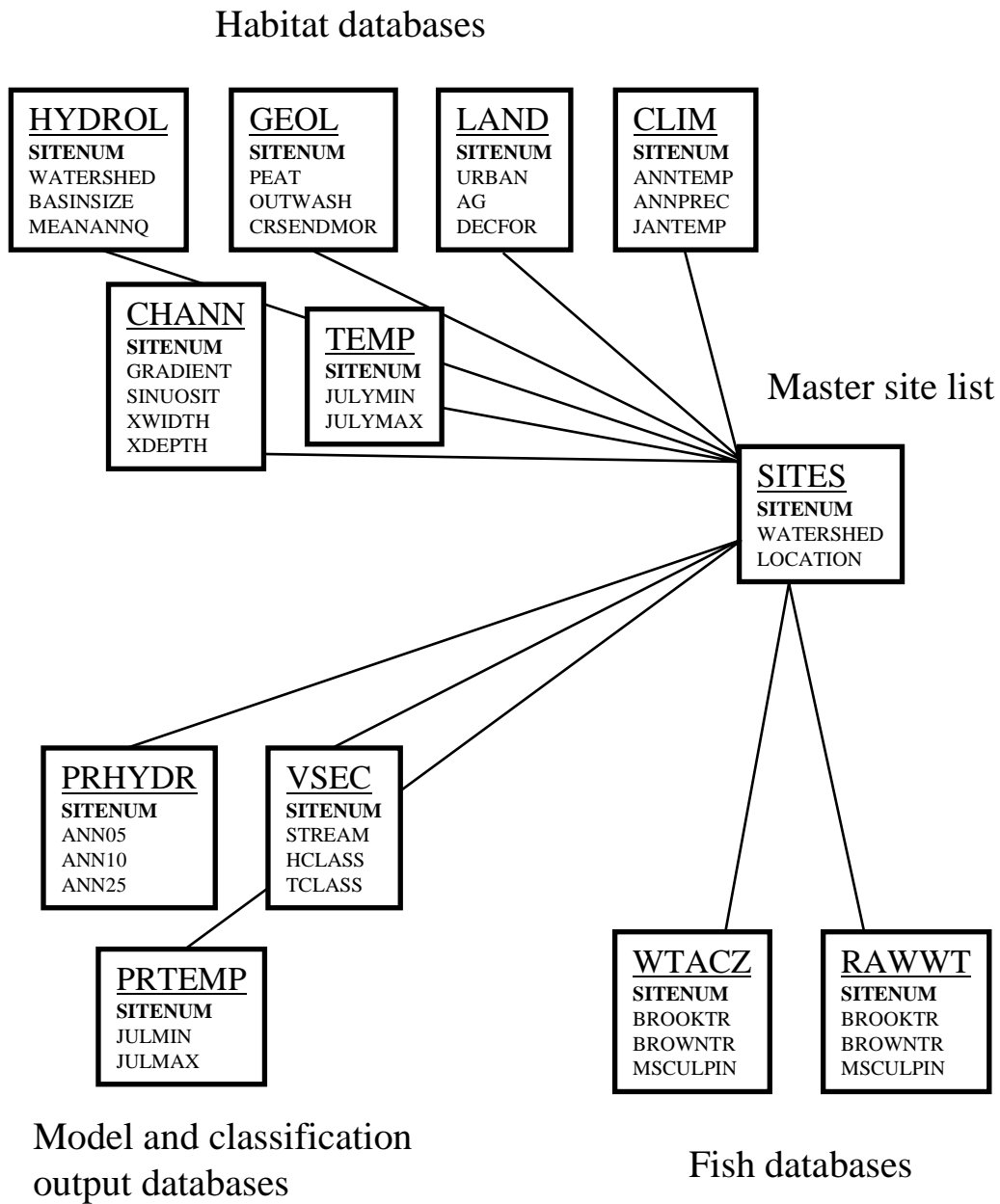


Figure 4.—General model of the MRI relational database, showing multiple database files and some examples of component data fields; files are linked by the common “SITENUM” field.

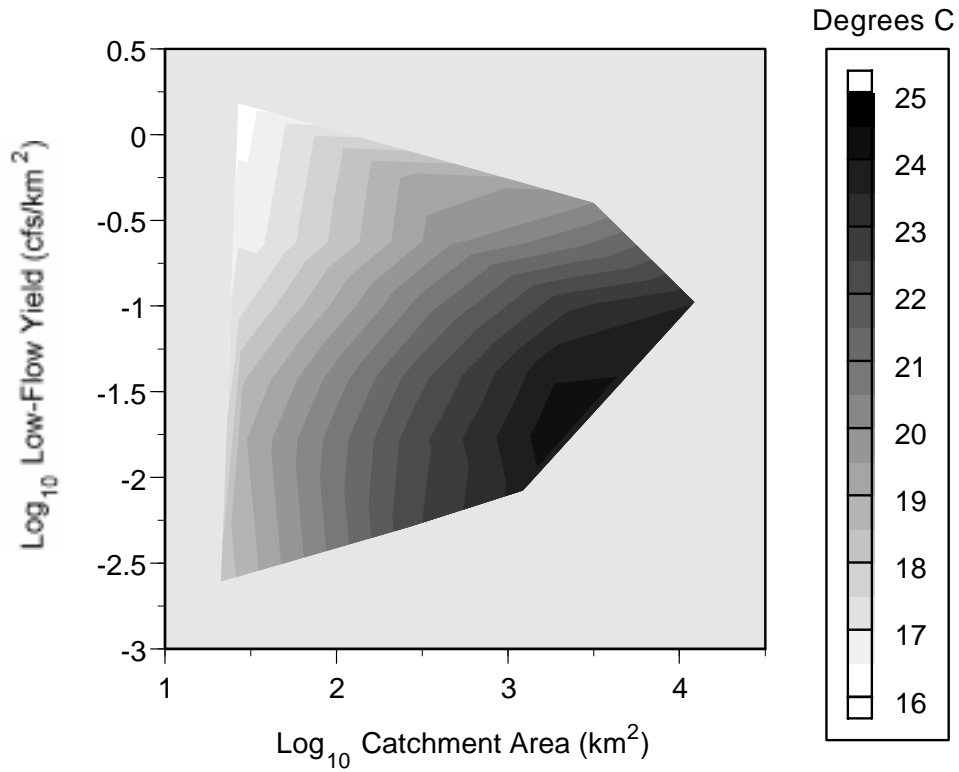


Figure 5.—Response surface of July weekly mean water temperature versus baseflow yield and drainage area for lower Michigan streams and rivers.

