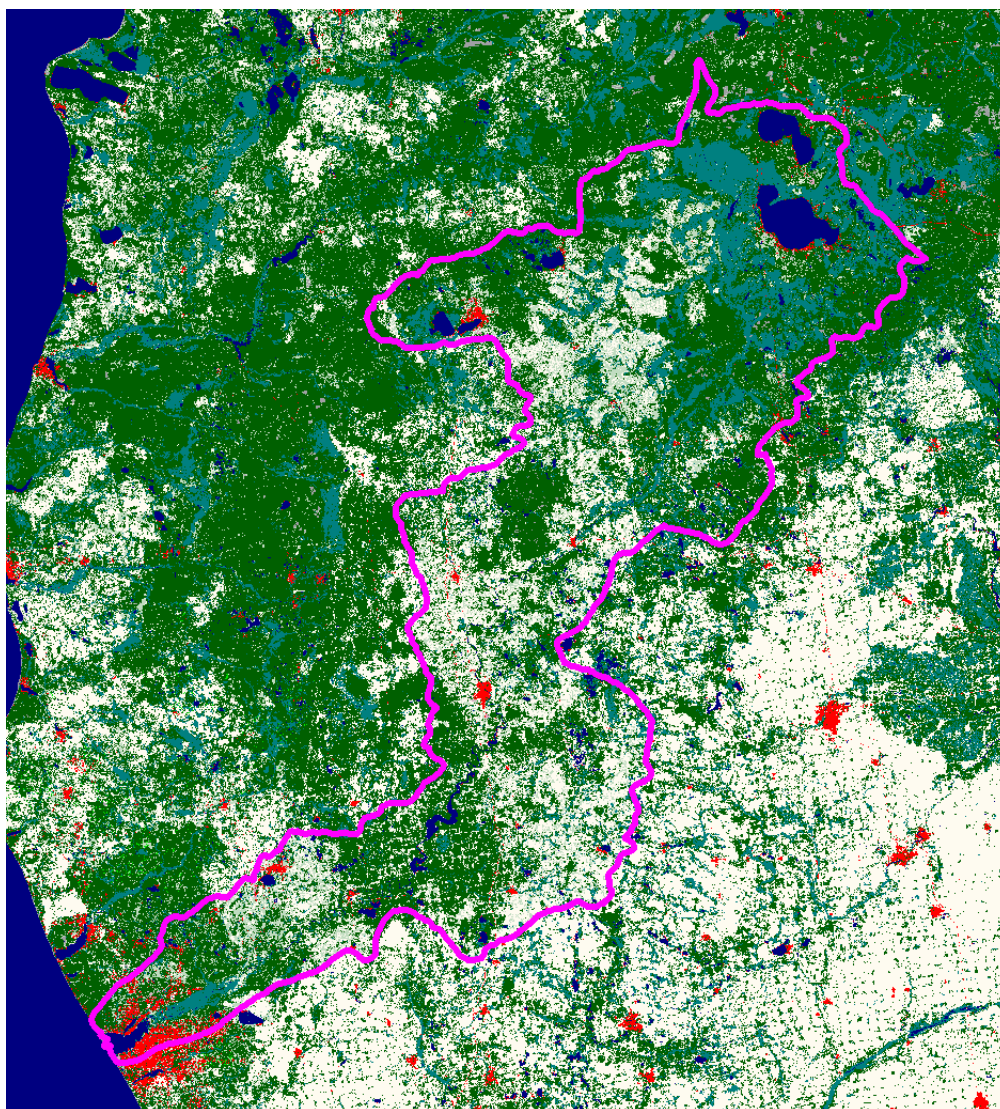


AN ECOLOGICAL ASSESSMENT OF THE MUSKEGON RIVER WATERSHED TO SOLVE AND PREVENT ENVIRONMENTAL PROBLEMS

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PROJECT SUMMARY

Preserving and restoring ecological integrity is a major goal for managing ecosystems. In the Great Lakes region, most assessment is done in lakes and streams with only a few parameters, such as fish and invertebrate biotic integrity and water clarity. Thorough study of physical, chemical, and biological health of terrestrial and all aquatic ecosystems is important for managing the complexity of watersheds. We propose an innovative monitoring program to thoroughly study the ecological integrity of streams, lakes, and wetlands within a model watershed, the Muskegon River Watershed (MRW). The proposed assessment program includes developing response-stressor-land use models to manage watersheds and exciting new measurement systems that will engage and educate stakeholders about the intrinsic value of ecosystems and how human activities affect them.

Our fundamental hypothesis is that changes in land use and land cover will affect ecological integrity of MRW ecosystems. Human activities in the watershed can alter habitat and add contaminants that degrade ecosystems. Quantifying relationships between specific human activities, the specific habitat and water quality changes that they cause, and the ecosystem services affected by those alterations, will enable more accurate prediction of ecological response to alternative plans for restoration and protection.

We propose a systematic, tiered sampling approach using scientists, adult volunteers, students, and a set of automated monitoring stations. We will assess ecological condition with measures of biological (e.g. fish, plants, invertebrates, algae), geochemical (e.g. nutrients, sediments, inorganic cations), and anthropogenic (e.g. % agriculture, buffer width) attributes. New and standard measurements, indicators, and analyses will be integrated to make more precise assessments in the MRW than in past studies. Ecological and land use information will be organized and related to develop quantitative predictive models of ecological responses to human activities. Our integrated, multihabitat assessment will also determine whether streams, lakes, or wetlands are most sensitive to human activities and whether valued ecological attributes such as endangered species are related to measures of ecological integrity. Data from automated sensors at selected MRW sites will be transmitted instantly using advanced radio-telemetry so that stakeholders can access video, sound, and environmental data to monitor, in real time, the heart-beat of their ecosystem with web-based "clickable ecosystems."

Specific outcomes of our research include: a comparative assessment of streams, lakes, and wetlands throughout the MRW; a database for future monitoring, environmental planning, and assessments of restoration success; regionally-defined, precise, quantitative relationships between ecosystem attributes, specific pollutants, and human activities for use in management models; new monitoring technologies that could serve as a basis for a national ecological observation network; and an increased public awareness of both the intrinsic values of MRW aquatic ecosystems and the science used to make management decisions.

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PROJECT DESCRIPTION

Introduction and Objectives

Ecological assessments are necessary to protect and restore ecological systems (US EPA 1996). Ecological systems provide many services that are irreplaceable (Costanza et al. 1997, Daily 1997), such as waste treatment and nutrient retention. Sustainable productivity of ecosystems for harvest of fish, timber, and crops may also require healthy ecological systems (Lubchenco et al. 1991, Ayensu et al. 1999). Ecological assessments increase our understanding of ecological systems as whole, enable evaluating human impacts on ecological systems, and allow determining which environmental factors and human activities most threaten or impair ecosystems (CENR 1997, Stevenson et al. in prep).

Recent advances in the conceptual and technical approaches for ecological assessment afford better management for sustaining healthy ecosystems. Sampling (e.g. integrated spatial sampling and clean techniques) and analytical methods (physical, chemical and biological) are improving and providing more precise characterization of ecosystems; thus ecosystem response can be better related to human activities. New computational power and statistical methods enable more thorough and quantitative exploration of relationships between ecological attributes and human activities. New developments in frameworks for ecological assessments provide a checklist of factors to consider and increase the certainty that relevant information will be collected for integration into a management plan to prevent or solve environmental problems.

The overall goal of our research is to develop new methods for assessing ecological systems and to apply those methods in an integrated watershed assessment, in this case to the Muskegon River Watershed (Fig. 1). We have four primary objectives:

1. assess and monitor the ecological health of streams, lakes, and wetlands throughout the MRW using a tiered, integrated approach with citizens and experienced scientists;
2. develop regionally-defined, quantitative relationships between ecosystem attributes, specific pollutants, and human activities that can be used in management models;
3. develop monitoring technologies that will enable continuous assessment of ecosystem processes at the land-water interface; and
4. increase public awareness of intrinsic values of MRW ecosystems and the science used to make management decisions.

The new data that we collect will be compatible with data that has been collected by state and citizen programs in the past, but our efforts will involve more detailed analysis and synthesis of information. The new data that we collect and monitoring protocols that we develop will also integrate with other projects in the Muskegon River Watershed Partnership (Fig. 1).

Our approach is to gather information that allows us to test the fundamental hypothesis that changes in land use and land cover affect valued ecological attributes of MRW ecosystems. Our work will focus on aquatic ecosystems. Measurements will be collected from streams, lakes, and wetlands using a tiered approach and from multiple locations and times using scientists, adult volunteers, students, and a set of automated biological monitoring stations. Measurements will include characteristics of invertebrates and algae, and less frequently birds and fish and other ecological indicators, pollution, and the human activities that may be causing watershed alteration. New measurements (e.g. developmental instabilities, inductively coupled mass spectrometry with hexapole technology, ICP-MS-HEX), indicators (e.g. relative composition of chemicals based on ICP-MS-HEX, biotic indicators of wetland), and analyses (cross-habitat, stressor-response comparisons), as well as standard approaches, will be integrated

to make more precise assessments in the MRW than in past studies. Ecological and land use information will be organized and related to develop quantitative predictive models of ecological responses to human activities. We will test hypotheses that relate measures of ecological integrity, stressors, and ecosystem services. Data from automated sensors at selected MRW sites will be transmitted instantly using advanced radio-telemetry so that stakeholders can access video, sound, and environmental data to monitor, in real time, the heart-beat of their ecosystem with web-based "clickable ecosystems."

Background

Preventing and solving environmental problems requires integration of a great diversity of information, ranging from the human health and ecological threats to economic, policy, social, and engineering issues (US EPA 1996, Christensen et al. 1996, Ayensu et al. 1999). The significance of establishing the tools to manage environmental problems is evident in challenges of global problems (such as elevated CO₂ and nitrogen deposition), restoration of the Everglades and salmon populations in the Northwest US, and management of fisheries and hazardous algal blooms in the Chesapeake Bay. A group of scientists and stakeholders have been brought together by the Muskegon River Watershed Partnership to develop these tools for a Great Lakes watershed. The group organized projects to generate and integrate the diversity of information needed to protect and restore environmental quality. These projects include assessments of human health risk by microbial contamination and ecological health risk for fish habitat, fisheries value, and ecological integrity; economic and development issues in the region and challenges associated with management; restoration and remediation strategies; a land transformation model that relates human activities and future changes in those activities to environmental responses; and program to involve and educate citizens in environmental issues.

Our project, MRW Ecological Assessment Program, is an important element of MRW Partnership as ecological assessment is in any environmental management program (Fig. 1). The proposed MRW Ecological Assessment Program will assess the ecological integrity and will develop ecological models that can be used to manage and protect the intrinsic values of those ecosystems. The MRW Ecological Assessment Program will provide information for educating citizens about ecological status of the MRW, for assessing success of restoration and remediation strategies, and for predicting effects of future economic development and land management plans. In addition the MRW Ecological Assessment Program will develop indicators and relationships among ecological factors that will increase precision of future MRW assessments and ecological assessments throughout the Upper Great Lakes region.

During the last decade, a growing consensus has been developing that environmental assessment requires a set of complementary indicators for a complete "check-up" and assessment of the causes and threats to ecological systems and for their protection and restoration (Paulsen et al. 1991, Council of Great Lakes Research Managers 1991, Cairns et al. 1993, U.S. EPA 1996, 1998). We plan development of response, stressor, and land use indicators that can be used to determine, respectively, whether problems exist, the probable stressors causing those problems, and the human activities that cause the stressors (Fig. 2). Distinguishing among these categories of indicators reinforces our development of conceptual models that clearly identify ecological endpoints, physical and chemical factors that directly or indirectly affect those endpoints, and the human activities that produce or even remediate contamination and habitat alteration. Even though the names for indicators may change among users, this same indicator framework is the foundation of many programs, such as EMAP (Paulsen et al. 1991, Hughes et al. 2000), and

SOLEC (1999a). We chose terms based on usage in EMAP documents (Paulsen et al. 1991, US EPA 1997) and apologize for conflicting use of terms with other groups of investigators.

Briefly:

- response indicators are related to endpoints of concern and typically, but not always, measure biological condition of a resource (Paulsen et al. 1991);
- stressor indicators are environmental measurements (e.g. sedimentation rate, nutrient concentrations or loading rates, contaminants in sediments) that either directly or indirectly affect endpoints of concern as indicated by a significant statistical relation between response and stressor indicators (US EPA 1997, Lubchenco et al. 1991); and
- land use indicators are, among other things, measures of land use which, when combined with landscape indicators (e.g., slope and connectivity to contaminant transport pathways), will identify which human activities are generating environmental stressors in the assessed ecosystem.

With a set of complementary indicators, assessments of valued ecological attributes (response indicators), stressors, and human activities at multiple sites can be integrated into response-stressor and stressor-human activity relationships that function as models for managing watersheds. In addition, assessment of response, stressor, and human activity indicators at a specific site can be used to diagnose the causes of impairment of ecological condition or the greatest threats to impairment. For example, with knowledge of stressor-response relationships from the literature or ongoing investigations, response indicators of ecosystem services and stressor indicators can be compared to determine which stressor(s) are likely most responsible for impairment or most threaten impairment (Fig. 3). This cause/threat assessment (Fig. 3) is, in fact, what ecologists often do even when they do not have good response-stressor relationships. They use best professional judgment to determine which responses of systems are related to which stressors. Determining which stressors are important for management and remediation is challenging for many reasons, but particularly because response-stressor relationships are poorly understood in complex natural ecosystems and because interactions among multiple stressors may be regulating ecological response. These common-sense steps in ecological assessment are the same steps, fundamentally, as hazard assessment, exposure assessment, stressor-response characterization, and risk characterization in ecological risk assessment (as defined in US EPA 1996, 1998).

General Study Plan

Study Area

The Muskegon River Watershed is an excellent choice for developing and testing watershed management concepts and in particular, developing an integrated ecological assessment program. The MRW is almost 7000 km² in size and includes 94 tributaries and 183 stream segments (interrupted by 95 dams), and hundreds of lakes and wetlands. Glacial deposits reach as much as 1 km deep over bedrock and create conditions with substantial groundwater-surface water exchange and excellent trout fisheries. Subwatersheds vary from largely forested to largely agricultural and no large subwatersheds have substantial urban coverage. However, residential development around many lakes is great. Historic, extensive logging is believed to have left a legacy of high sediment loads in streams (O'Neal 1997). Considerable interest exists in removing dams from the Muskegon River to increase fish habitat by cooling waters and decreasing residence time and associated algal blooms (O'Neal 1997). This restoration may generate significant transport of stored sediments in dams. Five species of fish and 15

invertebrate species are listed as threatened or endangered or on listed on the Michigan Natural Features Inventory.

Overview

The MRW Ecological Assessment Program has been designed to meet multiple objectives and is organized based on a modified version of the US EPA risk assessment framework (Fig. 4, Stevenson et al. in prep.). We identified four objectives:

1. assess and monitor the ecological health of streams, lakes, and wetlands throughout the MRW using a tiered, integrated approach with citizens and experienced scientists;
2. develop regionally-defined, quantitative relationships between ecosystem attributes, specific pollutants, and human activities that can be used in management models;
3. develop monitoring technologies that will enable continuous assessment of ecosystem processes at the land-water interface; and
4. increase public awareness of intrinsic values of MRW ecosystems and the science used to make management decisions.

The first three objectives are directly related to monitoring the status of ecological conditions in the MRW and determining the physical, chemical, and human factors that threaten or cause environmental problem (Figs. 1&4). The first and second objectives call for spatially extensive sampling (i.e. sampling many sites) to assess conditions in many streams, lakes, and wetlands, and relating valued ecosystem responses to stressors and human activities (i.e., stressor-response relationships, (Fig. 4). The combination of sampling strategies in the first and third objectives calls for summer sampling of many sites and continuous monitoring at a few sites. This sampling strategy is used by the USGS National Water Quality Program, although our methods will enable more intensive (continuous) sampling at fixed sites. Integrating high frequency spatial and temporal assessment will enable inference about year-round conditions in habitats throughout the watershed. Our goal with automated monitoring systems (AMSs) is to developing new technologies for linking land-water processes. Continuous monitoring enables characterizing diurnal changes in ecological conditions related to day/night cycles, daily and weekly patterns related to weather cycles, and seasonal patterns. Annual variability, the basis for determining long-term trends in conditions and success of management decisions, will be assessed with fixed stations and with repeated summer sampling. The final objective involves communicating the results of our ecological assessment to citizens, as well as decision makers and other scientists, which is a critical step in applying assessment in ecological management (Harwell et al. 1999).

We have organized the MRW Ecological Assessment Program (Fig. 1) with many elements of an ecological risk assessment (Fig. 4, Suter 1993, US EPA 1996, 1998, Foran and Forenc 1999). In fact, recent discussions have suggesting merging the concepts of ecological risk assessment and ecological assessment (Pittinger et al. 2000, Stevenson and Smol in press, Stevenson accepted, Stevenson et al. in prep). Our objectives and ecological endpoints have been related to other ecological factors in a conceptual model, particularly valued ecological attributes (response indicators), stressors, and human activities (as per Fig. 4). Our conceptual model focuses on ecological integrity of streams, lakes, and wetlands as well as the sediments, nutrients, and the human activities related to these stressors. Sediments and nutrients are common stressors in aquatic habitats of the MRW, as in most Midwestern streams and lakes. Little is known about effects on wetlands. Sediments transport is a stressor related to dam removal, which is a focus of management in the MRW and many other regions. Nutrients are

the focus of a major national regulatory effort (US EPA 2000a). Other stressors will be measured during assessments, but we target this 3-year program on the two most widespread stressors in Midwestern streams.

We target our study on the assessment of the ecological integrity of aquatic habitats because of Clean Water Act regulations and compatibility with other state and national programs. The purpose of the Clean Water Act was to "...restore and maintain the chemical, physical, and biological integrity of the waters of the United States." Concepts of ecological integrity are under continuing development to meet water quality and biocriteria requirements specified by Sections 303, 304, 305(b), and 319 of the CWA. Concepts of ecological integrity could be related to the endangered species act. Assessing biotic integrity using algae, invertebrates, and fish are central to many state and national (EMAP & NAWQA) assessment programs. Recent recommendations for national ecological indicators (National Research Council 2000) include many elements of ecological integrity, such as species diversity and diversity of native taxa.