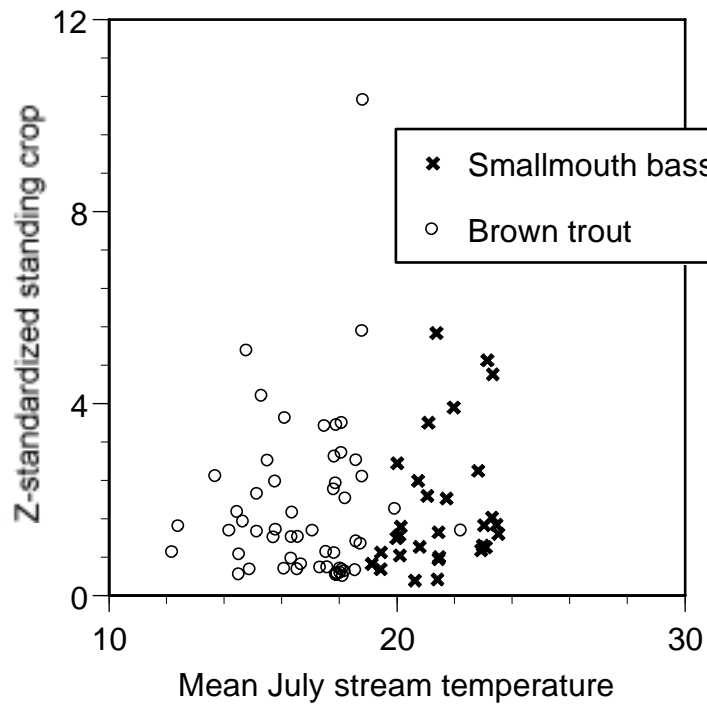


Figure 6.—Relationships between brown trout and smallmouth bass densities, and predicted mean July water temperatures.

Table 1.–Funded research projects developed collaboratively through the MRI partnership. Abbreviations are UM/SNRE, University of Michigan, School of Natural Resources and Environment; US EPA, U.S. Environmental Protection Agency; MDEQ-SWQD, Michigan Department of Environmental Quality, Surface Water Quality Division.

Years	Project title/principal investigators	Funding sources and (additional partners)
1988-98	Inventory and classification of Michigan rivers/ Seelbach and Wiley	Federal Aid to Sportfish Restoration, UM/SNRE grants
1993-98	Structure and function of trout-stream food webs/ Wiley and Kohler	National Science Foundation (with U. of Illinois)
1995-97	Ecological classification of Michigan rivers/ Seelbach and Wiley	MI Coastal Zone Management Program (with MI Natural Features Inventory)
1996-97	Ecological targets for rehabilitation of the Rouge River/ Seelbach and Wiley	Wayne Co., Rouge Program Office
1996-98	Decision tools for river management/ Seelbach	Federal Aid to Sportfish Restoration
1996-98	Nutrient effects on the organization of stream algal and invertebrate communities/ Wiley, Stevenson, and Holomuski	NSF--US EPA, Watershed Initiative (with University. of Louisville and Ohio State University.)
1997-98	Ecological valley segment classification/ Wiley and Seelbach	The Nature Conservancy, Great Lakes Regional Office
1997-99	Biological criteria for Michigan rivers/ Seelbach and Wiley	US EPA, Region 5 (with MDEQ, SWQD)
1997-00	Bio-indicators for the Northern Lakes and Forests Eco-region/ Seelbach and Wiley	US EPA, R-EMAP Program

Table 2.–Primary map layers currently used in the MRI GIS. Abbreviations are: MRI–Michigan Rivers Inventory; MDNR–Michigan Department of Natural Resources; USGS–U.S. Geological Survey; MIRIS–Michigan Resource Information System; MSU-CRS–Michigan State University, Center for Remote Sensing; MDA-MWS–Michigan Department of Agriculture, Michigan Weather Service; CRIES–Comprehensive Resource Inventory Evaluation System; MNFI–Michigan Natural Features Inventory; NOAA–National Oceanic and Atmospheric Administration; CES–Cooperative Extension Service; AES–Agricultural Experiment Station; USDA-NRCS–U.S. Department of Agriculture-Natural Resource Conservation Service; STATSGO–State Soil Geographic Database.

Maps	Map source, date, format	Data source, scale
<ul style="list-style-type: none"> statewide MRI site locations, site catchment and major watershed boundaries 	<ul style="list-style-type: none"> MRI, 1995, vector MRI, 1995, raster 	<ul style="list-style-type: none"> MDNR catchment boundaries, 1:2,000 (modified by MRI using 1:250,000 DEM)
<ul style="list-style-type: none"> statewide stream channels 	<ul style="list-style-type: none"> MRI, 1995, vector MRI, 1995, raster MDNR-MIRIS, 1987, vector 	<ul style="list-style-type: none"> USGS Digital Line Graphs, 1:100,000 USGS topographic maps, 1:24,000
<ul style="list-style-type: none"> annual and monthly mean precipitation, annual and monthly mean air temperature 	<ul style="list-style-type: none"> MSU-CRS, 1974, 1-km raster 	<ul style="list-style-type: none"> MDA-MWS data 1940-69.
<ul style="list-style-type: none"> quaternary geology 	<ul style="list-style-type: none"> MSU-CRIES, 1981, 1-km raster MRI, 1996, 1-ha raster MNFI, 1996, vector 	<ul style="list-style-type: none"> Farrand and Bell (1984) map, 1:500,000 Indiana portion of St. Joseph watershed digitized by MRI from Goebel et al. (1983) map, 1:1,000,000.
<ul style="list-style-type: none"> statewide digital elevation 	<ul style="list-style-type: none"> USGS/NOAA, 1984, 1-km raster MRI, 1996, 1-ha raster 	<ul style="list-style-type: none"> USGS Digital Elevation Model from 3 arc-second data, 1:250,000
<ul style="list-style-type: none"> soil texture 	<ul style="list-style-type: none"> MSU-CRS/CRIES, 1981, 1-km raster USDA-NRCS, STATSGO Soil Association Map, vector 	<ul style="list-style-type: none"> MSU-CES & AES and USDA-NRCS from Soil Association Map of Michigan statewide Michigan and Indiana portion of St. Joseph watershed from STATSGO Soil Association Map, 1:250,000.
<ul style="list-style-type: none"> statewide 1978 land cover 	<ul style="list-style-type: none"> MSU-CRS, 1981, 1-km raster MRI, 1996, 1-ha raster 	<ul style="list-style-type: none"> MDNR-MIRIS vector-format map from 1981-86 aerial photos, 1:24,000; Indiana portion of St. Joseph watershed from USGS Land Use/Cover Map, 1:250,000.
<ul style="list-style-type: none"> groundwater movement 	<ul style="list-style-type: none"> MRI, 1997, 1-ha raster 	<ul style="list-style-type: none"> modeled from 1-ha raster quaternary geology and digital slope maps

Table 3.—General overview of the MRI relational database.

Database name	Description of fields	Sample size	Temporal extent
Sites	<ul style="list-style-type: none"> site number, location, data types 	672	NA
Landcovers	<ul style="list-style-type: none"> site number catchment size from GIS analysis catchment means for precipitation, air temperature, evapotranspiration, topography from GIS analysis catchment percent coverage for surficial geology, soils, landuse from GIS analysis 	672 672 672	climate: means for period 1940-69 landuse for 1979-82
Hydrology	<ul style="list-style-type: none"> site number site USGS gage data: mean monthly and period discharges, and exceedence frequencies site USGS miscellaneous measures: mean late summer low discharge predicted monthly and period exceedence frequencies 	138 93 672	for period of record for period of record
Chemistry	<ul style="list-style-type: none"> site number site alkalinity, nutrients, suspended solids at high and low discharges? 	~200	variable
Temperature	<ul style="list-style-type: none"> site number site July water temperatures site annual water temperatures 	218 ~50	1+ years beginning late 1980s
Habitat	<ul style="list-style-type: none"> site number segment slope, sinuosity, stream network structure from 1:24,000 maps site channel geometry from USGS measures site channel geometry, substrates, riparian cover, slope from MRI field measures MRI-VSEC segment ID 	672 ~110 188 672	multiple measures 1-time measures
Fishes	<ul style="list-style-type: none"> site number site species presence site species abundance by number and weight site trout abundance only 	340 257 78	1-time samples
Benthic invertebrates	<ul style="list-style-type: none"> site number site species presence/abundance 	~100	single- and multiple-season samples
Other biota	<ul style="list-style-type: none"> site/segment number river otter trapping records breeding bird distributions (Brewer et al. 1991) 	271 672	past 10 years period 1983-88

Table 4.–Manuscripts produced through the MRI (status either completed or in preparation). Michigan Department of Natural Resources, Fisheries Division reports are (soon to be) available on the Institute for Fisheries Research Internet homepage (shown below by an “*”), at <http://www.dnr.state.mi.us/www/ifr/ifrlibra/ifrlibra.htm>.

Berry, T. 1992. Land use and stream discharge in Michigan's cold water streams. M.S. Thesis, University of Michigan, Ann Arbor.
Cornejo, C.R.T. 1992. Regional characteristics of longitudinal patterns in stream fish biodiversity. M.S. Thesis, University of Michigan, Ann Arbor.
Prasad, S. 1994. GIS-based watershed integrated water quality modeling. Ph.D. Dissertation, University of Michigan, Ann Arbor.
Gooding, M. 1995. Large-scale classification of Michigan watersheds. M.S. Practicum, University of Michigan, Ann Arbor.
Kleiman, R. 1995. Modeling water quality in Michigan rivers from landscape variables. M.S. Thesis, University of Michigan.
Wiley, M.J., S.L. Kohler, and P.W. Seelbach. 1996. Reconciling landscape and local views of aquatic communities: lessons from Michigan trout streams. <i>Freshwater Biology</i> 37:133-148.
Tompkins, T.M., W.W. Whipps, L.J. Manor, C.W. Radcliffe, D.M. Majewski, and M.J. Wiley. 1997. Wetland effects on hydrological and water quality characteristics of a mid-Michigan river system. In C.C. Trettin, D.F. Grigal, M.F. Jurgensen, M.R. Gale, and J.K. Jeglum, Editors. <i>Northern forested wetlands, ecology and management</i> . Lewis Publishers, Boca Raton, FL.
Seelbach, P.W., and M.J. Wiley. 1997. Overview of the Michigan Rivers Inventory (MRI) Project. Michigan Department of Natural Resources, Technical Report 97-3, Ann Arbor.*
Seelbach, P.W., M.J. Wiley, J. C. Kontanchik, and M. E. Baker. 1997. A landscape-based, ecological classification for river valley segments in lower Michigan. Michigan Department of Natural Resources, Research Report 2036, Ann Arbor.*
Wehrly, K.E., M.J. Wiley, and P.W. Seelbach. 1997. Landscape-based models that predict July thermal characteristics of lower Michigan rivers. Michigan Department of Natural Resources, Research Report 2037, Ann Arbor.*
Wehrly, K.E., M.J. Wiley, and P.W. Seelbach. 1997. A thermal classification for rivers in Michigan's Lower Peninsula. Michigan Department of Natural Resources, Research Report 2038, Ann Arbor.*
Wiley, M.J., and P.W. Seelbach. 1997. An introduction to rivers. Michigan Department of Natural Resources, Special Report 20, Ann Arbor.*
Zorn, T.G., P.W. Seelbach, and M.J. Wiley. 1997. Patterns in the fish communities of Lower Michigan streams. Michigan Department of Natural Resources, Fisheries Research Report 2035, Ann Arbor.*
Kotanchik, J. C. 1997. Large-scale distribution of river otters in Michigan's Lower Peninsula. M.S. Thesis, University of Michigan, Ann Arbor.
Zaber, D. . 1997. Multi-scale analysis of the correspondence between spacial patterns of avian and fish community diversity. PhD Dissertation, University of Michigan, Ann Arbor.