We have developed a study plan that includes: testable hypotheses (listed under respective objectives and tasks); sound measurement of valued ecological attributes (response indicators), stressors, and human activities (land use indicators); and a sampling plan to test our hypotheses (Fig. 4). Our results will produce:

- a better understanding of interrelations among ecological responses, stressors and human activities by testing hypotheses relating support of endangered species and ecosystem services to measures of ecological integrity;
- assessments of human effects on ecological integrity of streams, lakes, and wetlands of the MRW;
- quantitative relations among ecological responses, stressors, and human activities that can be used: and
 - to determine causes and threats to impairment of ecological conditions; and
 - management options for protecting or restoring ecological conditions.

Expected Results

In addition to the results mentioned above, our research will also provide:

- a comparative ecological assessment of streams, lakes, and wetlands of the MRW;
- a database for future monitoring, environmental planning, and assessments of restoration success;
- new monitoring technologies that could serve as a basis for a international ecological observation network; and
- an increased public awareness of both the intrinsic values of MRW aquatic ecosystems and the science used to make management decisions.

Research Team and Responsibilities

We have assembled an experienced team, whose members have assessed streams, lakes, wetlands, and land use in Michigan and many regions of the country. Each team member brings a different technical and conceptual expertise to the project (Table1).

Table 1. Responsibilities of Co-PIs in the Muskegon River Watershed Ecological Assessment Program. Project Coordination (Proj. Coord.), DI (Developmental Instabilities), RSR (Stressor-Response Relationships), AMS (Automated Monitoring Systems), and CE&E (Clickable Ecosystems and Education).

	Proj. Coord	Objective 1 - Assessment								Obj 2 RSR	Obj 3 AMS	Obj 4 CE&E
		Coord	Chem	Algae	Inverts	Fish	Plants	DI	Citizen			
Stevenson	X	X		X					X	X	X	
Gage	X										X	X
Hough							X	X	X			
Wiley					X	X						
Long			X								X	
Qi				X			X				X	
Pijanowski										X		
Bonnell									X			X
Dennison												X
Bowman						X						

Project Schedule

Under Objectives 1 & 2, summer is for sampling and the rest of the year is for getting ready for sampling by inventorying sites, defining land use, and by analyzing data from the previous year. Under Objective 3, the first year will be spent on developing instrumentation and digital libraries for species vocalizations before deployment of AMSs during spring of 2002. We will start using the AMS data to compare ecosystems and we will establish the web-based "clickable ecosystems" and ecosystem report cards during summer of 2002.

Task	2001 Seasons				2002 Seasons				2003 Seasons			
	W	S	S	F	W	S	S	F	W	S	S	F
Objective 1												
Tier 1 Assessments												
Inventory Sites	Blue	Blue										
LU Assessments	Green	Green			Green	Green			Green			
Tier 2 Assessments			Green				Green				Green	
Tier 3 Assessments												
Summer Sampling			Yellow				Yellow				Yellow	
Assess Human Effects												
Exp. Cond = Ref.				Orange	Orange	Orange						
Exp. Cond = Pred. Models								Orange	Orange	Orange	Orange	Orange
New Indicators												
Cause/Threat Assessment					Red	Red		Red	Red	Red	Red	Red
Objective 2 - Management Models					Purple	Purple		Purple	Purple	Purple	Purple	Purple
Objective 3												
Develop Instrumentation	Blue	Blue	Blue	Blue	Blue	Blue	Cyan	Cyan				
Develop Digital Library	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green	Green
Relate Sounds to Organisms			Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Compare Ecosystems								Orange	Orange	Orange	Orange	Orange

Objective 1 (Study Plan). Assess and monitor the ecological health of streams, lakes, and wetlands throughout the MRW using a tiered, integrated approach with citizens and experienced scientists.

Ecosystems will be assessed by testing the null hypothesis: *ecological conditions (biotic, physical, and chemical) at assessed sites are equal to conditions at reference sites.*

A multi-tiered approach has been designed for assessing ecological conditions, stressors, and human activities of streams, lakes, and wetlands in the MRW. This approach follows the CENR (1997) pyramid of effort approach, which stratifies effort to maximize spatial and temporal extent of assessments and also the detail of assessments. Distinguishing tiers in assessment also clarifies the types of assessments that will be conducted and the different objectives and hypotheses that will be tested with each. Tier 1 assessments, the simplest (or lowest effort per site) assessments, will inventory all stream segments, lakes, and wetlands in the MRW using maps and will assess habitats based on nearby land use. Tier 2 assessments will integrate citizen and scientist monitoring using methods that citizens can readily use. Scientists will aid citizens in Tier 2 monitoring by teaching new methods and by leading efforts to expand citizen monitoring efforts. Tier 3 assessments will be conducted by technicians and scientists will involve more thorough sampling and assessment of ecological condition and higher QA/QC. Tier 3 assessments will constitute the majority of effort of the MRW Ecological Assessment Program. They will use reference-based and probabilistic sampling approaches to characterize status of ecological condition, stressor-response relationships, and cause/effect assessments in the MRW. In addition, Tier 3 assessments will lay the foundation for assessing trends in ecological condition of the MRW.

In the following sections under Objective 1, assessment methods and the rationale for using them are described. Methods sections will be followed by discussions on how expected condition will be established, assessing human effects, identifying causes and threats, and developing new biological indicators of stressors.

Tier 1 Assessments

Tier 1 assessments will be conducted for all stream segments (section of stream between confluences), lakes, and wetlands in the MRW to provide thorough assessment of the MRW, to identify sites with high probabilities of impact, and to identify potential reference sites. The inventory of sites during Tier 1 assessment will also provide the basis for probabilistic sampling of sites during Tier 3 assessments. Inventories will include waterbody name, latitude, longitude, county, township, and probable access location. Tier 1 assessments will be conducted based on current map information, such as location, waterbody name, size, wetland class, and land use near the site. Methods for assessing land use are described under Objective 3. Land use - water quality relationships developed in other studies (e.g. Allan et al. 1997, Wiley et al. 1997, Wayland et al. 2000a) will be used to estimate level of impact in stream, lakes, and wetlands. Sites with high probabilities of impact will be determined by ranking estimated level of impact by habitat type (stream, lake, wetland) and type-class (riparian wetlands, lacustrine wetlands, bogs, fens; small and large lakes; small and large streams and rivers with high and low groundwater input, i.e. coldwater and warm-water streams).

Tier 2 Assessments

Tier 2 assessments will be conducted by citizens, technicians, and scientists. Citizen groups, coordinated by the Michigan Lake and Stream Association, have been monitoring waterbodies in Michigan for many years. About 10 lakes and streams in MRW are currently monitored by MLSA. Our goal is to work with MLSA, the Muskegon River Watershed Assembly (MRWA), regional teachers, and the MRW Education Program (Denison et al.) to develop a larger citizen watershed monitoring program for the MRW. In addition we will increase the quality of their assessments, increase the number of parameters that they assess, increase the number of sites that they assess. Many citizen volunteer programs exist around the world. Like MLSA, they usually monitor water transparency, dissolved oxygen, and aquatic invertebrate biodiversity and they make collect samples for nutrient and chlorophyll (chl) a analysis by other laboratories. We will bring this information to MLSA and MRWA and provide them with the opportunity to adopt new methods and new approaches to sample lakes and streams and to add wetland assessment to their program. The MRW citizen assessment program will increase the number of sites that we can be assess in our MRW program and they will enable analysis of the factors associated with precision of methods used by citizen monitoring groups. In addition, we plan to use Tier 2 results to develop relationships between ecological condition, stressors and human activities as measured by land-use and landscape. These relationships will be useful in watershed management and educating citizens on how monitoring results are used in watershed management (Objective 4). This knowledge will empower citizens to make informed decisions for management of their watershed (Harwell et al. 1999).

Tier 3 Assessments

Tier 3 assessments will incorporate state-of-the-art methods and sampling designs to develop new and highly precise condition and stressor indicators. In addition, Tier 3 assessments will be used to conduct a rigorous assessment of ecological condition, stressors, and human activities generating stressors in streams, lakes, and wetlands of the MRW. Tier 3 assessments will include all measurements of Tier 1 and Tier 2 assessments, and thus build on a consistent sampling effort across Tiers and incorporate all assessment efforts in final analyses.

We will conduct Tier 3 assessments in 42 streams, 42 lakes, and 42 wetlands per year during the 2001 and 2002. Only 24 streams, lakes, and wetlands will be sampled during 2003 because extra time will be required for final analyses. This large sample size is important for developing precise indicators for as many classes of streams, lakes, and wetlands as possible. 6 streams, 6 lakes, and 6 wetlands will be resampled each year to assess annual variability in ecological conditions. 3 streams and 3 lakes that were resampled annually will be monitored with automated monitoring systems, which are described in Objective 3. The remaining sites will be randomly picked from the population of stream segments, wetlands, and lakes in the MRW. Our goal is to use at least 25% of these habitats as reference sites. As many as five additional streams, lakes, and wetlands will be sampled each year to develop response-stressor relationships (Objective 2); the additional sites will ensure that a range of habitats are sampled with varying nutrient and sediment impacts. Wetlands will be sampled during early summer (mid-June - early July) and lakes and streams will be sampled during mid-summer (mid-July - mid-August).

Tier 3 assessments will be detailed assessments of the biotic integrity of habitats as well as the physical and chemical integrity of streams, lakes, and wetlands. The methods used in Tier 3 assessments will be a hybrid of methods used by MDNR and MDEQ plus national assessment

programs such as EMAP (EPA's Environmental Monitoring and Assessment Program) and NAWQA (USGS's National Water Quality Assessment Program). The short-term and long-term (3-yr) goals for Tier 3 assessments are:

1. Augment recent MI-DNR assessments of fish and invertebrate assemblages in the streams of the MRW with additional assessments to build more accurate and precise relationships between the biotic integrity and human activities in the watershed. This information can be used in Decision Management Models with existing indices to optimize watershed planning for multiple uses (MRW project proposed by Wiley et al.).
2. Assess ecological integrity of streams, lakes, and wetlands with algal, invertebrate, fish and plant assemblages and developmental instabilities of plants and fish, and physical and chemical attributes of these ecosystems.
3. Relate ecological integrity of streams, lakes, and wetlands to existing data on fishery quality and presence and absence of endangered and non-native species.
4. Develop new indicators of plant diversity and productivity in wetlands and algal blooms in lakes and streams using remote sensing.
5. Develop new biological indicators of the chemical and physical stressors that threaten or impair ecological condition in streams, lakes, and wetlands.

Tier 3 assessments will describe one or more of the following ecological attributes and their deviation from expected condition: species richness, number of native species, number of non-native species, relative abundances of species and biomass (density) of biological assemblages (algae, invertebrates, plants, and fish); developmental instabilities of plants and fish; physical habitat; relative and absolute concentrations of chemicals in water and sediments. In general, invertebrates, algae, and water chemistry will be sampled and assayed for ecological assessment, but in selected areas, fish (streams and lakes), plants (wetlands), and sediment chemistry (lakes and wetlands) will also be assayed. Tier 3 assessments will also utilize the reference approach to establish expected condition for assessment of all habitats in the watershed (described in a later section).

The remaining sections of Tier 3 Assessments describe the methods used to: delineate the region to sample; assess fish, invertebrates, algae and plant assemblages; assess water chemistry and physical habitat; use remote sensing to develop indicators of wetland size and vegetation; use remote sensing to develop indicators of algal composition and biomass in streams and lakes; assess land use; and assess developmental instabilities.

Delineating the area to sample. A reach is a sampling unit that provides a representative assemblage of aquatic organisms for a valley segment for streams. A reach is defined by the type and distribution of habitat units (riffles, pools, etc.) that are most representative of a valley segment. A reach must include multiple examples of the most common habitat units in the sequence that they are characteristically found in the valley segment. We will adopt this concept for sampling lakes and wetlands as well as streams.

Fish assessments. The goal of fish sampling at the site level is to obtain a sample of the complete assemblage of individuals, identify them to species and obtain measures of species size and weight distribution and abundance. This information will be used to classify the alliance level of community assemblages.

Fish sampling in wadeable streams and waters <2m in lakes will be performed by conducting depletion sampling using tow behind 240-volt pulse DC electroshock gear or backpack shockers and collecting seines where tow behind gear could not be used. Whenever feasible the sample site will be confined using blocking seines. A near-complete sampling of individuals

residing in a site is often possible using this method. Depletion sampling is generally completed within three or four passes through the reach. Occasionally time may permit only a single electrofishing pass, which will be recorded if a re-visitation cannot be scheduled. Of the fishes that can be identified in the field, 30 individuals representative of the size distribution of the sample population of each species will be measured and weighed. If fewer than 30 individuals of a species are present in the sample, all will be measured and weighed. If an individual sampled in the field cannot be identified a voucher specimen will be preserved for later identification. Observations of anomalies such as parasites, deformities, lesions, eroded fins and tumors will be noted. In addition, developmental instabilities of fish will be assessed, as described in a subsequent section.

The Michigan Council of Trout Unlimited will assist in the assessment of fish stocks by collecting data from guides and fishermen. Creel census forms will be developed for their use to optimize the quality and objectivity of information obtained.

Macro-invertebrate assessments. The goal for macro-invertebrate sampling will be characterizing the taxonomic composition and relative abundance of the macro-invertebrate assemblage at the habitat and site scales. A complete sample of macro-invertebrates with identification to the species level is beyond the scope of this investigation. There are generally 100-500 species of macro-invertebrates in a given sampling reach. The sampling procedure is designed to obtain a list of taxa identified to the finest level feasible in the field (with laboratory confirmation), qualitative relative abundance descriptions, and habitat unit specificity of the taxonomic groups.

Before a site is sampled, the types and relative proportions of habitat units will be recorded as part of the physical habitat assessment. The standard collection effort for a reach will be 2 person-hours per 150 m reach. Larger areas will receive proportionally more effort. Teams of two people will generally spend one hour collecting invertebrates. Each person will sample a set of macrohabitats assigned to him or her through group discussion. Habitat units are sampled using appropriate methods with the goal of providing the most complete taxonomic list possible given the sampling time allowed. Coarse and fine substrate, emergent and submergent vegetation, woody debris and bank-side habitats will be sampled using D-nets, slack samplers, screens or other appropriate devices for collection of a good, qualitative assemblage sample. In addition, several cobbles, pieces of woody debris and grabs of vegetation will be sampled with tweezers. If there is abundant vegetation, larger grabs were made and the vegetation "washed" into the current with a slack sampler immediately downstream to catch dislodged individuals. Ponar and Eckman Dredge samples will be collected in lakes. In each habitat type, taxa will be collected and recorded immediately on the field sheets, with notes on which macrohabitat unit(s) it occurred. At least 5 individuals of each taxonomic group collected will be placed into a vial of ETOH (90%) as a reference sample for the habitat unit and reach. If less than 5 individuals are found, all individuals will be preserved. Collection of specimens in the habitat units continued until the time/effort is completed or until it is obvious that no new taxa are being collected. Any taxonomic group that cannot be identified in the field will be collected and labeled for further identification. The shells of deceased mussels will be collected and taken back to the lab for further identification. Macro-invertebrates that are seen but not sampled, and signs of their presence, will be noted on field sheets. While picking samples of each taxa, a qualitative abundance will be noted as: Rare, 5 or less individuals for the habitat unit; common, >5 individuals for the habitat unit; and dominant, extremely abundant in each habitat unit.

Algal assessments. Algae will also be collected from multiple habitats, such as cobbles, snags, macrophytes, sediments, and plankton using standard sampling methods (Stevenson and Bahls 1999, Stevenson and Smol in press). Multiple habitats will be sampled to characterize as many taxa as possible and to ensure cross-ecosystem comparison of assemblages in targeted habitats. In addition, multiple habitat sampling enables testing the hypothesis that between-habitat diversity will decrease with human disturbance. Evidence of nuisance growths of benthic algae or plankton will also be noted in lakes and wetlands, plus algal biomass will be assessed based on amounts of algae sampled and area sampled. 4 L of planktonic algae will be collected from streams, lakes, and wetlands. All algae will be stored on ice and in the dark after collection and processed within 10 h. Benthic algal samples will be homogenized and subsampled for chl a analysis and assessment of species composition. Subsamples of plankton (1-2L) will be filtered for chl a assay. The rest will be preserved with Lugol's preservative and settled. Algal biomass will be estimated as chl a/cm² of benthic algae and chl a/L of plankton. Species composition will be determined with standard methods by identifying and counting 300 algal units (colonies, filaments, or single cells) in a Palmer Cell and also by identifying and counting 600 valves of diatoms after acid cleaning and mounting in NAPHRAX[®] (Porter et al. 1993). Standard metric approaches such as periphyton Indices of Biotic Integrity will be used as well as % similarity to reference conditions, % native diatom taxa, and % non-native diatom taxa will be determined.

Algal biomass and taxonomic composition will also be assessed in lakes, rivers, streams, and maybe wetlands after developing a remote sensing indicators. Remote sensing (discussed later) offers the unique capability of monitoring algal biomass and taxonomic composition in all lakes and streams at frequent time intervals. Thus, blooms are more likely detected.

Plants. Plant species composition in wetlands will be assessed using semi-quantitative methods as recommended by EPA Bioassessment of Wetlands Workgroup and by several state organizations. Transects are established radiating from the middle of the wetland to its perimeter. At ten or more 3m x 3m quadrats, % cover of each plant species will be estimated. We will also develop remote sensing indicators of plant biomass and species composition. In addition, developmental instabilities of plants will be assessed described in a subsequent section.

Water and Sediment Chemistry. The results (absolute and relative concentrations, biogeochemical models) from the water and sediment chemistry measurements will provide important information on environmental states and stressors that will help define the linkages between ecological response and landscape indicators. Water and sediment samples will be collected spatially throughout the MRW. Water (rivers, lakes, wetlands) samples will be collected using clean techniques that we have modified from the U.S. Geological Survey sampling protocols and are using for studies in the Grand Traverse Bay watershed (e.g., Boutt et al. 2000; Wayland et al. 2000b). These samples will be analyzed for two "classes" of water quality indicators. Class one indicators includes those parameters that are the dominant contributors to the electrical balance of the water (e.g., calcium, potassium, chloride, alkalinity) as well as basic parameters such as temperature, pH, dissolved oxygen, and total dissolved solids. These parameters can then be used in geochemical models that allow us to answer questions such as: 1) what is the current state of water quality, 2) how does this state relate to expected conditions based on the hydrogeologic and climate conditions of the MRW, and 3) what are the processes (natural and anthropogenic) that have lead to this state. Our extensive knowledge of the hydrogeochemical state of waters in the lower peninsula of Michigan from our RASA studies that were conducted in cooperation with the U.S.G.S. (e.g., Meissner et al. 1996;

Wharner et al. 1996) can be used to help establish reference conditions along with the results from geochemical modeling.

Class two indicators include a variety of other parameters dissolved in the water that range from elements such as aluminum, titanium, strontium to contaminants such as lead, cadmium, and arsenic. We will use inductively coupled mass spectrometry with hexapole technology (ICP-MS-HEX) to simultaneously determine approximately 26 elements in the water samples. When studied as a group, the relative abundances of these elements provide a geochemical “fingerprint” of a sample. Using these fingerprints and knowledge of the biogeochemical cycles of the elements, we will be able to make interpretations of ecological states and processes. We have been recently using this approach in our studies of environmental health problems in Bulgaria (e.g., Long et al. 2000a, b, c); the relationship of land use to ecosystem health in the Grand Traverse watershed (e.g., Wayland et al. 2000b).

We will use the ICP-MS-HEX to determine the chemical composition (26 chemicals) of the sediments in the MRW. Sediments will be assessed both spatially and temporally and we will compare the results from our sediment studies in the MRW to sediment quality guidelines for freshwater ecosystems (e.g., MacDonald et al. 2000). Temporal measurements will be made via sediment cores in selected lakes, wetlands, and perhaps quiescent portions of selected rivers. ²¹⁰Pb dating methods will be used to determine the ages of the sediment layers in selected cores. Typically deeper sediments in the core have ages that predate major human impacts on the ecosystem (e.g., > 1800). The geochemical fingerprints of these older sediments can be used to establish reference conditions. We can also establish reference geochemical fingerprints based on knowledge of the geologic setting of the watershed, an approach we are using to assess environmental recovery of anthropogenically disturbed lakes (e.g., Fett et al. 2000a, b). In addition, we are gaining extensive knowledge of spatial and temporal sediment geochemical fingerprints from our inland lakes studies (e.g., Simpson et al. 2000a, b, c).

Physical habitat characteristics. Physical habitat characteristics, such as stream channel width and slope, % riparian canopy and extent and width of riparian buffer, will be measured according to rapid bioassessment protocols (Barbour et al. 1999). Sedimentation indicators (such as substrate size fractions, percent organic matter, total suspended solids, percent filling of interstitial spaces among rocks in riffles with sediments) will be used to assess sedimentation stress. Water temperature will be measured in the field and estimated groundwater input will be estimated using existing hydrologic models. Additional measures of groundwater discharge may be necessary to develop these models to distinguish cold-water and warm-water streams. However, cold-water and warm-water reaches of the Muskegon River and its tributaries have been mapped (Wiley, personal communication). In addition, percent habitat that serves as substrate for algae and invertebrates will also be characterized.

Remote Sensing. Remote sensing indicators of wetland vegetation, lake trophic state, and nuisance algal growths in streams will be developed by: 1) acquiring supplementary remote sensing imagery both on the ground and from satellite sensors over study sites to characterize spectral properties of various vegetation species/types and water bodies with different biophysical attributes and 2) relating spectral properties of study sites to plant species and algal taxa (divisions and classes) and their biomass. Traditional land use and land cover mapping is often limited to the land use and types, where a piece of land is classified according to its current use. For example, legends of land use and land cover maps often include urban, cropland, forest, and wetland, which provide important information on the type of land use. However, it is highly desirable to attach physical attributes to these land use maps such as forest cover, crop density,

wetland vegetation type and species, and water temperature. However, derivation of these attributes from satellite imagery was limited in the past due to primarily limited spectral bands available on existing satellites and their coarser spatial resolutions. With new satellite technology such as IKONOS and Earth Observing-1 satellites, both spectral bands and spatial resolutions increased (see Table 1). Using new algorithms and improved satellite imagery, wetland classification down to species level may be possible.

We plan to acquire images from four satellite sensors (Table 1) over the study sites and the entire Muskegon watershed. We will acquire IKONOS and ASTER imagery over selected study sites and MODIS images over the watershed. The synchronized satellite imagery acquisition will ensure the scaling up of indicators with these remote sensing images (with their different spatial resolution) and correspondence to the same vegetation phenology and same biophysical properties of lakes and streams. Since the launch date of EO-1 is undetermined and plus its mission will be one year, we plan to acquire Hyperion images only during the satellite mission period. These images will be geometrically corrected and referenced to a UTM coordinate and atmospherically corrected using a new approach we developed. These images, with spatial resolution ranging from 1m to 1000m will enable us to scale up locale indicators to regional scales. We recognize that ASTER data will be available on demand; the primary imagery will be from Landsat ETM+ sensor at 30m and MODIS at 1000m resolutions.

Table 1. Specifications of the sensors planned to acquire images over the Great Lakes region

Satellites	IKONOS	Landsat 7	EO-1	Terra	
Parameters	Kodak	ETM+	Hyperion	ASTER	MODIS
Spectral range	0.4-0.9um	0.4-2.4um	0.4-2.5um	0.5-12um	0.4-14um
Spatial resolution	4m	30m	30m	15/30/90m	250/500m
Swath width	13km	185km	7.5km	60km	2330km
Spectral resolution	Variable	Variable	10nm	Variable	Variable
Temporal resolution	2-3 days	16 days	N/A	4-16 days	Daily
Spectral coverage	Discrete	Discrete	Continuous	Discrete	Discrete
Pan band resolution	1m	15m	N/A	N/A	N/A
Number of bands	5	7	220	14	36
Launch date	9/24/99	4/15/99	6/00	12/18/99	12/18/99

Supplementary field activities will be necessary to characterize spectral properties on the ground. At each of the study wetland sites where there are botanically different assemblages, we will acquire the following data and will be related to satellite observations:

- *GPS and Ground Control Network*: These sites will be marked with mounting posts and a real time, differential GPS will be used to achieve sub-meter location accuracy. These sites will be large enough to be visible from satellite sensors, so that they can serve as ground control points (GCP) for geometric calibration purposes.
- *Vegetation Survey*: Vegetation and algal surveys will be made along the above transects to record the species, distributions, density, heights, and their GPS locations. A GIS layer will be created and georeferenced to the remote sensing images. This will ensure that the botanical classification will reflect the point measurements. These vegetation details will be used as reference later on for wetland delineation and vegetation species classification.
- *Spectral Signatures*: For each vegetation species and algal sampling site identified above, a field spectroradiometer will be deployed to measure the spectral signatures, which will ultimately be linked to satellite imagery. Reflectance characteristics will be recorded over

homogeneous stands of the dominant emergent or submergent vegetation. Spectral reflectance data will be recorded for each stand at or near each transect within a four-week window centered on the satellite overpass date. This will ensure that the spectral reflectance data collected by both the satellite and the field spectroradiometer will have a similar vegetation phenology. The radiometric measurements will also serve as ground truth to calibrate satellite images. In addition, a digital camera will also be mounted on the boom to capture color photographs of the sampled vegetation.

- Vegetative Density (vd) – defined as the total amount of a pixel area being occupied by vegetation. To derive at this attribute, linear mixture modeling approach (Maas 1998, Zeng et al. 1999, and Qi et al. 2000) will be used to compute vegetative density. This approach requires multispectral remote sensing imagery and two empirical constants. We plan to use IKONOS and ASTER imagery for this computation and the empirical coefficients will be obtained by calibrating our estimates with the field survey. This attribute will be computed with satellite imagery of different spatial resolutions.
- Wetland Delineation (wd): Wetlands are defined as areas that are inundated or saturated by surface or groundwater at a frequency and with sufficient duration to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Delineation of wetland plant communities based on spectral reflectance characteristics is challenging because many species have very similar reflectance signatures across much of the electromagnetic spectrum. The width of spectral bands and incomplete spectral coverage of multi-spectral systems make detection of the relatively minor spectral differences needed to distinguish wetland plant genera impossible. Minor spectral features could either be hidden within the broad spectral bands or reside outside of the wavelengths sensed (Hardisky et al. 1986). The new Hyperion, ASTER, and MODIS sensors have narrow spectral bands with enhanced signal to noise ratio and should provide improved capability of wetland delineation. Therefore, we plan to use images from these sensors to delineate wetlands. To do this, we will use the supervised classification and neural network methods, with intensive ground survey from this and well as the other two projects. The delineation maps are then to be verified with the IKONOS data with 1m and 4m spatial resolutions.
- Wetland Vegetation and Algal Composition (vc): The processed and rectified imagery will be used to classify vegetation species of wetland areas and algal classes in lakes and streams. The first classification routine applied to the data will be a supervised classification that references the homogeneous training pixels identified at or near each transect. A supervised classification routine is an interactive methodology with which the user locates pixels that are known to contain a certain cover type (training pixels). Supervised classifications place each pixel into the statistically most likely vegetative or algal category. This is an iterative process that continues until the number of unclassified pixels are eliminated or minimized. The result of the supervised classification will be wetland vegetation maps. The second classification routine applied to the image data will be a Neural Network (NN). The NN training data (input layer) will also be the normalized spectral signatures from the training pixels. Neural networks utilize fuzzy logic or artificial intelligence to identify the spectral contributions for a given pixel. The output of the neural networks training will be a trained model that can be applied to non-trained pixels of the entire imagery. The images resulting from the supervised and neural network classification routines will be imported into a GIS as grid-based vegetative maps. Sub-meter GPS

accuracy ensures that the field surveyed and imagery derived vegetative data can be directly compared via an overlay analysis.

Land Use. Land use indicators of human activities and disturbance have been developed in many projects (e.g. Soranno et al. 1996, Wiley et al. 1997, Allan et al. 1997). Most land use indicators are based on the percentage of land with different human activities and shapes and connectivity of land use patches relative to the assessed ecosystem and its sourcesheds. Sourcesheds, a term emphasizing both surface and subsurface movement of contaminants to aquatic ecosystems, are our concern, even though we loosely refer to them throughout the proposal as watersheds. Watersheds (=sourcesheds) will be delineated for surface water and groundwater using ArcInfo® *flowdirection* and *flowaccumulation* with the highest resolution regional DEM (likely 7.5' 30m DEMs) and surface topography and groundwater head, respectively. % agriculture, % urban, % forest land use in watersheds will be determined for streams, lakes and wetlands. In addition, land use activity indicators will be weighted based on proximity of land use activities to the aquatic habitat and riparian indicators, such as width and longitudinal extent of buffers (Schuft et al. 1999, Weller et al. 1998). If the MRW project by Wiley et al. is funded, we expect significant improvements in the quality of land use indicators by adding estimates of the intensity of land use to spatial characterizations of land use near habitats and well as digital terrain modeling.

Developmental Instabilities. The assessment of morphological developmental instability provides a new approach for assessing the condition of indigenous populations with long generation times and relatively low species diversity as a component of an index of biological integrity and ecosystem health. Changes in species composition of invertebrate and algal assemblages are commonly used to assess ecological conditions in aquatic habitats because of the high diversity of these taxa, the relatively rapid response of species densities to environmental change, and the differential sensitivities of taxa to environmental stressors. For organisms with longer generation times, such as fish and plants, change in abundance occurs relatively slowly as their health diminishes and reproduction fails; plus, their recovery is expected to take longer. Thus early warning indicators of physiological stress are valuable for detecting environmental stress.

Physiological health of fish and plants is usually assessed either in physiological assays which are technology-intense, expensive, and narrow in applicability, or as the proportion of individuals with disease and gross anatomical anomalies (e.g. tumors), most of which are relatively coarse features that may appear only in the most highly polluted conditions. Developmental instability provides a more quantitative, rapid and sensitive measure of the condition of organisms in nature. It is especially useful at the ecosystem level because it can measure the same basic type of attribute in virtually all species at all trophic levels.

Developmental instability (DI) is the failure of a genotype to produce consistently the same phenotype in a given environment. Such failures occur during growth under stress

conditions if an organism is unable to buffer deviations from its normal developmental pathways. For example, it is this departure from normal development that underlies labial plate deformities in chironomid larvae that have been used as an indicator of environmental quality (Dermott 1991, Dickman et al. 1992, Diggins 1993). The DI approach to ecosystem assessment has matured to include more than simply the presence or absence of deformities; it involves highly quantitative data with statistical power to sensitively detect and compare levels of stress among sites in an ecosystem. Indeed, DI is based on small changes in development which are often measurable at stress levels below those required to influence growth, reproduction, and survivorship (Graham et al. 1993a, b).

The DI approach examines the quantitative extent of deviations from normal symmetry within individuals, and/or the level of variance among regularly repeated structures that are normally invariant, again within individuals. Focusing measurements *within* individuals is important because these emphasize environmental stress effects on development of single genotypes (i.e. where genotype is a constant), whereas comparisons of traits among individuals may reflect genotypic variation in populations. Also, in this approach, variance about the mean is more important than mean values of growth parameters, because it can reveal stress effects more sensitively than the mean size or biomass of the growth product (true even at the level of enzyme activities; see Callaghan and Holloway 1999).

Fluctuating asymmetry, the most common measure of developmental instability, quantifies the absolute difference in the expression of a trait on the left and right sides of bilaterally symmetrical parts of an organism. Numerous studies (reviewed in Tracy et al. 1995, Graham et al. 1998, Møller and Shykoff 1999) have documented stress-induced fluctuating asymmetry in a wide variety of species including, for example, mandible, dental and skull bone traits in mammals; tail ornaments in birds; gill rakers, pectoral fins, lateral line scales, postocular bones, and meristic traits in fish; antennae in crustaceans; mouth parts, bristles, legs, spines, wing veins, and eyespots in insects; leaves and flowers in plants; and fronds or cells in algae. Recently, investigators at Wayne State University and their colleagues have extended the approach to include radial symmetry, translational symmetry (repeated segments, e.g. internodes), and self-symmetry (fractal branching patterns), traits that are especially useful for DI in plants. These yield measures of within-individual variance and/or standard error of regression that have sensitively revealed stress in natural populations of a number of species (Graham et al. 1994, Freeman et al. 1993, Freeman et al. 1999, Tracy et al. 1995, Tracy 1999), and these include aquatic ecosystems with polluted habitats.

We propose to assess the health/condition of aquatic biotic communities in the Muskegon River watershed by examining developmental instability in a variety of species from multiple trophic levels across the spectrum of habitat types, including selected regions of the main river and its tributary streams, lakes, and wetlands. We will focus the measurements in populations of aquatic macrophytes of wetlands and lakes and fish of streams and lakes, although working with other organisms is possible. Under the hypothesis that toxic pollution produces DI in most species in a community, and that biomagnification produces the greatest DI in the highest trophic levels, we predict that DI will be greatest and most widespread among species in habitats known to be the most polluted (especially in the lower Muskegon River and Lake Muskegon), particularly in organisms high in the food chain, i.e. in carnivorous species of fish. Under the hypothesis that DI represents stress-induced developmental errors rather than genetic variation, we predict that mitigation of polluted sites will lead to decreases in DI in local populations, and

that reduction of DI to levels normal for those species in non-impacted sites will signal successful mitigation efforts.

Establishing Expected Condition

Most of our effort will be to characterize expected condition as reference condition and thus characterize "ecological integrity" of assessed sites. We will define reference conditions using two basic approaches:

1. conditions at minimally impacted streams, lakes, and wetlands (extant reference);
2. paleoecological reconstruction of historic condition in lakes and wetlands.

Extant reference sites will be sites with lowest levels of human activities within the watershed or sourceshed of the stream, lake or wetland (Hughes 1995). These sites will be selected using established protocols, which start with mapping land use around sites (Wiley et al. 1999, Seelbach et al. 2000). In addition, on-site assessments or habitat disturbance and local land use will be used to confirm reference status as well as preliminary analyses of water and sediment chemistry. We recognize that identifying human effects at minimally impaired sites is somewhat subjective and caution, models, and best professional judgment will be exercised to cull impaired sites from our reference set.

Predictive models of expected ecological conditions (reference condition) can increase precision of ecological assessments (Hawkins et al. 2000a, 2000b) and thus more sensitively detect deviation from reference condition. This approach is based on the idea that natural ecosystems vary continuously in response to environmental gradients. In this approach, an empirical model is built from the reference site database that allows the ecological attributes expected at a site to be predicted from a suite of easily measured environmental attributes (Moss et al. 1999). Predictor variables must be insensitive to human-related disturbance, such as some landscape attributes (geology, climate, elevation) and some local, physical attributes (habitat size (e.g. depth or area), slope, substrate size, hydrology). This concept has been widely applied in the United Kingdom and Australia as RIVPACs and AUSRIVPACs for streams (Armitage et al. 1983, Norris and Norris 1995). Seelbach et al. (1997) have built a similar model to predict expected condition for fish in streams in the Lower Peninsula of Michigan. We plan to expand this approach for use with algae, invertebrates, fish, and plants in lakes and wetlands, as well as streams.

Inferring historic conditions with paleoecological assessments of lakes, wetlands, and even watersheds is possible (see reviews in Stoermer and Smol 1999, Stevenson and Smol in press). We plan to modestly supplement an ongoing, statewide paleoecological assessment of lakes that is being conducted by Long by coring 2 additional lakes per year within the MRW. Sediment chemistry and diatom inference models (developed based on data gathered in our project and others, e.g. Hall and Smol 1992, 1996) will be used to infer historic conditions. Although paleoecological reconstruction of all wetlands and lakes is possible, we decided not to include that method of characterizing reference condition in this project due to added cost. However, statewide assessment of historic conditions in many wetlands is part of an extended project being conducted by Stevenson (see Stevenson et al. 1999 for initial results). Long is conducting a similar study in lakes.