References

- Bain, M.B. 1996. Application of gap analysis to aquatic biodiversity conservation: Aquatic GAP pilot project of the New York Cooperative Research Unit. GAP Bulletin 5, note. U.S. Geological Survey, National Biological Service, Moscow, ID.
- Bayley, P.B., and H.W. Li. 1992. Riverine fishes. Pages 251-181 *In* P. Calow and G.E. Petts, Editors. The rivers handbook—Volume 1. Blackwell Scientific Publ., Inc., Oxford, UK.
- Beard, T.D., Jr., D. Austen, S.J. Brady, M.E. Costello, H. G. Drewes, C.H. Young-Dubovsky, C.H. Flather, T.W. Gengerke, C. Larson, A.J. Loftus, and M.J. Mac. 1998. The Multi-state Aquatic Resources Information System. Fisheries 23:14-18.
- Becker, G.C. 1983. Fishes of Wisconsin. The University of Wisconsin Press, Madison.
- Biggs, B.J.F., M.J. Duncan, I.G. Jowett, J.M. Quinn, C.W. Hickey, R.J. Davies-Colley, and M.E. Close. 1990. Ecological characterization, classification, and modelling of New Zealand rivers: an introduction and synthesis. New Zealand Journal of Marine and Freshwater Research 24:277-304.
- Chamberlin, T.W. 1984. Systematic aquatic biophysical inventory in British Columbia, Canada. Pages 17-25 *In* N.B. Armantrout, Editor. Symposium on acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Symposium Proceedings, Portland, OR.
- Cooper, G.P., and J.R. Ryckman. 1981. Population estimates by mark-and-recapture. Appendix 2 *In* J.W. Merna, J.C. Schneider, G.R. Alexander, W.D. Alward, and R.L. Eshenroder. Manual of fisheries survey methods. Michigan Department of Natural Resources, Fisheries Management Report 9, Ann Arbor.
- Cupp, C.E. 1989. Valley segment type classification for forested lands of Washington. Washington Department of Natural Resources; Timber, Fish, and Wildlife Ambient Monitoring Program Report TFW-AM-89-001, Olympia.
- Dewberry, T.C. 1980. A stream classification system for midwestern North America. Unpublished manuscript. Current address: Pacific Rivers Council, Eugene, OR.
- Dunne, T., and L.B. Leopold. 1978. Water in environmental planning. W.H. Freeman and Co., New York, NY.
- Farrand, W.R., and D.L. Bell. 1984. Quaternary geology of Michigan. Department of Geological Sciences, The University of Michigan, Ann Arbor.
- Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199-241.
- Goebel, J.E., D.M. Mickelson, W.R. Farrand, L. Clayton, J.C. Knox, A. Cahow, H.C. Hobbs, and M.S. Walton, Jr. 1983. Quaternary geologic map of the Minneapolis 4 x 6 quadrangle, United States. G.M. Richmond and D.S. Fullerton, Editors. U.S. Geological Survey, Miscellaneous Publications Series, Map I-1420(NL-15), Arlington, VA.
- Gowan, C., M.K. Young, K.D. Fausch, and S.C. Riley. 1994. Restricted movement in resident stream salmonids: a paradigm lost? Canadian Journal of Fisheries and Aquatic Sciences 51:2626-2637.
- Hakanson, L. 1996. Predicting important lake habitat variables from maps using modern tools. Canadian Journal of Fisheries and Aquatic Sciences 53(Supplement 1):364-382.

- Hawkins, C.P., J.L. Kershner, P.A. Bisson, M.D. Bryant, L.M. Decker, S.V. Gregory, D.A. McCullough, C.K. Overton, G.H. Reeves, R.J. Steedman, and M.K. Young. 1993. A hierarchical approach to classifying stream habitat features. *Fisheries* 18:3-11.
- Holtschlag, D.J., and H.M. Croskey. 1984. Statistical models for estimating flow characteristics of Michigan streams. U.S. Geological Survey, Water-Resources Investigations Report 84-4207, Lansing, MI.
- Imhof, J.G., J. Fitzgibbon, and W.K. Annable. 1996. A hierarchical evaluation system for characterizing watershed ecosystems for fish habitat. *Canadian Journal of Fisheries and Aquatic Sciences* 53(Suppl. 1):312-326.
- Kleiman, R. 1995. The effects of season, land use/cover, and hydrology on stream water chemistry in Michigan's Lower Peninsula. M.S. Thesis, The University of Michigan, Ann Arbor.
- Knighton, D. 1989. *Fluvial forms and processes*. Edward Arnold Publishers, London, UK.
- Ladle, M., and D.R. Westlake. 1996. River and stream ecosystems of Great Britain. Chapter 11 In *River and stream ecosystems of the world*. C.E. Cushing, K.W. Cummins, and G.W. Minshall, Editors. Elsevier Publishers, New York, NY.
- Lammert, M., J. Higgins, D. Grossman, and M. Bryer. 1997. A classification framework for freshwater communities. The Nature Conservancy, Chicago, IL.
- Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology* 73:1943-1967.
- Maxwell, J.R., C.J. Edwards, M.E. Jensen, S.J. Paustian, H. Parrott, and D.M. Hill. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). U.S. Forest Service, North Central Forest Experiment Station, General Technical Report NC-186, St.Paul, MN.
- Myers, D. And D.P. Finnegan. 1995. National water-quality assessment program—Lake Erie-Lake St. Clair Basin. U.S. Geological Survey, Fact Sheet 94-056, Columbus, OH.
- Newson, M. 1994. *Hydrology and the river environment*. Clarendon Press, Oxford, UK.
- Pickett, S.T.A., and M.L. Cadenasso. 1995. Landscape ecology: spatial heterogeneity in ecological systems. *Science* 269:331-333.
- Poff, N.L. and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns. *Canadian Journal of Fisheries and Aquatic Sciences* 46:1805-1818.
- Rabeni, C.F., and S.P. Sowa. 1996. Integrating biological realism into habitat restoration and conservation strategies for small streams. *Canadian Journal of Fisheries and Aquatic Sciences* 53(Suppl. 1): 252-259.
- Rankin, E.T., C.O. Yoder, and D. Mishne. 1996. Ohio Water Resource Inventory. Volume I: summary, status, and trends. Ohio Environmental Protection Agency, Columbus, OH.
- Ricklefs, R.E. 1987. Community diversity: relative roles of local and regional processes. *Science* 235:167-171.
- Risser, P.G., J.R. Karr, and R.T.T. Forman. 1983. *Landscape ecology: directions and approaches*. Illinois Natural History Survey Special Publication Number 2, Champaign, IL.
- Rosgen, D.L. 1994. *A classification of natural rivers*. Elsevier Publications, Amsterdam, The Netherlands.
- Schlosser, I.J. 1991. Stream fish ecology: a landscape perspective. *BioScience* 41:704-712.

- Schneider, J.C., P.W. Laarman, and H. Gowing. 1996. Length-weight relationships. Appendix 12 In J.W. Merna, J.C. Schneider, G.R. Alexander, W.D. Alward, and R.L. Eshenroder. Manual of fisheries survey methods. Michigan Department of Natural Resources, Fisheries Management Report 9, Ann Arbor.
- Schumm, S.A. 1977. The fluvial system. Wiley-Interscience, New York, NY.
- Scott, W.B., and E.J. Crossman. 1979. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184, Ottawa, Canada.
- Seelbach, P.W., R.N. Lockwood, and J.R. Ryckman. 1994. Efficiency of sampling river fishes with rotenone. Michigan Department of Natural Resources, Fisheries Research Report 2009, Ann Arbor.
- Seelbach, P.W., G.L. Towns, and D.D. Nelson. 1988. Guidelines for sampling warmwater rivers with rotenone. Appendix 17 In J.W. Merna, J.C. Schneider, G.R. Alexander, W.D. Alward, and R.L. Eshenroder. Manual of fisheries survey methods. Michigan Department of Natural Resources, Fisheries Management Report 9, Ann Arbor.
- Seelbach, P.W., M.J. Wiley, J.C. Kotanchik, and M.E. Baker. 1997. A landscape-based system of ecological classifications for river valley segments in lower Michigan: VSEC Version 1.0. Michigan Department of Natural Resources, Fisheries Research Report 2036, Ann Arbor.
- Trautman, M.B. 1981. The fishes of Ohio. The Ohio State University Press, Columbus.
- Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.
- Wehrly, K.E., M.J. Wiley, and P.W. Seelbach. 1997. Landscape-based models that predict July thermal characteristics of lower Michigan rivers. Michigan Department of Natural Resources, Fisheries Research Report 2037, Ann Arbor.
- Wiley, M.J., and P.W. Seelbach. 1997. An introduction to rivers. Michigan Department of Natural Resources, Fisheries Special Report 20, Ann Arbor.
- Wiley, M.J., S.L. Kohler, and P.W. Seelbach. 1996. Reconciling landscape and local views of aquatic communities: lessons from Michigan trout streams. Freshwater Biology 37:133-148.
- Wright, J.F. 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. Australian Journal of Ecology 20:181-197.
- Zorn, T.G., P.W. Seelbach, and M.J. Wiley. 1997. Patterns in the fish communities of Lower Michigan streams. Michigan Department of Natural Resources, Fisheries Research Report 2035, Ann Arbor.
- Zippin, C. 1958. The removal method of population estimation. Journal of Wildlife Management 22:82-90.