Assessing Human Effects

Human effects at assessed sites will be calculated as the difference between observed (O) and expected (E) values of

response indicators, while normalizing for expected values of response indicators $((O-E)/E)$. Thus values will reflect proportional increases or decreases in valued ecological attributes. Absolute values of the assessment parameter $((O-E)/E)$ will be determined for basin wide characterizations in case different stressors cause different kinds of responses in valued ecological attributes. This is essentially the same parameter calculated in RIVPACS and AUSRIVPACS models, except that the expected condition does not have to be defined by predictive models and more response indicators that "number of native taxa" are used. With data from the first year when we expect low statistical power of predictive models due to few reference sites, we will classify reference sites *a priori* by habitat type (e.g. stream, lake, and wetland) and define reference condition according to habitat class. Most of the MRW is within one ecoregion, so subclassification of reference sites will not be attempted.

After year 2 we will improve precision of estimates of expected condition by using predictive models of reference condition based on site features not affected by humans (e.g. Hawkins et al. 2000a). Thus sensitivity of our assessments should increase by classifying streams, lakes, and wetlands according to hydrogeomorphic characteristics and other habitat. In these analyses, all data from all sites previously sampled will be reanalyzed. The same response indicators as earlier will be used to assess ecological integrity, but by comparing assessed sites with expected conditions that have been refined by predictive models.

Human effects on ecosystems will also be assessed with standard multimetric type approaches (Karr 1981, Kerans and Karr 1991, see review Barbour et al. 1999) to compare sensitivity of multimetric approaches and provide indicators that may be more transferable among watersheds of the Upper Great Lakes.

A framework for classifying ecological condition that is currently under development by the EPA's Tiered Aquatic Life Use Workgroup (Stevenson serves on this workgroup) will be used to classify ecological condition at sites. Cumulative frequency distributions will be used to summarize results and describe the proportion of habitats that meet different classification criteria for different metrics. Multimetric summaries of results will also be calculated.

Assessing Causes and Threats to Impairment

Distinguishing among factors that influence ecosystems is challenging because of the multiple endpoints and multiple stressors (Foran and Ferenc 1999, Dormand-King et al. 2000). Multiple stressors may occur at significant levels at a site.

Temporal variability can reduce precision or even bias assessment of stressor levels. Different stressors may affect different endpoints at a given site. The issue of multiple stressors will be addressed by establishing criteria for stressors based on reference conditions and on stressor-response relationships. Ideally, one endpoint is identified and stressors are related to endpoints and impact with stressor-response relationships (Fig. 3). Field based observations that responses are related to stressors in natural habitats should be accompanied by experiments that show similar responses in controlled situations where only one of many stressors has been manipulated. The experimental phase of showing cause-effect relationships is an important step in ecological assessment and confirming cause-effect relationships, however it is beyond the scope of the proposed project.

Observed response and stressor conditions will be compared to known response-stressor relationships to determine which stressors pose the greatest threats to impairment or are the most likely stressors that causing impairment at a site (Fig. 3). Stressor-response relationships from the literature, initially, and then from regionally defined relationships (see Objective 2) will be gathered and developed for the ecological endpoints (support of biotic integrity, support of endangered species, ect.). The stressors (and subsequently human activities) that are most likely affecting impaired systems can be identified by comparing observed stressor levels at sites and the predicted stressor levels necessary to cause the observed impacts based on stressor-response relationships and observed impacts (Fig. 3).

A weight of evidence approach will be used to increase certainty of assessing causes and threats to impairment. This approach calls for relating multiple ecological responses and multiple stressors in a matrix approach and assigning probabilities of impact (Foran and Ferenc 1999). In addition, biological indicators of chemical and physical stressors (sometimes referred to as diagnostic indicators (Stevenson 1998)) can provide additional evidence of stressors causing changes in biological assemblages.

Human activities and stressors and direct comparison of response-land use indicators (see Fig. 3) will also be evaluated to relate ecological responses to the physical, chemical, or biological factors that affect them and to the human activities causing those stressors.

Developing New Biological Indicators of Chemical and Physical Stressors

In brief, biological indicators of chemical and physical conditions have been used in ecological studies for a long time

(Kolkwitz and Marsson 1908). Simple statistical approaches (Zelinka and Marvan 1976, Juggins and ter Braak 1992) and studies with larger sample sizes have enabled development of highly precise inference models of physical and chemical conditions based on species composition and relative abundance of taxa at sites and on the tolerances and sensitivities of species to specific stressors (e.g. Fritz et al. 1991). This latter indicator technique (the weighted average indicator approach) is widely used in paleoecological reconstructions of lake conditions with diatoms and was successfully applied to assessments of lake responses to acid deposition (Charles et al. 1990). Weighted average indicators with diatoms have been developed for many parameters (e.g. nutrients, pH, and conductivity) in streams and wetlands as well as lakes (see reviews in Stoermer and Smol 1999). For stressors like nutrients, which are temporally variable, one-time sampling and assessment of stressors based on weighted average diatom indicators can more precisely estimate nutrient concentrations than one-time sampling and assessment of nutrient concentrations (Stevenson accepted). We plan to develop new indicators with invertebrate species composition and their species tolerances to low dissolved oxygen, sedimentation, and potentially other habitat alterations (habitat fragmentation). We also plan to refine diatom indicators of nutrient concentrations, conductivity, pH, and other stressors based on regional autecological characteristics of diatom populations.

Objective 2 (Study Plan). Develop regionally-defined, quantitative relationships between ecosystem attributes, specific pollutants, and human activities that can be used in management models.

Nutrients and sediments are two commonly cited contaminants in Midwestern streams, lakes, and wetlands (e.g. US EPA 2000). To assess the impact of specific levels of nutrients and sediments on ecological integrity of MRW habitats and relate these effects to human activities, we will supplement the sampling for Objective 1 to test the following hypotheses:

- Sediments, nutrient concentrations, and effects on ecological integrity can be related to human activities in the watershed, such as agricultural activity, road crossings, and septic tanks (having negative effects) and riparian buffer strips, no till farming, and bank stabilization (having positive effects).
- The sensitivity of the ecological integrity of streams, lakes, and wetlands differs in response to increasing contamination by nutrients and sediments.
- Algae assemblages are more sensitive to environmental change than invertebrates, fish, and plants.
- The following attributes of biological assemblages will have increasing tolerance to environmental change: developmental instabilities; relative abundances of species presence; invasion of non-native species; presence of all native species. This gradient of impacts is hypothesized by the Aquatic Life Use Group.

Relationships among response indicators, stressor indicators, and land use indicators will be explored using multivariate statistics such as correspondence analysis and canonical correspondence analysis. In addition, we will test relationships that have been hypothesized to be related to environmental stress (e.g. Odum 1985). These hypotheses will be tested using standard regression analysis. The occurrence of threshold changes in response indicators along stressor and land use gradients will be assessed with regression tree analysis.

Objective 3 (Study Plan). Develop monitoring technologies that will enable continuous assessment of ecosystem processes at the land-water interface

New thinking and new methods are needed to address the interpretation of ecosystem character (Matthews 2000). Although automated measurement of specific ecosystem events have been used for some time, new measurement and communication technologies provide an emerging opportunity to automate environmental sensors to measure and assess the changing characteristics of ecosystems within a day, or over days, seasons, years, decades, and longer. Existing transducers that have been developed to measure parameters associated with ecosystem change have yet to be integrated into a biological monitoring system. Application of an integrated technology system could capture data remotely, transmit data to a site for archiving, and then the application of pattern recognition algorithms could measure multiple indicators of ecosystem change using digital libraries. Biological events are time dependent. We anticipate that the findings from Objective 3 will translate into an innovative design for measuring ecosystem change that will have the potential to be adopted globally. The importance of this approach will be the possibility of expanding the period of time to conduct measurements and of capturing the incidence of unpredictable punctuated events. Events such as insect emergence or initiation of frog or bird breeding are highly temporal in nature and are difficult to document at the appropriate temporal scales (Bradbury and Vehrencamp 1998, Kroodsmma and Miller 1996). These events represent important indicators of ecosystem change. This subproject proposes the development of an analytical and technological framework to quantify ecological dynamics that will provide the scientific community and the public with new types of data to enable new interpretations of organisms and subsequently the characterization of ecosystem vulnerability. This can result in the interpretation of ecosystem complexity.

An added benefit, associated with the development of a full-scale analysis system, is to enable real-time delivery of sound, imagery, and other ecosystem characteristics into the homes and laboratories of the world (which is the purpose of the objective 4). We plan to undertake the development of a template to quantify ecosystem characteristics by synthesizing new measures of the ecosystem and developing new indices based on these new high frequency measurements. To deliver this information we will make use of Internet technology and wireless communications.

Application of new indicators for ecosystem assessment

This objective will focus on a subset of measurement systems that characterize ecosystems. The following table represents the array of ecosystem characteristics and indicators that we will attempt to automate using innovative continuous measurement systems. The monitoring and delivery system will initially focus on characterizing general ecosystem sound, imagery as well as measurement of temperature. The frequency and occurrence of many bird and amphibian species are sensitive to human disturbance in riparian and wetland habitats. In addition, the presence of human activity can be an indication of ecosystem disturbance. In

addition to quantifying bird and amphibian species-specific sounds, human sounds (voices, type of voice) and human transportation activities will be recorded to indicate degrees of disturbance in the ecosystem (boats; jet skies; airplanes; trains; automobiles).

General Ecosystem Characteristics	General Ecosystem Indicators
Biological	
Birds	Tree swallow, etc.
Arthropods	Tree cricket
Amphibians	Green frog
Mammals	Human voice
Vegetation	Aquatic Vegetation
Environmental	
Temperature	Water temperature
Primary productivity	Dissolved Oxygen
Storm events	Water depth, wind
Water chemistry	Conductivity
Transportation	Vehicles

General ecosystem sounds and imagery will be collected from habitats associated with the Muskegon River. Standard bluebird nest boxes will be established at each automated monitoring site to attract birds to this confined habitat. We will place imagery and sound transducers within the nest boxes to record bird activity and behavior.

A central theme of Objective 3 is to use “environmental sound and imagery” to detect changes in the characteristics of an ecosystem. Environmental sound emanating from an ecosystem can be a valuable index to allowing comparisons between ecosystems. Conventional monitoring systems used to assess birds, frogs, and other organisms are very imprecise. As an example, using the traditional bird census approach, an ornithologist has only a few short-term observations at each sampling point to measure bird populations in a habitat. There is almost no information on when a species starts and stops singing during a day. Knowledge of this type can be related to characterization of habitat quality and physical characteristics such as temperature, precipitation, and solar radiation levels. We plan to use existing technology to capture bird song in real time at multiple locations and place the sounds on the Internet for access by the scientific community and the public (see Objective 4). This is an important new way to observe ecosystems because continuously and automatically monitored variables will enable observations of new characteristics of ecosystems at spatial and temporal scales that have not previously been possible.

Most of the existing studies have not taken advantage of the entire range of environmental sounds in an ecosystem but rather have focused on single groups (Kime et al. 2000, Naguib 1996, Penna and Solis 1998) to assess the presence and frequency of a species in a system. We plan to take a holistic view of environmental acoustics and use the statistical characteristics of sound as a **state variable** in the ecosystem. It is anticipated that environmental acoustics will become an important variable that will be used for an array of applications to characterize ecosystem quality.

Sound. Sound is a manifestation of ecosystem activity (due to natural or human induced causes) that changes over time, and thus can be used to detect human/natural impacts on

ecosystem. Sound can be related to the ecosystem in general or to specific organisms that are key components of the ecosystem. Specific organisms that emit sound can be an indicator of ecosystem status and changes over time (bird, frogs). Sound is measurable, and can be used to identify specific organisms. The components of sound can be a valuable tool to characterize ecological vulnerability. Pitch; volume; frequency; temporal occurrence (hourly, daily, monthly, seasonal); periodicity are all components of sound that can help quantify ecosystem character. The table above illustrates that general ecological sounds as well as sound from a species (green frog) or an entity (automobile) can be utilized to identify an ecosystem characteristic.

Imagery. Imagery can also characterize the ecosystem to capture events and their dynamics. Imagery is multi-dimensional and may include: heat (infrared radiation), radar (microwave radiation), animal activity and behavior (normal picture), light (natural light in the system), organisms (normal picture), landscape changes (seasonal pictures).

Methods and Phases

To accomplish the above-mentioned objectives the following activities are proposed:

- Develop the methodology to collect and transmit environmental sounds from the field to the laboratory using a network of sound sensors. This includes the design of the sound measurement devices.
- Utilize existing and new statistical analytical techniques to analyze environmental sounds
- Develop a digital library of environmental sounds and analytical procedures
- Conduct experimental studies comparing sounds produced in different ecosystems
- Publish new information on ecological complexity indices using sounds recorded in multiple ecosystems.

Develop the methodology to collect and transmit ecosystem character from the field to the laboratory using a network of sensors.

The instrumentation package to monitor ecosystem character will include the following components (Fig. 5):

Remote Instrument. We will examine YSI, Hydrolab, and other existing transducer technologies to determine the most appropriate environmental sensors to link to our biological Remote Monitoring Instrument (RMI) package. Field data acquisition technology from IO Tech (www.iotech.com) will be used to interface the transducers to the computer. Each RMI will be housed in a secure weatherproof container, powered by a hydrogen solar system manufactured by Uni-Solar (www.uni-solar.com). The field computer will transmit acquired information using wireless network technology linked to a base server.

Automated procedure. The RMI will trigger data acquisition including imagery, sound and selected physical and chemical measurements at a predetermined time interval (i.e. 1 minute sample at 15 minute intervals).

Remote computer. The Internet camera, using Surveyor Corporation's WebCam 32 Version 6.0.1 (<http://www.surveyorcorp.com/>), will record images and sound at selected time intervals. WebCam's built-in sound and video capabilities are critical to the data-gathering process. Images and audio streams will be transmitted, via wireless communication to an FTP site for processing, analysis, storage, and delivery to a web site. The computer will also designate a limited amount of hard drive space for temporary data storage in the event of a network failure. IO Tech's Personal DAQ or WaveBook will interface the remote computer with the selected transducers, and their DasyLab software will interpret the information.

Server. The server, located in the Computational Ecology and Visualization Laboratory (www.cevl.msu.edu), is a critical to the automated operation of the network. The server will be linked directly to the monitoring network through Enterasys' RoamAbout outdoor wireless network (www.enterasys.com) and will receive data from remote sites. Due to the nature and volume of information being sent to the server, it must a high-speed machine with large capacity disk space. The server also needs to have a high degree of functionality, as it will be handling much of the processing of the information for worldwide web access.

Relational database. The information will be stored and sorted in a database on the server. Once in the database, the information can be made available to the public via the MRW Biological Monitoring Web Site. The information will be extracted from the database and analyzed using statistical and other analytical systems (i.e. S-Plus (<http://www.splus.mathsoft.com/splus/Default.htm>)). Frequency and periodicity of biological, physical and chemical measures will be analyzed using pattern-matching algorithms to classify the observations and to develop indices. The results of these analyses will be stored in the database and made available on the web site.

Utilize existing and new statistical analytical techniques to analyze environmental sounds.

Analytical methods (Fourier analysis), statistical processes (wavelet statistics) and neural network technologies have proven to be a valuable means to extract appropriate harmonics and patterns from environmental sound data. These analytical methods will be refined using existing environmental sounds collected from existing sources. In addition, a digital library of known environmental sounds will be archived to enable comparison of known and unknown sounds collected from the field. Intelligent pattern matching methodologies will be developed to enable real-time species identification based on pattern recognition (ex. voice recognition technologies). Prototype instrumentation will be tested in the laboratory prior to initiation of field experiments. These methods will be applied to field collected observations from unique observation sites (see below).

Develop a digital library of environmental sounds and analytical procedures.

We will gather acoustical information from academics, government and industrial experts including acoustical engineers, musicians, and ecologists. Initially, we plan to focus on acoustics produced by birds, amphibians, insects and aquatic mammals. Information from these groups will help to establish methods and technologies needed to measure and interpret sounds and to develop indices of environmental sounds to characterize ecosystem complexity.

Conduct experimental studies comparing sounds produced in different ecosystems.

Once the instrumentation package has been developed, it will be deployed within a selected section of the Muskegon River Watershed to test the capacity of the instrumentation to capture and transmit, via wireless communications, environmental sounds, imagery and physical and chemical measurements to the server based network where the data will be archived and placed into a database for organization, summary, analysis and deposition on the web for subsequent delivery. Upon completion of 12 prototype instrumentation packages, we will examine ecosystem characteristics in two groups of environments: a) rivers, lakes and streams, and b) urban, cropland, and forests to detect differences among and between them. We will repeat the evaluation at different locations through the watershed. Identical data will be collected from each instrumentation site at identical times. We hypothesize that 1) statistic and analytical

methods will enable separation of environmental sounds emanating from each of the habitat types and 2) individual species can be identified from field collected sounds based on pattern matching with known sounds of organisms archived in the digital library.

There will be two types of instrumentation packages. One set located at permanent sites and other set which will be mobile. The permanent systems will be located in habitats throughout the watershed. The mobile set will be deployed to strategically measure ecosystem events at key times of the season. Additional studies will be established, based on observed differences in the patterns in the data collected from permanent and mobile sites within different habitats.

Objective 4 (Study Plan). Increase public awareness of intrinsic values of the MRW ecosystem and the science use to make management decisions

The MRW monitoring project (this proposal) is designed to provide both the scientific community and the public with quality, quantitative information in real time about the character of the ecosystems associated with the Muskegon River. The objective of the “Public Awareness” component of the proposal is to provide simultaneous information about the MRW character to the public and the science community. The desire for the public to access visual and audio information via the Internet provides an unprecedented opportunity to provide quality information about the MRW environment to the public. It also permits placing the information into a palatable scientific framework to enable both the public and the environmental science community to gather valuable observations (current and historical) about out changing ecosystems (see REINAS project¹, Sawhney 1997). We believe the public should not have to wait until scientists have digested observations before providing information to the public. Our goal is to deliver raw and basic real time data about the MRW ecosystem character to the public. Therefore, this objective links directly to the MRW *Education Project*.

The potential of visiting real time images on the World Wide Web is an obvious interest of society (IWA²). Recently, the general public has become infatuated with new technologies that allow visual access to environmental experiences or to assess environmental recreation potential and ecological tourism through “web-cams”. Users can now visit many locations to watch, for instance, landscapes (Virtual Yosemite³), human activities (Muskegon Lake⁴), or animals (Toledo Zoo⁵). In addition, there is a surge in public interest in access to music and other sounds via the Internet (Mann 2000). Most of these web cams do not provide enough information on ecosystem character. Our objective is to make vast improvement on the quality and quantity of real time information provided to the public.

MRW Clickable Ecosystems

Our goal is to design a system that can be accessed through the worldwide web so that MRW members of the Michigan Lake Stream Association can access real time ecosystem sounds, imagery, physical and chemical variables. This “Clickable Ecosystem” will be developed to provide the best and most readily interpreted information gathered as part of Objective 3 to the MRW public via the Internet and made accessible via a www browser. Several products will be

¹ <http://csl.cse.ucsc.edu/projects/reinas/>

² <http://www.webcasters.org/>

³ <http://www.yosemite.org/vryos/index.htm>

⁴ http://bsd.torresen.com/web_cam/

⁵ <http://www.toledo.com/zoocams/>

targeted for initial delivery to the public. Sound is a manifestation of ecosystem activity. One objective is to illustrate through data analysis (See Objective 3), that sound may be interpreted as “the heartbeat of an ecosystem (ecosystem symphony)”. In conjunction with sound, imagery provides a snapshot in time of events within the ecosystem and may characterize “ecosystem vitality”. We plan to capture and deliver to the public, the dynamics, and events that occur in the MRW ecosystems. As part of our outreach strategy we will introduce the public to new ways to perceive the character of ecosystems. These observations will allow the public to continuously view the ecosystem from a unique and different perspective. We will focus on quantifying known and interesting ecosystem events including the dawn chorus and the frog chorus.

Dawn Chorus. The *Dawn Chorus* occurs about twilight during spring when birds are in an active breeding state. One of the initial efforts will be to provide historical and real time audio and associated video of the “Dawn Chorus” to the public from multiple selectable sites in the MRW.

Frog Chorus. The *Frog Chorus* occurs in the evening during early spring and summer when frogs are actively seeking mates. This is a valuable index of the quality and quantity of wetlands. Several species contribute to the Frog Chorus depending on time of year, type and quality of wetland. One of the initial efforts will be to provide historical and real time audio and associated video of the “Frog Chorus” to the public from multiple selectable sites in the MRW. Participants will be able to examine the Frog Chorus in both historical and real time via Internet Browser.

Development of public access to the *Dawn Chorus* and the *Frog Chorus* will enable the participants to hear the “ecosystem symphony” in the MRW in real time or at any time and will enable participants to compare the “ecosystem symphony” from different types of MRW ecosystems; examine ecosystem characteristics and their natural changes over time; examine differences among ecosystems under different human intervention in the watershed; and detect anomalies in the natural characteristics of ecosystems.

Report Card

With the temporal and spatial information collected on characteristics of the Muskegon River Watershed, we will be able to develop an ecosystem report card (e.g. Harwell et al. 1999) that addresses the following elements:

- A comparison of indicators measured in different ecosystem types
- Evaluations of trends and/or changes of indicators over time in selected ecosystems
- Quantifying the linkage between indicator and land use/cover change
- Summarize and evaluate patterns and trends of citizen/scientist collected observations on lakes and streams
- Quantify and use new indices and measurements as indicators of ecosystem change
- Characterize the temporal frequency of frogs and birds on lakes, rivers and streams of MRW

This report card will be simple to read, but will have linkages to databases and basic statistical analyses of data so that citizens can explore their ecosystem.

LITERATURE CITED

- Allan, J. D. and J. B. Johnson (1997) Catchment-scale analysis of aquatic ecosystems. *Freshwater Biology* 37:107-111.
- Armitage, P. D. D. Moss, J. F. Wright, and M. T. Furse (1983) The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research* 17:333-347.
- Ayensu, E., D. van R. Claasen, M. Collins, A. Dearing, L. Fresco, M. Gadgil, H. Gitay, G. Glaser, C. Juma, J. Krebs, R. Lenton, J. Lubchenco, J. A. McNeely, H. A. Mooney, P. Pinstrup-Andersen, M. Ramos, P. Raven, W. V. Reid, C. Samper, J. Sarukhán, P. Schei, J. Galízia Tundisi, R. T. Watson, X Guanhua, and A. H. Zakri (1999) International Ecosystem Assessment. *Science* 286:685-686.
- Barbour, M. T., J. Gerritsen, & B. D. Snyder [Eds] (1999) Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. Second Edition. EPA 841-B-99-002 United States Environmental Protection Agency, Washington. pp 6-1 through 6-22.
- Bradbury, J.W. and S.L. Vehrencamp (1998) Principles of animal communication. Sinauer Associates, Inc., Sunderland, Massachusetts. 882pp.
- Boutt, D.F., Hyndman, D.W., Pijanowski, B.C., and Long, D.T. (in press) The Use of a High Resolution Groundwater Flow and Transport Model in a Large Coastal Watershed Undergoing Land Use Change. *Groundwater*.
- Callaghan, A. and Holloway, G.J. (1999) The relationship between environmental stress and variance. *Ecol. Applications* 9: 456-462.
- CENR (Committee on Environment and Natural Resources) (1997) Integrating the Nation's Environmental Monitoring and Research Networks and Programs: A Proposed Framework. White House National Science and Technology Council. Washington, D. C.
- Charles, D.F., Binford, M.W., Furlong, E.T., Hites, R.A., Mitchell, M.J., Norton, S.A., Oldfield, F., Paterson, M.J., Smol, J.P., Uutala, A J., White, J.R., Whitehead, D.R. & Wise, R.J (1990) Paleocological investigation of recent lake acidification in the Adirondack Mountains, N.Y. *J. Paleolimnol.* 3:195-41.
- Christensen, N. J., Bartuska, A. M., Brown, J. H., Carpenter, S, D'Antonio, C., Francis, R., Franklin, J. FMacMahon, J. A., Noss, R. F., Parsons, D. J., Peterson, C. H., Turner, M. G., Woodmansee, R. G. (1996) The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. *Ecological Applications* 6:665-691.
- Dermott, R. M. (1991) Deformities in larval Procladius spp. and dominant Chironomini from the St. Clair River. *Hydrobiologia* 219: 171-185.
- Dickman, M., Brindle, I. and Benson, M. (1992) Evidence of teratogens in sediments of the Niagara River watershed as reflected by chironomid (Diptera: Chironomidae) deformities. *J. Great Lakes Res.* 18: 467-480.
- Diggins, T.P. and Stewart, K.M. (1993) Deformities of aquatic larval midges (Chironomidae: Diptera) in the sediments of the Buffalo River, New York, *J. Great Lakes Res.* 19:648-659.
- Dormand-King, E. J., Suter II, G. W., Kapustka, L. A., Mount, D. R., Reed-Judkins D. K.S., Cormier, S. D. Dyer, Luxon, M. G., Parrish, R. and Burton, G. A. (2000) (in press). Distinguishing among factors that influence ecosystems. In: G. W. Suter II ed.

- Ecological Complexity: New Directions for Assessing Responses to Stress. SETAC Press. Boca Raton, FL.
- Fett, J.D., Simpson, S.J., Long, D.T., and Patino, L.C. (2000a) A multi-elemental approach to assess recovery of highly anthropogenically disturbed lakes: Torch Lake, (Upper Peninsula, MI). 25th International Conference on Heavy Metals in the Environment. University of Michigan, Ann Arbor Michigan. August 2000.
- Fett, J.D., Simpson, S.J., Long, D.T., and Patino, L.C. (2000b) A multi-elemental approach to assess recovery of highly anthropogenically disturbed lakes. 2000 Annual Meeting of the Geological Society of America, Reno NV.
- Foran, J. A. and Ferenc, S. A. (1999) Multiple Stressors in Ecological Risk and Impact Assessment. SETAC Press. Boca Raton, FL. 100 pp.
- Freeman, D. C., Graham, J.H. and Emlen J.M. (1993) Developmental stability in plants: symmetries, stress, and epigenesis, *Genetica* 89:97-119.
- Fritz, S.C., Juggins, S., Battarbee, R.W. & Engstrum, D.R. ((991) Reconstruction of past changes in salinity and climate using a diatom-based transfer function. *Nature* 352:706-08.
- Graham, J.H., J.M. Emlen, D.C. Freeman, L.J. Leamy and J.A. Kaiser (1998) Directional asymmetry and the measurement of developmental instability. *Biol. J. Linn. Soc.* 64:1-16.
- Graham, J.H., Freeman D.C. and Emlen J.M. (1993a) Developmental instability: a sensitive indicator of populations under stress, In: *Environmental Toxicology Risk Assessment*, W.G. Landis, J.S. Hughes, and M.A. Lewis (eds.), pp. 136-158, ASTM STP 1179, American Society for Testing and Materials, Philadelphia.
- Graham, J.H., Freeman D.C. and Emlen J.M. (1993b) Developmental stability and its applications in ecotoxicology, *Ecotoxicology* 2:175-184.
- Graham, J.H., Freeman D.C. and Emlen J.M. (1994) Antisymmetry, directional asymmetry, and dynamic morphogenesis, In: *Developmental instability: its origins and evolutionary implications*, Markow, T.A (ed.), pp. 123-140, Kluwer Academic Publishers, Dordrecht, Netherlands.
- Hall, R.I. & Smol, J.P. (1992) A weighted-averaging regression and calibration model for inferring total phosphorus from diatoms from British Columbia (Canada) lakes. *Freshw. Biol.* 27: 417-37.
- Hall, R.I. & Smol, J.P. (1996) Paleolimnological assessment of long-term water quality changes in south-central Ontario lakes affected by cottage development and acidification. *Can. J. Fish. Aq. Sci.* 53:1-17.
- Hardisky, M. A., Gross, M.F., and Klemas, V. 1986. Remote Sensing of Coastal Wetlands, *Bioscience*, Vol. 36-(7): 453-460.
- Harwell, M. A., Myers, V. Young, T. Bartoska, A. Gassman, Gentile, J. H. Harwell, C. C. Appelbaum, S. Barko, J. Causey, B. Johnson C. N., McLean, A. Smola, R. Templet, P. and Tosini S. (1999) A framework for an ecosystem report card. *BioScience* 49:543-546.
- Hawkins, C. P., R. H. Norris, J. N. Hogue, and J. W. Feminella. (2000a) Development and evaluation of predictive models for measuring the biological integrity of streams. *Ecological Applications* 10:1456-1477.
- Hawkins, C. P., R. H. Norris, J. Gerritsen, R. M. Hughes, S. K. Jackson, R. K. Johnson, and R. J. Stevenson (2000b) Evaluation of the use of landscape classifications for the prediction of

- freshwater biota: synthesis and recommendations. *Journal of the North American Benthological Society* 19:541-556.
- Hughes, R. M., Paulsen, S. G. and Stoddard J. L. (2000) EMAP-Surface Waters: a multi-assemblage, probability survey of ecological integrity in the U.S.A. *Hydrobiologia* 422/423: 429-443.
- Juggins, S. & ter Braak, C.J.F. (1992) CALIBRATE - A Program for Species-Environment Calibration By [Weighted Averaging] Partial Least Squares Regression. Environmental Change Research Center, University College, London. 20 pp.
- Karr, J.R. (1981) Assessment of biotic integrity using fish communities. *Fisheries* 6:21-7.
- Karr, J.R., (1991) Biological integrity: a long-neglected aspect of water resource management, *Ecol. Applications* 1:66-84.
- Kerans, B.L. & Karr, J.R. (1994) A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. *Ecol. Applic.* 4:768-85.
- Kime, N.M., Turner, W.R. and Ryan. M.J. (2000) The transmission of advertisements calls in Central American frogs.
- Kolkwitz, R. & Marsson, M. (1908) Ökologie der pflanzliche Saprobien. *Ber. Deutsche Bot. Ges.* 26:505-19.
- Kroosma, D.E. and Miller E.H. (1996) Ecology and evolution of acoustic communication in birds. Cornell University Press, Ithaca, New York. 587 pp.
- Long, D. T., Icopini, G.I., Ganev, V. Petropoulos, E., Voice, T. and Chou, K. (2000a) Finger-Printing Balkan Endemic Nephropathy Etiology in the Bulgarian Environment With Geochemical Markers: A Pilot Study. 31st International Geological Congress, Rio de Janeiro (poster and keynote address).
- Long, D., Icopini, G., Ganev, V., Petropoulos, E., Havezov, I., Spassov, A., Voice, T., and Chou, K., (2000 b). Geochemistry of Bulgarian Soils and Other Media in Areas Affected and Not Affected by Balkan Endemic Nephropathy. 5th International Symposium & Exhibition on Environmental Contamination in Central & Eastern Europe (12-14 September 2000).
- Long, D., Icopini, G., Ganev, V., Petropoulos, E., Havezov, I., Spassov, A., Voice, T., and Chou, K., (2000 c). Finger-Printing Balkan Endemic Nephropathy Etiology in the Bulgarian Environment With Geochemical Markers: A Pilot Study. Metals in Eastern and Central Europe: Health Effects, Sources of Contamination and Methods of Remediation. Prague (November 2000).
- Lubchenco, J., Olson, A. M. Brubaker, L. B. Carpenter, S. R. Holland, M. M. Hubbell, S. P. Levin, S. A. MacMahon, J. A. Matson, P. A. Melillo, J. M. Mooney, H. A. Peterson, C. H. Pulliam, H. R. Real, L. A. Regal, P. J. and Risser P. G. (1991) The sustainable biosphere initiative: an ecological research agenda. *Ecology* 72:371-412.
- MacDonald, D.D., Ingersoll, C.G., and Berger, T.A. (2000) Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Arch. Environ. Contam. Toxicol.* 39: 30-31.
- Mann, C.C. (2000) The heavenly jukebox. *The Atlantic Monthly* 286(3): 39-59.
- Maas, S. (1998) Estimating cotton canopy ground cover from remotely sensed scene reflectance, *Agron. J.*, 90:384-388.
- Matthews, C.M. (2000) Report for Congress 95-307: U.S. National Science Foundation: An Overview. Congressional Research Service. <http://www.cnie.org/nle/st-6.html>.
- Meissner, B.M., Long, D.T., and Lee, R.W. (1996) Selected Geochemical Characteristics of

- Ground Water from the Grand River-Saginaw Aquifer, Michigan Basin. U.S. Geological Survey Water Resources Investigations 93-4220.
- Møller, A.P. and Shykoff J.A. (1999) Morphological developmental stability in plants: Patterns and causes. *Int. J. Plant Sci.* 160(suppl.):135-146.
- Moss, D., J. F. Wright, M. T. Furse, and R. T. Clarke (1999) A comparison of alternative techniques for prediction of the fauna of running-water sites in Great Britain. *Freshwater Biology* 41:167-181.
- Naguib, M. (1996) Auditory distance estimation in song birds: implications, methodologies and perspectives. *Behav. Process.* 38: 163-168.
- National Research Council. (2000) *Ecological Indicators for the Nation*. National Academy Press. Washington, DC. 180 pp.
- Norris, R. H. and K. R. Norris. (1995) The need for biological assessment of water quality: Australian perspective. *Australian Journal of Ecology* 20:1-6.
- Odum, E. P. (1969) The strategy of ecosystem development: An understanding of ecological succession provides a basis for resolving man's conflict with nature. *Science* 164:262-270.
- Odum, E. P. (1985) Trends expected in stressed ecosystems. *BioScience* 35:419-432.
- O'Neal, R. P. (1997) *Muskegon River Watershed Assessment*. Michigan Department of Natural Resources, Fisheries Division. Fisheries Special Report 19. 187 pp.
- Paulsen, S. G., Larsen, D. P. Kaufmann, P. R. Whitier, T. R. Baker, J. R. Peck, D. V. McGue, J. Hughes, R. M. McMullen, D. Stevens, D. Stoddard, J. L. Lazorchak, J. Kinney, W. Selle, A. R. and Hjort R. (1991) *Environmental Monitoring and Assessment Program: EMAP-surface waters monitoring and research strategy- fiscal year 1991*. EPA/600/3-91/022. United States Environmental Protection Agency. Washington, D. C.
- Penna, M. and Solis R. (1998) Frog call intensities and sound propagation in the South American temperate forest region. *Behav. Ecol. Sociobiol.* 42: 371-381.
- Pijanowski, B. C., Gage, S. H. and Long D. T. (2000) A land transformation model: Integrating policy, socioeconomics and environmental Drivers using a geographic information system. in L. Harris and J. Sanderson editors. *Landscape ecology: A top down approach*.
- Pittinger, C.A., Norton, S.K. Barbour, M.T. and Thornton K.A. (2000) The converging paths of ecological assessment and ecological risk assessment. *SETAC Globe.* 1(3):25-27.
- Porter, S.D., Cuffney, T.F., Gurtz, M.E. & Meador, M.R. (1993) *Methods for Collecting Algal Samples as Part of the National Water-Quality Assessment Program*. U. S. Geological Survey, Report 93-409, Raleigh, North Carolina, USA.
- Qi, J., R. C. Marsett, M. S. Moran, D. C. Goodrich, P. Heilman, Y. H. Kerr, G. Dedieu, and A. Chehbouni (2000) Spatial and temporal dynamics of vegetation in the San Pedro river basin area, *Agric. For. Meteorol.*, in press.
- Rapport, D. J., Regier, H. A. and Hutchinson T. C. (1985) Ecosystem behavior under stress. *American Naturalist* 125:617-640.
- Sawhney, N. (1997). *Situational Awareness from Environmental Sounds*, Speech Interface Group, MIT Media Lab: 10.
- Schuft, M. J. T. J. Moser, P. J. Wigginton, Jr., D. L. Stevens, Jr., L. S. McAllister, S. S. Chapman and T. L. Ernst (1999). Evelopment of landscape metrics for characterizing riparian-stream networks. *PhotogrammetricEngineering and Remote Sensing* 65:1157-1167.