Appendix 1. Selected bibliography of major inventory work on Michigan rivers; arranged by discipline and chronology. This is not intended to be comprehensive, but rather to illustrate the historical scope of inventories. Reports that are examples of an existing series are indicated as "(S)".

Hydrology

Streamflow gaging, statewide

Martin, H. M., and M. T. Straight. 1956. An index of Michigan geology [1823-1955, early reports on water resources and supplies]. State Printers, Lansing.

Bent, P. C. 1970. A proposed streamflow data program for Michigan. U.S. Geological Survey, Water Resources Division, Open-file Report, Lansing, Michigan.

Anonymous. 1995. Water Resources Data, Michigan, Water Year 1994. U.S. Geological Survey, Water-Data Report MI-94-1, in cooperation with the State of Michigan, Lansing. (S)

Summaries and modeling of streamflows, statewide

Knutilla, R. L. 1967. Flow characteristics of Michigan streams. U.S. Geological Survey, Open-File Report, in cooperation with the State of Michigan, Lansing.

Velz, C. J., and J. J. Gannon. 1960. Drought flow characteristics of Michigan streams. The University of Michigan, Department of Environmental Health, in cooperation with the Michigan Water Resources Commission, Ann Arbor.

Bent, P. C. 1971. Influence of surface glacial deposits on streamflow characteristics. U.S. Geological Survey, Open-File Report, in cooperation with the Michigan Geological Survey Division, Lansing.

Holtschlag, D. J., and H. M. Croskey. 1984. Statistical models for estimating flow characteristics of Michigan streams. U.S. Geological Survey, Water-Resources Investigations Report 84-4207, in cooperation with the Michigan Water Management Division, Lansing.

Mandle, R. J., and D. B. Westjohn. 1989. Geohydrologic framework and ground-water flow in the Michigan basin. Pages 83-110 In L. A. Swain and A. I. Johnson, Editors. Regional aquifer systems of the United States: Aquifers of the midwestern area. American Water Resources Association Monograph 13.

Rheaume, S. J. 1991. Hydrologic provinces of Michigan. U.S. Geological Survey, Water-Resources Report 91-4120, Lansing.

Water quality

Point source water quality, select streams

Anonymous. 1937. Saginaw Valley Report. Michigan Stream Control Commission, Lansing.

Anonymous. 1968. Water pollution control in the Michigan portion of the Lake Michigan basin and its tributaries. Michigan Department of Natural Resources, Water Resources Commission, Lansing. (S)

Anonymous. 1972. Evaluation of the aquatic environment of the Kalamazoo River watershed: Part A: Biological survey; Part B: Water quality survey; Part C: Fisheries survey. Michigan Department of Natural Resources, Fisheries Division Report, Lansing. (S)

Myers, D. N., and D. P. Finnegan. 1995. National Water-Quality Assessment Program--Lake Erie-Lake St. Clair Basin. U.S. Geological Survey Fact Sheet. Columbus, OH.

Summaries of water quality, statewide

Anonymous. 1932. First biennial report, 1931-1932, The Stream Control Commission (first in series). State of Michigan, Lansing. (S)

Surber, E.W. 1954. Biological surveys of Michigan's polluted streams and lakes. Michigan Water Resources Commission, Lansing.

Anonymous. 1963. Water quality monitoring program: Water quality records--1963. Michigan Water Resources Commission, Lansing. (S)

Giroux, P. R., and G. C. Huffman. 1966. Water quality standards for Michigan intrastate waters. U.S. Geological Survey, in cooperation with the Michigan Geological Survey, Lansing.

Anonymous. 1970. A survey of background water quality in Michigan streams. Michigan Department of Natural Resources, Water Resources Commission report, Lansing.

Anonymous. 1972. Heavy metals in surface waters, sediments, and fish in Michigan. Michigan Department of Natural Resources, Water Resources Commission, Lansing. (S)

Anonymous. 1973. Trout water quality. Michigan Department of Natural Resources, Water Resources Commission, Lansing.

Anonymous. 1977. Water quality inventory and environmental/water quality relationships. East Central Michigan Planning and Development Region, areawide waste treatment management plan. The Chester Engineers. (S)

Anonymous. 1983. Water quality inventory--A guide to Michigan water quality data in STORET. Michigan Department of Natural Resources, Surface Water Quality Division, Lansing.

Goudy, G. W. 1986. Water quality and pollution control in Michigan. Michigan Department of Natural Resources, Surface Water Quality Division, Lansing. (S)

Nonpoint source water quality, select basins and statewide

Anonymous. 1972. Grand River basin comprehensive water resources study. U.S.D.A. Soil Conservation Service, Lansing. (S)

Buda, S., Editor. 1988. Michigan's nonpoint-source pollution control management plan. Michigan Department of Natural Resources, Surface Water Quality Division report, Lansing.

Suppnick, J.D. 1993. A status report on Michigan's comprehensive water quality plan for Sycamore Creek. Pages 361-366 In Proceedings, Watershed '93--A National Conference on Watershed Management, Alexandria, VA.

Consumptive water uses, statewide and select basins

Bedell, D.J., and R.L. Van Til. 1979. Irrigation in Michigan 1977. Michigan Department of Natural Resources, Water Management Division, Lansing (S).

Bartholic, J.F., B.D. Knezek, and R.L. Cook. 1983. Impact evaluation of increased water use by agriculture in Michigan. Michigan State University, Agricultural Experiment Station Research Report 449, East Lansing.

Fulcher, G.W., S.A. Miller, and R. VanTil. 1986. Effects of consumptive water uses on drought flows in the River Raisin. Michigan Department of Natural Resources, Engineering--Water Management Division, Lansing.