- Seelbach, P. W., M. J. Wiley, J. C. Kotanchik, and M. E. Baker. 1997. A landscape-based ecological classification system for river valley segments in Lower Michigan. Fisheries Research Report No. 2036. Michigan Department of Natural Resources.
- Seelbach, P. W., M. J. Wiley, P. A. Soranno, and M. T. Bremigan. (2000) Aquatic conservation planning: using landscape maps to predict ecological reference conditions for specific waters. In K. Gutzwiller, ed. Concepts and Applications of Landscape Ecology in Biological Conservation. Springer-Verlag, New York. In press.
- Simpson, S.J., Fett, J.D., Long, D.T., and Patino, L.C. (2000a) Understanding Chemical Loading to the Environment Through the Use of Multi-Element Sediment Chronologies 23rd Annual Midwest Environmental Chemistry Workshop. Kalamazoo Michigan October, 2000.
- Simpson, S.J., Fett, J.D., Long, D.T., and Patino, L.C. (2000b) Understanding Processes influencing patterns of chemical loadings to the environment: sources, pathways, and environmental regulations. 25th International Conference on Heavy Metals in the Environment. University of Michigan, Ann Arbor Michigan. August 2000.
- Simpson, S.J., Fett, J.D., Long, D.T., and Patino, L.C. (2000c) Department of Geological Sciences, Michigan State University Using a multi-element approach to understand and differentiate processes influencing trace metals loadings to the environment. 2000 Annual Meeting of the Geological Society of America, Reno NV.
- SOLEC (1999a) State of the lakes ecosystem conference. Selection of indicators for Great Lakes basin ecosystem health. Draft version 3.
- SOLEC (1999b) State of the lakes ecosystem conference: Conference proceedings 1998.
- Soranno, P. S. L. Huber, S. R. Carpenter and R. C. Lathrop (1996) Phosphorus loads to surface waters: a simple model to account for spatial patterns of land use. *Ecological Applications* 6:865-878.
- Steedman, R. J. (1994) Ecosystem health as a management goal. *Journal of the North American Benthological Society* 13:605-610.
- Stevenson, R. J., Sweets, P. R. Pan, Y. and Schultz R. E. (1999) Algal community patterns in wetlands and their use as indicators of ecological conditions. In: A. J. McComb and J. A. Davis, eds. Proceedings of INTECOL's Vth International Wetland Conference. Pp.517-527. Gleneagles Press, Adelaide, Australia.
- Stevenson, R. J. and J. P. Smol. in press. Use of algae in environmental assessments. In: J. D. Wehr and R. G. Sheath, eds. *Freshwater Algae in North America: Classification and Ecology*. Academic Press, San Diego.
- Stevenson, R. J. accepted. Using algae to assess wetlands with multivariate statistics, multimetric indices, and an ecological risk assessment framework. In: D. Batzger, R. Rader, S. Wissinger, eds. *Biomonitoring and Management of North American Freshwater Wetlands*. John Wiley & Sons, Inc. New York.
- Stevenson, R. J., Bailey, R. Alba-Tercedor, J. Barbour, M. Couch, C. Dyer, S. Fulk, F. Harass, M. Hawkins, C. Harrington, J. Hunsaker, C. and Johnson R. (In prep) Design and implementation of ecological assessments. In: M. Barbour, K. Thornton, and R. Preston, eds. *Ecological Assessment of Aquatic Resources: Application, Implementation, and Communication*. SETAC Press.
- Stevenson, R. J. and J. P. Smol (in press) Use of algae in environmental assessments. In: J. D. Wehr and R. G. Sheath, eds. *Freshwater Algae in North America: Classification and Ecology*. Academic Press, San Diego.
- Stoermer, E.F. & Smol, J.P. [Eds.] (1999) *The Diatoms: Applications for the Environmental and Earth Sciences*. Cambridge University Press, Cambridge, 484 pp.

- Suter, G. W., II. (1993) Ecological Risk Assessment. Lewis Publishers. Boca Raton, FL. 538 pp.
- Tracy, M., Freeman, D.C. Emlen, J.M. Graham J.H. and Hough R.A. (1995) Developmental instability as a biomonitor of environmental stress: An illustration using aquatic plants and macroalgae. In Butterworth FM, Corkum LD, Guzman-Rincon J (eds.). 1995. Biomonitoring and Biomarkers as indicators of environmental change: A handbook. Plenum Press, New York. 348.
- Tracy, M. (1999) Developmental instability as an indicator of environmental stress. Dissertation, Wayne State Univ. 85 p.
- U.S. Environmental Protection Agency (1992) Framework for Ecological Risk Assessment. EPA 630/R-92/001, United States Environmental Protection Agency. Washington, D. C.
- U. S. Environmental Protection Agency. 1996. Strategic Plan for the Office of Research and Development. EPA/600/R-96/059. Washington, D. C.
- U. S. Environmental Protection Agency (1997) Environmental Monitoring and Assessment Program (EMAP): Research Strategy. EPA/620/R-98/001. United States Environmental Protection Agency. Washington, D. C.
- U. S. Environmental Protection Agency (1998) Guidelines for Ecological Risk Assessment. EPA/630/R-95/002F. United States Environmental Protection Agency. Washington, D. C.
- U. S. Environmental Protection Agency (2000) Nutrient Criteria Technical Guidance Manual: Rivers and Streams. EPA-822-
- Wahrer, M.A., Long, D.T., and Lee, R.W. (1996) Selected Geochemical Characteristics of Ground Water from the Glacial Drift Aquifer, Lower Peninsula of Michigan. U.S. Geological Survey Water Resources Investigations 94-4017.
- Wayland, K.G., Long, D.T., Hyndman, D.W., Pijanowski, B.J., and Woodhams, S. (2000a). Biogeochemical Fingerprinting of a Rapidly Urbanizing Watershed. In 8th National Workshop on Monitoring and Modeling Nonpoint Source Pollution, J.C. Clausen (ed.), Hartford, CT. In press with the U.S. Environmental Protection Agency
- Wayland, K.G., D.T. Long, D.W. Hyndman, B. Pijanowski, and S. Woodhams (2000b). Biogeochemical Fingerprints of Land Use in Surface Waters of a Rapidly Urbanizing Watershed. 2000 Annual Meeting of the American Geophysical Union, San Francisco.
- Weller, D. E., T. E. Jordan and D. L. Correll. 1998. Heuristic models for material discharge from landscapes with riparian buffers. Ecological Applications 8:1156-1169.
- Wiley, M. J., S. L. Kohler, and P. W. Seelbach. (1997) Reconciling landscape and site based views of aquatic stream communities. Freshwater Biology 37:133-148.
- Wiley, M. J., P. W. Seelbach, and P. Rentschler. (1999) Feasibility of explicitly modeling reference conditions for ecological assessment of Michigan streams using landscape data. Final Rept. To US EPA, Water Quality Criteria Program, Grnat X985499-01-0. School of Natural Resources, University of Michigan, Ann Arbor.
- Zelinka, M. & Marvan, P (1961) Zur Prazisierung der biologischen Klassifikation des Reinheit fliessender Gewässer. Arch. Hydrobiol. 57:389-407.
- Zeng, X., R. E. Dickinson, A. Walker, M. Shaikh, R. S. DeFries, and J. Qi (1999) Derivation and evaluation of global 1-km fractional vegetation cover data for land modeling, *J. Applied Meteorology* (forthcoming)

VITAE

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Education:

Ph.D.	University of Michigan, Ann Arbor, MI	1977-1981
M.S.	Bowling Green State Univ., Bowling Green, OH	1974-1976
B.S.	Bowling Green State Univ., Bowling Green, OH	1973-1974
	Miami University, Oxford, OH	1970-1973

Professional Experience:

Michigan State University Professor, Department of Zoology	1999-pres
University of Louisville, Louisville, KY Executive Director, Kentucky Institute for Environment and Sustainable Development	1998-1999
Director, Center for Environmental Sciences KY Inst. for Environment and Sustainable Development	1993-1999
Professor, Department of Biology	1993-1999
Director, Water Resources Laboratory	1993-1995
Associate Professor, Department of Biology	1987-1993
Assistant Professor, Department of Biology	1981-1987

Professional Societies:

American Association for the Advancement for Science	
American Society for Limnology and Oceanography	
International Association for Theoretical and Applied Limnology	
Ecological Society of America	International Ecological Society
North American Benthological Society	Society for Wetland Scientists
Phycological Society of America	International Diatom Society

Recent Extramural Grants and Contracts:

Stevenson, R. J. "Environmental Monitoring and Assessment of Wetlands using Sedimentary Diatoms from Present and Past." U.S. Environmental Protection Agency. \$257,000. 1993-1996.

Stevenson, R. J., M. Wiley, and J. Holomuzki. " An ecoregion-specific comparison of stream community responses to nutrient gradients using both survey and experimental approaches. NSF/EPA Joint Program for Water and Watersheds. 1996-1999. \$380,000.

Stevenson, R. J. "Developing and testing algal protocols for the Bioassessment of Wetlands: A proposal to the EPA Office of Science and Technology." U. S. Environmental Protection Agency. \$139,916. 1998-2001.

Stevenson, R. J. "Development of protocols for establishing nutrient criteria with new and available data." U. S. Environmental Protection Agency. \$48,711. 1999-2000.

Stevenson, R. J. "Assay of periphyton communities for the USGS National Water Quality Program." Academy of Natural Sciences of Philadelphia Subcontract \$89,925. 1999-2000.

Hawkins, C. P., R. J. Stevenson, and D. W. Roberts. "An empirical evaluation of the performance of different approaches for classifying reference conditions in streams." U. S. Environmental Protection Agency. \$1,499,691. 2001-2003.

Related and Recent Publications:

- Stevenson, R. J. 1998. Diatom indicators of stream and wetland stressors in a risk management framework. *Environmental Monitoring and Assessment* 51:107-118.
- McCormick, P. V. and R. J. Stevenson. 1998. Periphyton as a tool for ecological assessment and management in the Florida Everglades. *Journal of Phycology* 34:726-733.
- Biggs, B. J. F., R. J. Stevenson, and R. L. Lowe. 1998. A habitat matrix conceptual model for stream periphyton. *Archiv für Hydrobiologie* 143:21-56.
- Stevenson, R. J., P. R. Sweets, Y. Pan, and R. E. Schultz. 1999. Algal community patterns in wetlands and their use as indicators of ecological conditions. In: A. J. McComb and J. A. Davis, eds. *Proceedings of INTECOL's Vth International Wetland Conference*. Pp.517-527. Gleneagles Press, Adelaide, Australia.
- Stevenson, R. J. and Y. Pan. 1999. Assessing ecological conditions in rivers and streams with diatoms. In: E. F. Stoermer and J. P. Smol, eds. *The Diatoms: Applications to the Environmental and Earth Sciences*. Pp. 11-40. Cambridge University Press, Cambridge.
- Pan, Y., R. J. Stevenson, B. Hill, P. R. Kaufmann, and A. T. Herlihy. 1999. Spatial patterns and ecological determinants of benthic algal assemblages in Mid-Atlantic Highland streams. *Journal of Phycology* 35:460-468.
- Stevenson, R. J. and L. L. Bahls. 1999. Periphyton protocols. In M. T. Barbour, J. Gerritsen, & B. D. Snyder, eds. *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish*. Second Edition. EPA 841-B-99-002 United States Environmental Protection Agency, Washington. 22pp.
- Hill, B. H., A. T. Herlihy, P. R. Kaufmann, R. J. Stevenson, F. H. McCormick, and C. B. Johnson. 2000. The use of periphyton assemblage data as an index of biotic integrity. *Journal of the North American Benthological Society* 19:50-67.
- Pan, Y., R. J. Stevenson, P. Vaithyanathan, J. Slate, and C. J. Richardson. 2000. Changes in algal assemblages along observed and experimental phosphorus gradients in a subtropical wetland, U.S.A. *Freshwater Biology* 43:1-15.
- Slate, J. and R. J. Stevenson. 2000. Recent and abrupt environmental change in the Florida Everglades indicated from siliceous microfossils. *Wetlands* 20:346-356.
- Pan, Y., R. J. Stevenson, B. H. Hill, and A. T. Herlihy. 2000. Ecoregions and benthic diatom assemblages in the Mid-Atlantic Highland streams, USA. *Journal of the North American Benthological Society* 19:518-540.
- Hawkins, C. P., R. H. Norris, J. Gerritsen, R.M. Hughes, S.K. Jackson, R.K. Johnson, and R. J. Stevenson. 2000. Evaluation of landscape classifications for biological assessment of freshwater ecosystems: synthesis and recommendations. *Journal of the North American Benthological Society* 19:541-556.

Synergistic Activities:

- Stevenson, R. J., M. Bothwell, and R. L. Lowe, eds. 1996. *Algal Ecology: Freshwater Benthic Ecosystems*. Academic Press, San Diego, CA.
- In addition the rapid bioassessment protocols for periphyton (Stevenson and Bahls 1999), I wrote four book chapters during the last two years on algal bioassessment methods.
- I serve on three US EPA workgroups to develop protocols and guidelines for states: Bioassessment of Wetlands Workgroup; Nutrient Criteria Workgroup; and Tiered Aquatic Life Workgroup.



Short Curriculum Vitae

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Education

B.S. Agriculture (1968) North Dakota State University
M.S. Entomology (1972) Michigan State University
Ph.D. Entomology (1974) Michigan State University

Employment

1984 Professor, Entomology Dept., Michigan State University
1980-1984 Associate Professor, Entomology Dept., Michigan State University
1981-1982 Extension Project Leader, Entomology Dept, Michigan State University
1977-1980 Assistant Professor, Entomology Dept., Michigan State University
1974-1977 Research Scientist, Agriculture Canada, Saskatoon, Saskatchewan.
1975-1977 Adjunct Asst. Professor, Dept of Geography, Univ. Sask, Saskatoon, Sask.

Awards and Recognition

Bailey Scholar, College of Agriculture and Natural Resources, MSU 1997
Visiting Professor Award, San Diego Supercomputer Center, San Diego, CA 1996
Agricultural Ecosystem Management Chair Applicant, Ohio State Univ., 1998
San Diego Supercomputer Liaison with NSF-LTER, Albuquerque, NM 1998
Hayward Senior Fellow Award, Landcare Research, Lincoln, New Zealand 1999
Outstanding Contribution to Aerobiology Award, Aerobiology 2000

Professional Societies:

Entomological Society of America; Sigma Xi; Phi Kappa Phi; American Geophysical Union; Institute of Biological Sciences; American Meteorological Society

Interests

Landscape ecology, computational biology; scientific visualization, environmental monitoring; agricultural ecosystem dynamics; systems thinking; digital visualization; insect population dynamics; regional assessment of agricultural productivity; land use trends and modeling; Chinese agriculture; environmental acoustics.

Recent Extramural Grants and Contracts

Gage, S.H. and D. Skole. Pattern to process: development of a signature program in land use and land cover change. MSU Foundation. \$590K. 1999-2002.
Gage, S.H. Slow the Spread of the Gypsy Moth. U.S. Forest Service. \$210K. 2000-2001. (Continuation)
Gage, S.H. and 11 Co.PI's. Impact of Climate and Soils on Crop Selection and Management. USDA CSREES Regional Project. \$50K. 2000-2005. (Continuation)
Robertson, G.P, S.H. Gage, K. Gross, S. Hamilton, R.Harwood, and C. Vanderpool. Long Term Ecological Research in Field Crop Systems. NSF LTER. \$4,200K. 1998-2004. (Continuation)

Skole, D. S.H. Gage, and B.P. Pijanowski. Assessment tool to characterize the impact of changes in Land Use. Michigan Economic and Environmental Round Table (MEER) \$124 K. 2000-2002.

Bauer, M. and 12 Co-PI's. Upper Great Lakes Regional Earth Sciences Application Center. NASA. \$400K.

Link, T. and UCSC Committee. Practicing sustainability: Integrating teaching, research and operations to promote an ecologically sound learning-living environment within a large land-Grant university. U.S. EPA. \$312K. 2000-2003.

Selected Referred Publications

Gage, S.H., J. Helly and M. Colunga. 2000. A framework to integrate analytical and visual applications to regional models: development of and application for simulation of daily crop productivity in the Corn Belt. 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs. Banff Alta. 10 pp.

Gage, S. H., M. Colunga-G, G.R. Safir, and A. Momin. (submitted). A structural design for management and visualization of information from regional agricultural models. *Computers and Electronics in Agriculture*.

Gage, S.H., S.A. Isard and M. Colunga-G. 1999. Ecological Scaling of Aerobiological Dispersal Processes. *Agric. And Forest Meteorology* 97: 249-261.

Sharov, A., B.C. Pijanowski, A. Liebhold and S.H. Gage. 1999. What affected the rate of Gypsy Moth (Lepidoptera: Lymantriidae) spread in Michigan: Winter temperature or forest susceptibility? *Agriculture and Forest Entomology* 1:37-45.

Menalled, F.D., P.C. Marino, S.H. Gage and D.A. Landis. 1999. Does agricultural landscape structure affect parasitism and parasitoid diversity? *Ecological Applications*. 9:634-641.

Isard, S.A., D.A.R. Kristovich, S.H. Gage, C.J. Jones, and N.F. Laird. 1999. Atmospheric motion systems that influence the redistribution and accumulation of insects on the beaches of the Great Lakes in North America. *Physical Aerobiology* [<http://www.fisbat.bo.cnr.it/AERO/PA/PAIJ.html>].

Johnson, L.B. and S. H. Gage. 1996. A landscape perspective for analyzing aquatic ecosystems. *Freshwater Biology*. 36:101-120.

Recent Books and Book Chapters

Isard, S.A. and S.H. Gage. 2000. *Flow of Life in the Atmosphere: an airscape approach to understanding invasive organisms*. Michigan State University University Press. 304 pp.

Pijanowski, B.C., S.H. Gage, D.E. Long and W.E. Cooper. 2000. A land transformation model for the Saginaw Bay Watershed. [In] *Landscape Ecology: A Top Down Approach* [Eds.] J. Sanderson and L. Harris. CRC Press. Boca Raton, FL. 246 pp.

Colunga-G., M. S.H. Gage, and L. E. Dyer. 1998. The insect community. In: Cavigelli, M.A., S.R. Deming, L.K. Probyn, and R.R. Harwood (eds.) *Michigan field crop ecology: managing biological processes for productivity and environmental quality*. Michigan State University Extension Bulletin E-2646: 59-70.

Pijanowski, B.C. and S.H. Gage. 1997. Use of GIS to understand population dynamics of the gypsy moth. [In]: *Getting started with Geographic Information Systems*. Ed. K.C. Clark. Prentice Hall. 353 pp.

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Academic Training

B.S. (Zoology), University of Illinois, 1964
M.S. (Zoology), University of Michigan, 1966
Ph.D. (Botany), Michigan State University, 1973

Positions

Research Assistant, Great Lakes Research Division, U. of Michigan, 1962-65
Oceanographer, U.S. Naval Oceanographic Office, 1966-69
Research Assistant, Coherent Area Program for Investigation of Freshwater Ecosystems (NSF),
Kellogg Biological Station, Michigan State U., 1970-73
Assistant Professor, Department of Biological Sciences, Wayne State U., 1973-80
Associate Professor, 1980-90
Professor, 1990-present
Associate Department Chair, 1990-present
Chair, departmental Division of Evolutionary and Organismal Biology, 2000-present

Memberships

American Association for the Advancement of Science
American Society of Limnology and Oceanography
Ecological Society of America
International Association of Aquatic Vascular Plant Biologists
International Association of Theoretical and Applied Limnology
International Association for Great Lakes Research
Sigma Xi
Society of Wetland Scientists

Funding History

National Science Foundation, GB 40311. Photorespiration in Aquatic Plants; 46,000; 1973-76
National Science Foundation, DEB 7604503. Photosynthesis and Photorespiration in Aquatic
Plants; 50,000; 1976-79
Wayne State University Research Award. Nutrient Processing in the Bald Mt. Wetland
Ecosystem; 3,500; 1979-80
National Science Foundation, DEB 81-O3528. Metabolic Influence and Population Response of
Aquatic Plants in a Freshwater System; 41,000; 1981-84
Wayne State University Small Grants Program. Nitrogen enrichment in a calcareous freshwater
ecosystem; 500; 1986-87
Wayne State University President's Fund Award. Photoinhibition of phytoplankton; 5,900;
1990-91

Most Relevant Publications

- Hough, R.A., M.D. Fornwall, B.J. Negele, R.L. Thompson, and D.A. Putt. 1989. Plant community dynamics in a chain of lakes: Principal factors in the decline of rooted macrophytes with eutrophication. *Hydrobiologia* 173:199-218.
- Hough, R. A., T. E. Allenson, and D. D. Dion. 1991. The response of macrophyte communities to drought-induced reduction of nutrient loading in a chain of lakes. *Aquat. Bot.* 41:299-308.
- Freeman, D.C., J.M. Emlen, J.H. Graham, R. A. Hough, and T.A. Bannon. 1994. Biological monitoring of environmental quality: The use of developmental stability. *Environ. Engineering and Management* 4(2):6-11.
- Tracy, M., D.C. Freeman, J.H. Graham, J.M. Emlen, and R.A. Hough. 1995. Developmental instability as a biomonitor of ecosystem stress: An illustration using aquatic plants and macroalgae. Pp. 313-337 in: F.M. Butterworth et al. (eds), *Biomonitoring and Biomarkers as Indicators of Ecosystem Change*. Plenum Press.
- Hough, R.A., and R.L. Thompson, Jr. 1996. The role of nutrient limitation in phytoplankton dynamics in a chain of lakes. *Hydrobiologia* 319:225-235.

Additional publications forthcoming

- Tracy, M.A., D.C. Freeman, J. Duda., K. Miglia, J.H. Graham, R.A. Hough. In review. Developmental instability as an indicator of plant fitness.
- Freeman, D.C., J.H. Graham, J.M. Emlen, Tracy, M.A., R. A. Hough, C.L. Alados, and J. Escos. In review. Plant developmental instability: New measures, applications and regulation.
- Tracy, M.A., J.M. Montante, T.E. Allenson, and R.A. Hough. In prep. Long term responses of aquatic macrophyte communities to variations of nutrient loadings in a chain of lakes.
- Tracy, M.A., D.C. Freeman, and R.A. Hough. In prep. Developmental instability in freshwater macrophytes as a biomonitor of pollution in the Clinton River system, Southeast Michigan. (Based on M.A. Tracy's Wayne State U. dissertation under direction of R. A. Hough, 1999).

Collaborators (other than in publication list and former mentors and students)

None

Graduate Students Directed in Past Five Years

Mary Tracy, James Montante

Total all years: 12

Graduate Mentors:

George W. Saunders, Jr.; Robert G. Wetzel

VITA: David T. Long

Personal Data

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Internet: <http://www.cevl.msu.edu/~long>
Address: Department of Geological Sciences
Michigan State University
East Lansing, MI 48824-1115

Education

BA Monmouth College – Geology - (1969) advisor: G. Merrill
MS Univ. Illinois-Chicago – Hydrogeochemistry (1974) advisor: MS - Z. Saleem
Ph.D. Univ. Kansas (Honors) – Aqueous Geochemistry (1977) advisor: E. Angino

Selected Recent Academic Activities

1996-present Core faculty Earth System Science Education Program
1996-present Adjunct Professor – Kellogg Biological Laboratory, MSU
1993-present Contributing Faculty Entomology Spatial Analysis Laboratory S. Gage, Dir.
1989-present Professor Michigan State University
1989-present Faculty – Institute for Environmental Toxicology

Selected Recent Outreach and Service Activities

1997-present Associate Editor Ground Water
1994-present Michigan DNR task force on contaminated sediments
1994-present Treasurer – International Association of Geochemistry & Cosmochemistry
1992-present Governor appointed to Michigan Environmental Science Board
1991-1997 Associate Editor – Journal of Great Lakes Research
1991-1992 Michigan Risk Assessment Project
1984-1987 Governor appointed to Michigan Environmental Review Board

Military Record – Reserve duty, Army, 1970-1976; Artillery and Strategic Intelligence

Research Field – Aqueous and Environmental Geochemistry

Selected Papers

Long, D.T., Fegan N.E., Lyons, W.B., Hines, M.E., and Macumber, P.E. (1992). Geochemistry of acid-brines: Lake Tyrrell, Victoria, Australia. *Chemical Geology* 96: 19- 32.
Long, D.T. and Lyons, W.B. (1992) Continental denudation and climate in the evolution of acid-hypersaline ground-water. *GSA Today* 2: 185-186, 188-190
Wilson, T.P. and Long D.T. (1993) Geochemistry and isotope chemistry of Michigan Basin brines: Devonian Formations. *Applied Geochemistry*, 8:81-100
Matty, J.M. and Long, D.T. (1995) Early diagenesis of mercury in large lakes. *Journal of Great Lakes Research* 21: 574-587

- Kolak, J.J., Long, D.T., Matty, J.M., Larson, G.J., Sibley, D.F., and Councell, T.B. (1999) Ground-water, large-lake interactions in Saginaw Bay, Lake Huron: A geochemical and isotopic approach. Geological Society of America Bulletin.
- Wong C.S., Sanders G., Engstrom D.R., Long D.T., Swackhamer D.L., and Eisenreich S.J. (1995) Accumulation, inventory and diagenesis of chlorinated hydrocarbons in Lake Ontario sediments. Environmental Science and Technology 29: 2661-2672.
- Pearson, R.F., Swackhamer, D.L., Eisenreich, S.J. and Long, D.T. (1997) Concentrations, accumulations, and inventories of toxaphene in sediments of the Great Lakes. Environmental Science and Technology 31: 3523-3520.
- Kolak, J.J., Long, D.T., Beals, T.M., Eisenreich, S.J., and Swackhamer, D.L. (1998) Anthropogenic inventories and historical and present accumulation rates of copper in Great Lake Sediments. Applied Geochemistry 13: 59-75
- McGuire, J.T., Smith, E.W., Long, D.T., Hyndman, D.W., Haack, S.K., Kolak, J.J., Klug, M.J., Velbel, M.A., and Forney, L.J. (1999) Temporal variations in biogeochemical processes that influence ground water redox zonation, in Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999--Volume 3 of 3--Subsurface Contamination from Point Sources: U.S. Geological Survey Water-Resources Investigations Report 99-4018C, p. 641-652
- Kolak J.J., Long D.T., Kerfoot W.C., Beals T.M., and Eisenreich S.J. (1999) Nearshore versus offshore copper loading in Lake Superior sediments: Implications for transport and cycling. Journal of Great Lakes Research 25:611-624.
- McGuire, J.T., E.W. Smith, D.T. Long, D.W. Hyndman, S.K. Haack, M.J. Klug, M.A. Velbel (in press) Temporal variation in parameters reflecting terminal-electron-accepting processes in an aquifer contaminated with waste fuel and chlorinated solvents. Chemical Geology 169:471-485.
- Wayland, K.G., Long, D.T., Hyndman, D.W., Pijanowski, B.J., and Woodhams, S. (2000a). Biogeochemical Fingerprinting of a Rapidly Urbanizing Watershed. In 8th National Workshop on Monitoring and Modeling Nonpoint Source Pollution, J.C. Clausen (ed.), Hartford, CT. In press with the U.S. Environmental Protection Agency
- Long, D.T., Sitarz, W., Eisenreich, S.J., and Swackhamer, D.L. (in press) Production and consumption history of mercury and its accumulation in sediments of Lake Ontario.
- Long, D., Icopini, G., Ganev, V., Petropolous, E., Havezov, I., Spassov, A., Voice, T., and Chou, K., (2000 c). Finger-Printing Balkan Endemic Nephropathy Etiology in the Bulgarian Environment With Geochemical Markers: A Pilot Study. International Journal of Occupational Medicine and Environmental Health. (in prep.)

Collaborators

W.B. Lyons, M.E. Hines, S. Eisenreich, D. Swackhamer, A. Nishri, T. Berman, T. Wilson, J. Matty, N. Ostrom, P. Ostrom, B. Cooper, T. Burton, S. Gage, B. Pijanowski, P. Murphy, G. Larson, D. Sibley, M. Velbel, D. Hyndman, S. Haack, N. Grannemann. L. Forney, T. Marsh, F. Pierce, M. Colunga, J. Geisy

Graduate Students/Post Docs last 5 years (total 40)

Adam Heft, Nancy E. Fegan, William Sitarz, Sang Jo Jeong, Jon Kolak, Gary Icopini, Tina Beals, Thomas Sampson, Robert Ellis, Joe Kozak, Oghenerioke Z Ekpere, Eric Lietz, Sarah Woodhams, Matt Harold, Gary Icopini, Jeff Vought, Hilary Thacher, C. Merlin, S. Simpson, K. Wayland, Shane Snaveley, Joel. Fett

Bryan C. Pijanowski

I. Education

B.S. Hope College - Biology (1983), Holland, Michigan.

Ph.D. Michigan State University - Zoology (1991)

II. Recent Positions

August 2000 Research Associate Professor, Department of Entomology, MSU.

1996-present Assistant to the Deans, College of Natural Science, MSU.

1993-present Assistant Research Professor, Department of Entomology, MSU.

1992-1993 Research Associate, Department of Entomology, MSU and Staff Scientist, Consortium for International Earth Sciences Information Network, University Center, MI.

III. Research Interests

Principal investigator on two projects that examine the influence of development on groundwater dynamics and biogeochemistry of large ecosystems. Projects involve substantial amount of computer simulation modeling using geographic information systems, artificial neural network software, and standardized hydrogeologic simulation (MODFLOW and MT3D) software. Considerable outreach is conducted so that scientific results of the project reach watershed stakeholders. Also Co-PI in two NASA funded, land use related projects. Main focus of these projects is modeling the socioeconomic, political and environmental drivers of land use/land cover change in the forested ecosystems of the Great Lakes. Have also conducted research on the population dynamics and spread of the gypsy moth, a damaging non-indigenous pest, and on the reproductive performance of altricial birds in response to variable environmental conditions. Currently collaborating with two research scientists at the EROS Data Center that would involve the use of the LTM in Senegal.

IV. Current Research Support

Hierarchical Investigation of Socioeconomic Drivers of Decadal Scale Land-Cover Changes in the Upper Midwest, NASA Land Use/Cover Change Program. \$372,000. 1997-2001. Brown, Pijanowski and Vasievich; Modeling the Influence of Land Use Change on Biogeochemical Indicators and Great Lakes Loadings for Watershed Management. \$432,000. 1998-2001. Pijanowski, Haack, Long, and Hyndman. Michigan Great Lakes Protection Fund; Using A Land Transformation Model to Assess Fragmentation of Natural Resources in Michigan. With Stuart Gage and David Skole. \$123,000, from the Kellogg and Frey Foundations. 2000-2001. Forecasting Arctic Vegetation: The Interaction Between Surface Disturbance and Climate Change, 1999-2003. \$320,000 (collaborator, Webber is PI). A Regional Environmental Science Applications Center for the Upper Great Lakes States. \$2,100,000, 1999-2001, with Stuart Gage, David Skole, Richard Groop at MSU.

V. Recent Relevant Publications

Pijanowski, B.C., D. G. Brown, G. Manik and B. Shelitto. In Review. Coupling neural networks and GIS to forecast land use changes in Michigan's Grand Traverse Bay Watershed. *Computers, Environment and Urban Systems*.

Pijanowski, B.C., S. Pithadia, D. Brown and B. Shellito. In Review. Integrating GIS, Artificial Neural Networks and Geospatial Analysis Tools: Architecture of the Land Transformation Model. *International Journal of Geographic Information Systems*.

Boutt, D.F., D.W. Hyndman, B.C. Pijanowski, and D.T. Long. In press. The Use of a High Resolution Groundwater Flow and Transport Model in a Large Coastal Watershed Undergoing Land Use Change. *Groundwater*.

Brown, D. B. Pijanowski and J Duh. 2000. Coupling Land Use to Land Cover on Private Lands in the Upper Midwest: The Missing Link. *Journal of Environmental Management* 59:247-263.

Pijanowski, B.C., S.H. Gage, and D.T. Long. 2000. A Land Transformation Model: Integrating Policy, Socioeconomics and Environmental Drivers using a Geographic Information System; In *Landscape Ecology: A Top Down Approach*, Larry Harris and James Sanderson eds.

Sharov, A., B.C. Pijanowski, A. Liebhold and S.H. Gage. 1999. What affected the rate of Gypsy Moth (*Lepidoptera: Lymantriidae*) spread in Michigan: Winter temperature or forest susceptibility? *Agriculture and Forest Entomology* 1:37-45.

- Moran, M. S., D. C. Hymer, **J. Qi** and E. E. Sano, 2000, Soil Moisture evaluation using Synthetic Aperture Radar (SAR) and optical remote sensing in semiarid rangeland, *J. Agr. For. Meteorol.*, in press.
- Moran, M. S., R. B. Bryant, T. R. Clarke and **J. Qi**, 2000, Deployment and calibration of reference reflectance tarps for use with airborne cameras, *Photog. Eng. Rem. Sens.*, in press.
- Moran, M.S. R. Bryant, K. Thome, W. Ni, Y. Nouvellon, M. P. Gonzalez-Dugo, **J. Qi**, and T. R. Clarke, 2000, A Refined Empirical Line Approach for Reflectance Factor Retrieval from Landsat-5 TM and Landsat-7 ETM+, *Remote Sens. Environ.* (submitted)
- Nouvellon, Y., D. LoSeen, S. Rambal, A. Begue, M. S. Moran, Y. Kerr and **J. Qi**, 2000, Time course of radiation use efficiency in a shortgrass ecosystem: consequences for remotely-sensed estimation of primary production, *Remote Sens. Environ.* 71:43-55.
- Nouvellon, Y., M. S. Moran, D. LoSeen, R. B. Bryant, S. Rambal, W. Ni, A. Bégué, A., Chehbouni, P. Heilman, B. Emmerich, and **J. Qi**, 2000. Combining a grassland ecosystem model with Landsat TM imagery for a ten year simulation of carbon and water budget, *Remote Sens. Environ.*, (in review).
- Qi, J.**, R.C. Marsett, M.S. Moran, D.C. Goodrich, P. Heilman, Y.H. Kerr, G. Dedieu, A. Chehbouni and X.X. Zhang, 2000, Spatial and temporal dynamics of vegetation in the San Pedro River Basin Area, *J. Agr. For. Meteorol.*, in press.
- Qi, J.**, Y. H. Kerr, M. S. Moran, M. Weltz, A. R. Huete, S. Sorooshian, and R. Bryant, 2000, Leaf area index estimates using remotely sensed data and BRDF models in a semi-arid region, *Remote Sens. Environ.* 73:18-30.
- Zeng, X., R. E. Dickinson, A. Walker, M. Shaikh, R. S. DeFries, and **J. Qi**, 2000, Derivation and Evaluation of Global 1-km Fractional Vegetation Cover Data for Land Modeling, *Journal of Applied Meteorology*, Vol. 39, Iss. 6; pg. 826.
- Zhang, R., A.J. Krzyszowska-Waitkus, G. F. Vance, and **J. Qi**, 2000, Pesticide transport in field soils. *Advances in Environmental Research*, in press.
- Moran M. S., D. C. Hymer, **J. Qi**, and Y. H. Kerr, 1999, Monitoring agricultural crop and soil conditions by combining ERS-2 SAR and Landsat imagery, *Remote Sens. Environ.*, (submitted)
- Moran, M. S., D. C. Hymer, **J. Qi** and Y. Kerr, 1998, Radar imagery for precision crop and soil management, *Modern Agriculture*, Winter '98 2:21-23.
- Dymond, J. R., **J. Qi**, 1997, Reflection of visible light from a dense vegetation canopy-a physical model. *Agr. and Forest Met.*, 86: pp 143-155
- Moran, M.S., A. Vidal, D. Troufleau, T. Clarke, T. Mitchell, P. J. Pinter Jr., **J. Qi**, Y. Inoue, and C. Neale, 1997, Combining multi-frequency microwave and optical data for farm management, *Remote Sens. Environ.* 61: 96-109
- Qi, J.** and Y. Kerr, 1997, On current compositing algorithms, *Remote Sens. Reviews. Vol. 15*, pp. 235- 256.
- Chebouni, A., W. D. Nichols, E. G. Njoku, **J. Qi**, et al., 1995, A three component model to estimate sensible heat flux over sparse shrubs in Nevada, *Remote Sensing Reviews*, Vol. 15, pp. 99-112.
- Moran, M. S., R. D. Jackson, T. R. Clarke, **J. Qi**, F. Cabot, K. J. Thome, and B. N. Markham, 1995, Reflectance factor retrieval from Landsat TM and SPOT HRV data for bright and dark targets, *Remote Sens. Environ.*, 52:218-230.
- Qi, J.**, F. Cabot, M. S. Moran, and G. Dedieu, 1995, Biophysical parameter retrievals using multidirectional measurements, *Remote Sens. Environ.*, 54:71-83.
- Qi, J.**, M. S. Moran, F. Cabot, and G. Dedieu, 1995, Normalization of sun/view angle effects on vegetation indices with bidirectional reflectance function models, *Remote Sens. Environ.*, 52: 207-217.
- Chebouni, A., **J. Qi**, A. R. Huete, Y. H. Kerr, and S. Sorooshian, 1994, Towards the development of multidirectional vegetation index(MVI), *Water Res. Research*, vol. 30, no. 5, 1281-1286.
- Qi, J.**, A. Chehbouni, A. R. Huete, and Y. Kerr, 1994, A modified soil adjusted vegetation index (MSAVI), *Remote Sens. Environ.* 48:119-126.
- Qi, J.**, A. R. Huete, F. Cabot, and A. Chehbouni, 1994, Bidirectional properties and utilizations of high resolution spectra from a semi-arid watershed, *Water Res. Research*, vol. 30, no. 5, 1271-1279.
- Qi, J.**, F. Cabot, M. S. Moran, G. Dedieu and K. J. Thome, 1994, Biophysical parameter retrievals using multidirectional measurements, *Proc. IEEE Geosci. and Rem. Sens. Symp.*, August 8-12, Pasadena, CA, p.1816-1818, 1994.
- Qi, J.**, A. R. Huete, M. S. Moran, A. Chehbouni, and R. D. Jackson, 1993, Interpretation of vegetation indices derived from multi-temporal SPOT images, *Remote Sens. Environ.* 44: 89-101.
- Huete, A. R., G. Hua, **J. Qi**, A. Chehbouni, and W. J. D. van Leeuwen, 1992, Normalization of multidirectional red and NIR reflectances with the SAVI, *Remote Sens. Environ.* 41:143-154.