Hydropower impacts on flows and water quality, select streams

Humphrys and Green. 1962. Preliminary inventory of Michigan's artificial surface water. Michigan State University, Department of Resource Development, Water Bulletin 12, East Lansing.

Anonymous. 1972. Status report on Michigan dams. Michigan Department of Natural Resources, Fisheries Division, Lansing.

Anonymous. 1974. Thermal discharges and water quality control. Michigan Department of Natural Resources, Water Resources Commission, Lansing.

Anonymous. 1982. Inventory of Michigan Dams. Michigan Department of Natural Resources, Water Management Division, Lansing.

Anonymous. 1991. Tippy Project 2580, Application for License to the Federal Energy Regulatory Commission, Exhibit E (Environmental Report). Consumers Power Co. (S)

Basin morphometry and landscapes

Stream network and basin morphometry, statewide

Brown, C.J.D. 1944. Michigan streams-their lengths, distribution, and drainage areas. Michigan Department of Natural Resources,

Folsom, M.M., and H.A. Winters. 1970. Drainage orders in Michigan. The Michigan Academician 3:79-91.

GIS landscape data, statewide

Anonymous. 1985. Michigan Geographic Information System. Michigan State University, Center for Remote Sensing, East Lansing.

Anonymous. 1990. Michigan Resource Information System. Michigan Department of Natural Resources, Land and Water Management Division, Lansing.

Channel geomorphology and habitat

Streambank erosion and sand sediment loads, select coldwater streams

Tarzwel, C. M. 1936. Streambank improvement evaluation in Michigan. Transactions of the American Fisheries Society 66:177-187.

Wicklund, R.G., and B.C. Dean. 1958. Betsie River watershed: survey and plans report. Michigan Department of Conservation, Fisheries Division, Lansing.(S)

Striffler. 1960. Streambank stabilization in Michigan--a survey. Michigan Department of Conservation, Lansing.

Reynolds, D.E. 1973. Michigan Fisheries Centennial Report: Lake and stream improvement. Michigan Department of Natural Resources, Fisheries Division, Lansing.

Anonymous. 1986. Northwest Michigan streambank erosion inventory. U.S.D.A. Soil Conservation Service (in cooperation with the Northwest Michigan Research, Conservation, and Development Area), Traverse City, MI.

Habitat measures and modeling, select streams

Gowan, C. 1984. The impacts of irrigation water withdrawals on brown trout (*Salmo trutta*) and two species of benthic macroinvertebrates in a typical southern Michigan stream. M.S. Thesis, Michigan State University, East Lansing.

Alexander, G.R. and E.A. Hansen. 1986. Sand bed load in a brook trout stream. North American Journal of Fisheries Management 6:9-23.

Anonymous. 1991. Tippy Project 2580, Application for License to the Federal Energy Regulatory Commission, Exhibit E (Environmental Report). Consumers Power Co. (S)

Bovee, K.D., and T.J. Newcomb. 1994. Relations between habitat variables and population dynamics of bass in the Huron River, Michigan.

Baker, E.A. and T.G. Coon. 1995. Comparison of predicted habitat change and brook trout population response to a simulated irrigation withdrawal in Hunt Creek, Michigan.

River corridor protection—Statewide

Anonymous. 1978. Nationwide rivers inventory-to identify high potential candidates for the National Wild and Scenic Rivers system; Report on Lake Central Region Component. Heritage Conservation and Recreation Service, Ann Arbor, MI.

Goldie, M. S. 1982. Pere Marquette Natural Scenic River Management Plan. U.S. Forest Service, Manistee, MI. (S)

Albert, D. A., G. Reese, S. R. Crispin, M. R. Penskar, L. A. Wilsman, and S. J. Ouwinga. 1988. A survey of Great Lakes marshes in the southern half of Michigan's Lower Peninsula. Michigan Department of Natural Resources, Natural Features Inventory, Lansing.

Warbach, J. 1991. Natural Rivers Programs in Michigan. Planning and Zoning News 9:7-13. Planning and Zoning Center, Inc., Lansing, MI.

Hosek, G. 1994. Floodplain management for local officials; Appendix B--Michigan National Flood Insurance Program Listing [mapped communities]. Michigan Department of Natural Resources, Land and Water Management Division, Lansing.

Fishes and mussels

Distributions of fishes and mussels, statewide and select rivers

Hubbs, C.L., and J. Metzelaar. 1924. Unpublished field notes—Au Sable River fish collections. Michigan Department of Natural Resources, Ann Arbor. (representing the beginning of collections by the University of Michigan, Museum of Zoology, Ann Arbor).

Van der Schalie, H. 1930. The clamming industry of the St. Joseph River. Michigan Department of Natural Resources, Fisheries Research Report 38, Ann Arbor.

Hubbs and Cooper. 1936. Minnows of Michigan. Cranbrook Institute of Science, Bulletin 8, Bloomfield Hills, MI.

Brown, C.J.D., and J.L. Funk. 1945. A fisheries survey of the Huron River, its tributaries, and impounded waters. Michigan Department of Natural Resources, Fisheries Research Report 1003, Ann Arbor.

Hubbs and Lagler. 1947. Fishes of the Great Lakes Region. Cranbrook Institute of Science, Bulletin 26, Bloomfield Hills, MI.

Martin, H. M., and M. T. Straight. 1956. An index of Michigan geology [1823-1955, early reports on distributions of aquatic species]. State Printers, Lansing.

Morman, R.H. 1979. Distribution and ecology of lampreys in the Lower Peninsula of Michigan, 1957-75. Great Lakes Fisheries Commission, Technical Report 33, Ann Arbor, MI. (representative of a major, ongoing survey program on coastal streams).

Smith, G.R., J.N. Taylor, and T.W. Grimshaw. 1981. Ecological survey of fishes in the Raisin River drainage, Michigan. Michigan Academician 13:275-305.

- Hoeh, W. R. 1983. A survey of the freshwater mussels of the Maumee and St. Clair river drainages of southeastern Michigan. Michigan Department of Natural Resources, Living Resources Program, Lansing. (S)
- Oemke, M. 1988. Biological survey of Kalamazoo River between Comstock and Plainwell, July 1988. Michigan Department of Natural Resources, Surface Water Quality Division Report 88/088, Lansing. (S)
- Anonymous. 1996. GLEAS Procedure #51: Qualitative biological and habitat survey protocols for wadable streams and rivers. Michigan Department of Environmental Quality, Surface Water Quality Division, Lansing.
- Latta, W. C. 1995. Status of some of the endangered, threatened, and special-concern fishes of Michigan in 1995. Michigan Department of Natural Resources, Natural Heritage Program, Lansing.
- Myers, D. N., and D. P. Finnegan. 1995. National Water-Quality Assessment Program--Lake Erie-Lake St. Clair Basin. U.S. Geological Survey Fact Sheet. Columbus, OH.
- Distribution and estimates of trout populations, select coldwater streams*
- Shetter, D.S. 1937. Contributions to the natural history of some game fishes of Michigan, particularly the brook trout, *Salvelinus f. Fontinalis* (Mitchell), as determined by tagging experiments. Ph.D. Dissertation, University of Michigan, Ann Arbor.
- Anonymous. 1941. Michigan trout streams. In Michigan lakes and streams directory. McCarthy Publishing Co., Lansing.
- Pratt, V.S. 1953. Populations, ecology, and management of marginal trout streams in southern Michigan. Ph.D. Dissertation, University of Michigan, Ann Arbor.
- Schultz, E.E. 1953. Results of a biological and physical survey of the White River drainage system in Newaygo, Oceana, and Muskegon counties. Michigan Department of Natural Resources, Fisheries Research Report 1378, Ann Arbor. (S)
- Schultz, E.E. 1954. The rate of growth of brook, brown, and rainbow trout in Michigan streams. Michigan Department of Natural Resources, Fisheries Research Report 1417, Ann Arbor.
- Bullen, W. H. 1974. The trout streams of Michigan, No. 16; the Little Manistee River. Michigan Department of Natural Resources, Fisheries Technical Report, Ann Arbor. (S)
- Stauffer, T.M. 1977. Numbers of juvenile salmonids produced in five Lake Superior tributaries and the effect of juvenile coho salmon on their numbers and growth, 1967-1974. Michigan Department of Natural Resources, Fisheries Research Report 1846, Ann Arbor.
- Gowing, H. and G.R. Alexander. 1980. Population dynamics of trout in some streams of the northern lower peninsula of Michigan. Michigan Department of Natural Resources, Fisheries Research Report 1877, Ann Arbor.
- Alexander, G.R., and A.J. Nuhfer. 1993. Population dynamics of wild brook trout in Hunt Creek, Michigan, with and without fishing. Michigan Department of Natural Resources, Fisheries Research Report 1996, Ann Arbor.
- Distributions of gamefishes, statewide and select warmwater rivers*
- Anonymous. 1967. Michigan stream classification. Michigan Department of Natural Resources, Unpublished, Lansing.
- Shepard, R.E. 1973. Inventory of fish and evaluation of water quality during minimum flow period in the River Raisin, August 1971. Michigan Department of Natural Resources, Fisheries Division, Lansing. (S)

Estimates of fish community composition, statewide and select rivers

Anonymous. 1996. Qualitative biological and habitat survey protocols for wadable streams and rivers. Michigan Department of Environmental Quality, Surface Water Quality Division, GLEAS Procedure #51, Lansing. (S)

Towns, G.L. 1987. A fishery survey of the Battle Creek River, August 1986. Michigan Department of Natural Resources, Fisheries Division Technical Report 87-3, Ann Arbor. (S)

Integrated watershed assessments

Water resource assessments, select basins

Anonymous. 1955. Water resource conditions and uses in the Paw Paw River basin (one of a series covering many basins). Michigan Water Resources Commission, Lansing. (S)

Anonymous. 1968. The water resources of the lower Lake Michigan drainage basin. Michigan Water Resources Commission, Lansing. (S)

Knutilla, R.L. 1971. A reconnaissance of the River Rouge basin. U.S. Geological Survey, with the Michigan Geological Survey; Hydrologic Investigations, Atlas HA-356, Washington, D.C. (S)

Hendrickson, G.E., and C.J. Doonan. 1972. A reconnaissance of the Manistee River. U.S. Geological Survey, with the Michigan Geological Survey; Hydrologic Investigations, Atlas HA-436, Washington, D.C. (S)

Hendrickson, G.E. and C.J. Doonan. 1972. Hydrology and recreation on the coldwater rivers of Michigan's southern peninsula. U.S. Geological Survey, in cooperation with the Michigan Geological Survey, Water Information Series Report 3, Lansing.

Hendrickson, G.E., R.L. Knutilla, and C.J. Doonan. 1973. Hydrology and recreation on the cold-water rivers of Michigan's Upper Peninsula. U.S. Geological Survey, in cooperation with the Michigan Geological Survey, Water Information Series Report 4, Lansing.

Anonymous. 1976. Great Lakes Basin Commission framework study--environmental impact statement. Great Lake Basin Commission, Ann Arbor, Michigan.

Fishery resource assessments, select basins

Wicklund, R.G., and B.C. Dean. 1958. Betsie River watershed: survey and plans report. Michigan Department of Conservation, Fisheries Division, Lansing. (S)

Coopes, G.F. 1974. Au Sable River watershed project biological report (1971-73). Michigan Department of Natural Resources, Fisheries Management Report 7, Ann Arbor.

Hay-Chmielewski, E.M., P.W. Seelbach, G.E. Whelan, and D.B. Jester, Jr. 1995. Huron River Assessment. (S)

Ecosystem studies, select basins

Ball, R.C., K.J. Linton, and N.R. Kevern. 1968. The Red Cedar River Report. I: Chemistry and hydrology; II: Bioecology.

Watershed management projects, select basins

Gowing, H. 1968. Effects of the Rifle River watershed development program on trout fishing. Michigan Department of Conservation, Fisheries Research Report 1745, Ann Arbor.

Stone, M., and P.L. Benington. 1993. The Mitchell Creek Watershed - Landowner's Handbook. Fen's Rim Publications, Traverse City, MI.

Anonymous. 1994. Saginaw Bay Watershed prioritization process. Michigan Department of Natural Resources, Bay City.

Appendix 2.—Methods for developing physical and biological site databases

Hydrology

Discharge data for all historical and current USGS stream discharge gaging stations (N=138; these were all included as MRI sampling sites) in the Lower Peninsula were obtained from the Michigan Department of Environmental Quality, Land and Water Management Division--Hydrology Section. Data were summaries for the period of record: mean annual and mean monthly discharges; and annual, April (period of saturated soils), and August (period of unsaturated soils) percent exceedence frequencies (for the percent series: 5, 10, 25, 50, 75, 90, 95). We also computed the mean of any MDEQ miscellaneous discharge measures taken at an MRI site during the low-flow months of July, August, and September. Discharges were converted to catchment yields with units cfs/km². Discharges at the above range of exceedence frequencies were also predicted for all 672 sampling sites using MRI models (unpublished).

Water chemistry

Most data on water chemistry were obtained by collections at selected MRI sites during 1992-1997. Alkalinity and conductivity were analyzed in situ; while concentrations of phosphorus, nitrogen, ammonia, and suspended solids were analyzed in the lab using standard and automated methods (Kleiman 1995). Some additional chemistry data for MRI sites were obtained from the STORET database.

Water temperature

Water temperature regimes were characterized for selected sites during July 1989-90 using weekly-readings of maximum-minimum thermometers, and at some over a year's time using continuous recorders deployed for 1-2 years per site, beginning in 1988 (Wehrly et al. 1997). Data were summaries of mean July

weekly minimum, median, and maximum temperatures.

Channel habitat

Data on channel characteristics and habitats were collected at both segment and site scales. For each MRI study site, we measured (digitized or counted) slope, sinuosity, and stream network structure (link number and derivations) for the encompassing stream reach from 1:24,000 maps. We characterized channel geometry (mean width and depth) and hydraulics (mean velocity) at high and low flows for as many sites as possible, using both measures available from USGS gaging activities and field measurements. Some additional channel characteristics, such as percent composition of riparian vegetation and substrates, were assessed by eye during field sampling.

Fishes

Data on fish community characteristics at selected MRI sites were gathered from existing Michigan Department of Natural Resources and USDA Forest Service records and from field surveys. For most sites data described the abundance of fish species, as estimated from either rotenone sampling or 3-pass-removal electrofishing. For sites where 1-pass electrofishing was used, our data described either species presence and absence, or presence only (depending on thoroughness of effort). We incorporated population estimates of selected gamefishes, such as trout, at sites where such estimates were available. When the fish community at a site had been sampled more than once, we used the most recent or most exhaustive collection to characterize the site. Consequently, the data represent the most recent, complete "snapshots" of fish communities at MRI sites. The collections were categorized according to sampling method used and the quality of data.

To date, rotenone surveys have been conducted at 160 sites, mostly in medium to large (3rd to 5th order) warmwater streams, in the lower half of the Lower Peninsula, from

1978-93 by MDNR Fisheries Division field crews. Collection methods used were described by Seelbach et al. (1988). With the exception of non-game species collected during the 1978 Grand River surveys, lengths of individuals and total numbers caught were recorded for all species sampled. We consider the quality of the fish identification as good since early samples were being sent to the University of Michigan to confirm species identity, and later sampling crews included persons skilled at species identification. Seelbach et al. (1994) suggest that these samples provide fair estimates of total standing crop of a stream site (about 75% of actual), but are not as useful for describing numerical abundance unless corrected for biases in species- and site-specific recapture efficiency. Rotenone survey data in the MRI databases were not corrected for such biases.

Multiple-pass depletion sampling using electrofishing has been done at 97 sites, mostly in small (1st or 2nd order) streams, from 1990-95. Sampling was done by MDNR Fisheries Division, University of Michigan, and USDA Forest Service crews. We considered the quality of species identification by crews as very good for MDNR and UM surveys, but only fair for USDA Forest Service surveys as these were conducted by part-time workers and there appeared to be some identification errors. Blocking nets were used in most (if not all) surveys, and the number of passes in each survey ranged from two to five. To allow estimates to be calculated for each species at a site, we initially made a depletion estimate for all species combined (Zippen 1958). We estimated population size for each species as: $N_i = (N_t / C_i) * C$; where N_i is the estimated abundance (number or weight) of species i ; N_t is the total catch (number or weight) of species i ; C is the estimated numerical abundance of all species combined; and C_i is the total numerical catch of all species.

Length and weight data for each species were typically collected for rotenone and depletion surveys, and lengths were measured for mark-recapture estimates. When weight for a species was not measured in the field, we estimated it using length-weight regressions developed for Michigan fishes (Schneider et al. 1991; and from unpublished data for lampreys).

When length-weight regressions were unavailable for a species, we used equations from Schneider et al. (1996) for fishes with similar body shapes (Table A1). To compensate for differences in the accuracy of the balances used on various surveys, we re-estimated weights for all species whose total weights at a site were minimal (< 0.03 pounds). Occasionally, neither length nor weight data were available for small individuals (such as minnows and young of the year fishes) when only a few were collected at a site. When this occurred, we used lengths in August for fishes collected in Wisconsin (Becker 1983), Ohio (Trautman 1981), or Ontario (Scott and Crossman 1979).

Mark-recapture population estimates, using the Bailey modification (Cooper and Ryckman, 1981), were obtained (primarily for salmonids) at 82 sites between 1960-95. All surveys were conducted by MDNR Fisheries Division field crews, and fish identifications are considered excellent.

Two types of single-pass electrofishing data were obtained. Thorough single-pass electrofishing runs were completed at 190 sites between 1951-95. These data reflect several hours of electrofishing at the site, with the collection and identification of all species present. They provide reliable information on species presence and absence at sites, and where effort has been recorded, can be used in calculating catch per unit effort.

Cursory single-pass electrofishing and seine survey data were collected at 82 sites from 1926-95. These surveys typically involved less than an hour of electrofishing effort by crews, and represent a less-exhaustive attempt at collecting all individuals at sites. We refer to these data as "presence only" (pr) because they provide reliable information only on species presence at sites, but cannot be used to confirm absence.

We constructed several databases (RAWWTS, RAWNUM, ONEPASS, and HABITAT) from these collection records. RAWWTS and RAWNUM contain total weights and numbers for each species collected at sites along with sample area dimensions for computing fish densities. ONEPASS contains catch information for the first pass of electrofishing runs, along with sample area

dimensions and the number of minutes electrofished, for use in generating catch per unit effort data. Several missing value codes were used to complete the databases: “-1” indicated species present at site, but abundance unknown; “-99” indicated site sampled, but species’ status at site unknown; and “-111” indicated fishes not sampled at site.

Numerical and weight estimates were standardized by surface area (acres) of the sampling site, producing databases on density (NUMACRE) and standing crop (WTACRE), respectively. A standardized transformation,

calculating the Z-score (mean of distribution = 0) for each species produced 2 additional databases, ZNUM and ZWTS. This transformation allowed us to evaluate the relative abundance of one or more species across sites, without the confounding effect of differential fish absolute abundance or size. Z-scores would therefore be comparable between fish like common carp (typically few in number but very large in total weight) and bluntnose minnows (typically very numerous but small in total weight).

Table A1.—Sources of length-weight regression equations for Michigan fishes from Schneider et al. (1991) used in estimating weights for fishes without species-specific length-weight regressions.

Equation applied to	Equation source
Redside dace	Finescale dace
Pirate perch	Creek chub
Hybrid sunfish	Bluegill
Black redhorse	Golden redhorse
River redhorse	Golden redhorse
Greater redhorse	Golden redhorse
Chinook salmon	Rainbow trout
Coho salmon	Rainbow trout
Spotted sucker	Golden redhorse
Pugnose shiner	Spottail shiner
Troutperch	Rainbow trout
Silverjaw minnow	Bluntnose minnow
Least darter	Johnny darter
Banded killifish	Blackstripe topminnow
Lake chub	Creek chub