RESUME

MICHAEL J. WILEY

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EDUCATION

B.G.S.	1973	University of Michigan (LSA)
M.S.	1976	University of Michigan (SNR)
Ph.D	1980	University of Michigan (SNR)

PROFESSIONAL EXPERIENCE

1993-Present

Associate Professor, School of Natural Resources and Environment, Univ.of Michigan.

1987-1993

Assistant Professor, School of Natural Resources and Environment, Univ.of Michigan.
Research in aquatic community ecology, fisheries, benthic invertebrates, river ecosystems and management. Primary funding from NSF, MDNR, EPA.

COURSES: Intro to Aquatic Ecosystems, Aquatic Entomology, Stream Ecology, Fluvial Ecosystems, Intro to Natural Resource Planning and Management, Habitats and Organisms.

1980-87

Assistant and Associate Professional Ecologist, Illinois Natural History Survey
Champaign, Illinois: Assistant Professor, University of Illinois.

Principal investigator on several large research grants dealing with river ecosystem management. Issues addressed include instream flow regulation, land use practices, and controls on large-scale patterns of biological productivity. Director of benthic invertebrate laboratory for Aquatic Biology Section. Program advisor for Aquatic Plant Management Program. Principal investigator for three year study of techniques for predicting impacts of instream flow reductions on riverine fisheries. Principal investigator on four year study of Hybrid and Triploid Grass Carp. Co-investigator in three year study of the ecology of the Braidwood Nuclear Plant Cooling Lake. Principal lecturer for a graduate level course dealing with the use of simulation modelling in natural resource management.

Professional Affiliations, Boards and Committees

Ecological Society of America, American Fisheries Society, North American Benthological Society.

- Member, (1991-1994) National Research Council's Committee to review EPA's Environmental Monitoring and Assessment Program
- Member, (1996) National Research Council's Committee on Research Opportunities and Priorities for EPA
- Huron River Watershed Council- Technical Advisory Committee 1991-2001
- Huron-Clinton Wetland Initiative- Technical Advisory Council 1997-1998
- External Reviewer for the Louisiana State Board of Regents 1998: UNO Program in Conservation Biology

Selected Publications related to proposed research

- Osborne, L. L. and M. J. Wiley. 1988. Empirical relationships between land use/cover and stream water quality in an agricultural watershed. *J. Environmental Management* 26: 9-27.
- Osborne, L. L., M. J. Wiley and R. W. Larimore. 1988. Assessment of the water surface profile model: accuracy of predicted in stream fish habitat conditions in low-gradient, warm water streams. *Regulated Rivers: Research and Management*. Vol 2, 619-631.
- Wiley, M. J., L. L. Osborne and R. W. Larimore. 1990. Longitudinal structure of an agriculturally developed prairie river system and its relationship to current stream ecosystem theory. *Can. J. Fish. Aquat. Sci.* 47:373-384.
- Osborne, L.L. and M.J. Wiley. 1992. The influence of tributary spatial position on the structure of warmwater fish communities. *Can. J. Fish. Aquat. Sci.* 49(4):671-681.
- Tompkins, T., W. Whipps, L. Manor, M.J. Wiley, C. Radcliffe and D. Majewski. 1997. Wetland effects on hydrological and water quality characteristics of a mid-Michigan river system. IN: Trettin et al, Eds. *Northern forested wetlands: ecology and management*, Chapter 19. CRC Press Inc. Boca Raton FL.
- Wiley, M.J., S.L. Kohler and P.W. Seelbach. 1997. Reconciling landscape and site based views of aquatic stream communities. *Freshwater Biology* 37:133-148.
- Seelbach, P.W., M.J. Wiley, P.A. Soranno, and M.T. Bremigan. 2000. Aquatic conservation planning: Using landscape maps to predict ecological reference conditions for specific waters. Chapter 26 In Gutzwiller, K., Editor. *Concepts and applications of landscape ecology in biological conservation*. (In Press) Springer-Verlag, New York, NY.
- Baker, M.E., M. J. Wiley, and P.W. Seelbach. 2001. Spatially-explicit models of groundwater loading in glaciated landscapes: considerations and development in Lower Michigan. Michigan Department of Natural Resources, Fisheries Research Report (In Press), Ann Arbor.

Other significant Publications

- Wiley, M. J. 1980. Interacting influences of sediment preferences and density on the emigration rates of some trout stream chironomid larvae (Diptera: Chironomidae). *Ecology* 62(2):426-438.
- Wiley, M. J. and S. L. Kohler. 1981. An assessment of biotic interactions in an epilithic community using time-lapse macrocinematography. *Hydrobiol.* 78:183-188.
- Kohler, S.L. and M.J. Wiley. 1997. Pathogen Outbreaks reveal large-scale effects of competition in stream communities. *Ecology* 87(7): 2164-2176
- Seelbach, P.W., M.J. Wiley, J.C. Kotanchik and M.E. Baker. 1997. A Landscape-based ecological classification system for river valley segments in Lower Michigan. Fisheries Research Report No. 2036. Michigan Department of Natural Resources, Ann Arbor, MI. 51 pp.

Recent (last 48 months) Collaborators:

P.W. Seelbach, S.L. Kohler, R. Jan Stevenson, J. Holomuzki, D. Allan, P. Webb

Graduate Studies Advisor(s):

Frank F. Hooper, Justin Leonard

Graduated Student Advisees (Ph.D only):

Lynn Wike, Donna Francis, Roger Haro, C. Elzinga, L. Hinz, D. Zaber, K. Wehrly, C. Riseng

BUDGET

Muskegon River Watershed Budget		Year 1 2001	Year 2 2002	Year 3 2003	3-Yr Budg
Personnel					
Salaries					
Stevenson	1 mo	11083	11638	12219	34940
Gage	1 mo	0	0	0	0
Qi	1 mo	5624	5905	6200	17729
Long	1 mo	9529	10006	10506	30041
Pijanowski	1 mo	6667	7000	7350	21017
Sum Fac. Salaries		32903	34548	36276	103728
Assessment Coordinator/ Database Mgmt	12 mo	32000	33600	35280	100880
New Tech Coordinator	12 mo	32000	33600	35280	100880
Biochemistry Tech	6/12 mo	16000	33600	35280	84880
Volunteer Coordinator and Trainer	12 mo	27000	28350	29768	85118
Sum Post-doc and Technician Salaries		107000	129150	135608	371758
GRA (RJS)		10456	17430	18301	46187
GRA (Qi)		10456	17430	18301	46187
Sum GRA Stipends		20912	34860	36603	92374
UGRA (Long)	12 mo(pt)	4433	6983	7332	18747
UGRAs (Summer)	10 wks	9600	9600	9600	28800
Sum UGRA Wages		14033	16583	16932	47547
Fringes					
Faculty 8%		2632	2764	2902	8298
Post-Docs and Technicians (0.33,30.8, 31.9, 32.6%)		34133	40489	43733	118355
GRA(s)		7387	12735	13372	33493
UGRAs		0	0	0	0
Total Fringes		44152	55987	60007	160147
Total Salaries and Fringes		219000	271128	285425	775553
Supplies and Equipment					
New Tech Budget		40000	40000	40000	120000
Supplies		20000	20000	20000	60000
Computer (Server)		7000			7000
Total Supplies and Equipment		67000	60000	60000	187000
Travel					
Travel to Field Sampling and Related Activities		20000	20000	20000	60000
Travel to Annual Meetings (2 each PI)		10000	10000	10000	30000
Travel to Annual Meetings for Assistants (2 each)		9000	9000	9000	27000
Total Travel		39000	39000	39000	117000

Muskegon River Watershed Budget (page 2)	Year 1 2001	Year 2 2002	Year 3 2003	3-Year Budget
Subcontracts				
WSU	40000	46000	48000	134000
UM (Wiley)	64000	77000	80000	221000
JR Smith	10000	10000	10000	30000
Trout Unlimited	10000	10000	10000	30000
Conference/Training Budget (Michigan Rivers)	20000	20000	20000	60000
Total Subcontracts	144000	163000	168000	475000
Sum Direct Costs	469000	533128	552425	1554553
Overhead (0%)	0	0	0	0
Total Direct Costs	469000	533128	552425	1554553

BUDGET JUSTIFICATION

More than 80% of our budget requests funds for salaries for personnel (including fringe benefits and overhead) to gather, analyze, and present data. Most of the rest is for supplies and travel to sites. 98% of the equipment request is for setting up automated monitoring stations. The research team has almost all the standard equipment needed to conduct the research.

Personnel:

One month of summer salaries have been requested for Co-PIs who are on 9-month appointments: Stevenson (MSU), Qi (MSU), Long (MSU), Pijanowski (MSU), Hough (WSU), and Wiley (UM). Stevenson will supervise the entire project and especially the algal assessments. Gage, who will not draw a summer salary, will supervise development of automated monitoring stations and data visualization through web-pages and other media. Qi will have primary responsibility for remote sensing. Long will supervise geochemical analyses. Pijanowski will gather land use information. Hough will supervise plant assessments and assessments of developmental instabilities. Wiley will supervise invertebrate and fish assessments. All Co-PIs will be responsible for getting data to the central project database and for using data to write papers focused on their specialties and on interdisciplinary papers. Our budget will be reduced if the companion Integrated Assessment Project is funded, from which Wiley and Pijanowski will be drawing summer salary. Our plan is to reduce the MSU budget and UM subcontract by removing their summer salaries if the Integrated Assessment Project is funded.

Funds have been requested for 2 post-docs or research associates. One will coordinate the field sampling teams, maintain the database for the project, and assist in data analysis and writing papers. Another post-doc will be responsible for developing and maintaining the automated monitoring stations, analyzing data, and writing papers. Salary for a technician has been requested to conduct water and sediment chemistry analyses. Salary for a coordinator to work with citizen monitoring groups, train the groups, assemble data, work with groups to analyze and present the data in web-pages and publications.

Funds for graduate and undergraduate assistants are requested. Graduate students will work with Stevenson, Qi, Hough (WSU subcontract), and Wiley (UM subcontract) for development and application of algal, remote sensing, developmental instabilities, and invertebrates/fish, respectively. Undergraduate student assistants have been requested to help with chemical assays and summer sampling.

Supplies and Equipment:

Supplies were estimated at approximately \$4000 per year per PI. These funds will be used to purchase field and laboratory supplies for collecting samples, preserving samples, and analyzing samples. Supply expenses were estimated to be higher for the biogeochemical analyses versus other analyses. Similarly, supplies were requested in the remote sensing project for disk space, satellite imagery, upgrading sensors, and basic office supplies. Publication costs were requested based on publication of results each year by each PI. Publication in journals that do not charge page charges will be encouraged.

Funds for only one piece of equipment are requested, a new high speed and high storage computer that can store the GIS and Program data.

Travel

Travel budgets were developed for field trips and scientific meetings. Our \$20000/yr travel budget was estimated based on the following:

- We plan to rent lodging for the field crews during the 8 week summer sampling period to minimize housing costs, increase the number of sites that can be sampled, and enable sample processing (\$1500/mo). A small preparation lab will be set-up at the rented facility.
- We plan 3-3 person crews in the field, 4 days per week during summer sampling and reconnaissance. We will rent 3 vehicles at \$500 per month for three months. Based on sampling from a centrally located facility in the MRW, we estimated travel distance for each crew to be approximately 250 miles per day, gas costing \$2/gal, and 15 mi/gal per car.
- One crew will travel weekly to the automated sampling units throughout the year. Thus, we will rent a vehicle for the year, which can also be used by the citizen group coordinator and PIs to travel to regional meetings. We estimate weekly trips of 400 miles to service the automated sampling units.
- \$2000/yr was budget for PIs and the citizen coordinator to travel to the field.

Travel to one national or international scientific meeting per year was budgeted for each PI at \$1000/meeting for each PI, post-doc, tech, and graduate research assistant. Travel to 2 regional meetings was planned for each PI at \$500/meeting. Travel for 1 regional meeting was budgeted for each post-doc, tech, and graduate research assistant.

Subcontracts

Subcontracts were calculated based on the same factors as above for research budgets for Hough and Wiley at WSU and UM, respectively. Each has funding for one month summer salary, a graduate student and undergraduate assistant, supplies, and travel. In addition, Hough has requested funding for a computer during first year of the project to handle data entry and analysis of this project.

The subcontract for JR Smith, Inc. will be for consulting services to develop the computer technology for the automated monitoring systems. Trout Unlimited will be gathering fish stock data by creel census and their subcontract is for supplies and travel. Michigan Lakes and Streams Association will be organizing citizen monitoring for Tier 2 assessment and their subcontract will support supplies and travel expenses for conducting and supervising the monitoring.

Overhead

We assume that the budget will be adjusted according to the overhead allowed by the granting agencies that fund this project. We calculated this budget assuming no overhead, but expect to get appropriate overhead funding if agency policies allow it.

Summary

We've requested almost \$1.5 million for the ecological assessment of the Muskegon River Watershed over 3 years. Although the budget for the proposed ecological assessment exceeds the \$1.0 million guidelines, the assessment as proposed provides a unique opportunity to develop and integrate new assessment techniques and to integrate application of those techniques in a thorough assessment of the Muskegon River Watershed. Reducing the budget from the

proposed level will require eliminating spatial coverage of the project or some particular element, such as remote sensing, wetlands, paleoecology.

FACILITIES

ENVIRONMENTAL ISOTOPE AND GEOCHEMICAL LABORATORIES DEPARTMENT OF GEOLOGICAL SCIENCES, MICHIGAN STATE UNIVERSITY

1. Overview of Laboratories

The **Environmental Isotope and Geochemical Laboratories** at MSU comprise an Aqueous/Inorganic/Environmental Geochemistry laboratory, an Organic/ Biogeochemistry laboratory, a Solids Geochemistry laboratory, a Stable Isotope Geochemistry laboratory, an ICPMS/Ultra-Clean laboratory, a Tritium Analysis laboratory, and a Mineral-Surface Chemistry laboratory. Associated with the labs are large freezers for sample storage and a 15' x 20' cold room (4°C) for sample storage and cold temperature experiments. The first four laboratories are climate (temperature and humidity) controlled with filtered air in neutral-pressure rooms. The laboratories are equipped with hoods, benches, and clean hoods (class 100) appropriate for general and trace biogeochemical analyses. In addition to the Environmental Isotope and Geochemical Laboratories two other facilities at Michigan State University are available for the project the **Center for Advance Microcopy** and the **Center For Fundamental Materials Research**.

2. Description of Laboratories

The *Aqueous/Inorganic/Environmental laboratory* (669 ft²) room includes a Perkin- Elmer atomic absorption unit (Zeeman 5100) equipped with HGA 600 graphite furnace with AS- 60 autosampler; and FIAS 200 flow injection system with AS-90 autosampler and hydride generation and mercury amalgamation accessories. It also includes a Shimadzu Total Organic carbon Analyzer (TOC-5000A) with auto sampler (ASI-5000), a Trace Analytical reduction gas Analyzer (RGA3), and a Hewlett Packard Capillary Electrophoresis Analyzer (3^DCE). Analytical quality clean water is produced from a Corning AG-11 distillation unit which processes deionized water (unitbed, S.B. anion, cation cartridges) and a Barnstead E-Pure water purification system. The laboratory also includes Teflon sub-boiling and quartz acid distillation units, clean boxes (Class 100) with controlled atmospheres for preparing standards, Spectronic Instruments 20D+ spectrophotometers, Milton Roy Spectronic 1001 uv- vis spectrophotometer, high speed centrifuges, Mettler analytical balances, Corning and Orion pH multi-purpose meters, and various models of water baths and shaker baths. IBM-compatible PCs are available for advanced statistical and geochemical modeling.

The *Organic/Biogeochemical laboratory* (740 ft²) includes a Rainin Gradient Analytical HPLC with columns for ions and cations.

The *Stable Isotope laboratory* (669 ft²) includes a VG PRISM high sensitivity isotopic mass ratio unit with automatic samplers. Lines are available for C, N, O, and H isotopic analyses. Equipment is available for compound specific work.

The *Tritium Analysis laboratory* (195 ft²) includes a Packard Tricarb 1050 liquid scintillation counter. Tritium can be analyzed directly and through concentration of sample.

The ***Solids Geochemistry laboratory*** (200 ft²) contains a Rigaku-Gergerflex S/Max-EII X-ray Fluorescence unit and Ortec multi-channel analyzer with GELI detector.

The ***Mineralogy-Surface Chemistry laboratory*** (365 ft²) has a automated, digital output Rigaku-Gergerflex V/Max-1a X-ray diffraction unit and JEOL-JSM SEM unit with Tracor Northern X-Ray Microanalysis system. A Beckman/ARL Spectra-Span VB DCP is available through the Department of Crop and Soil Sciences at Michigan State University.

The ***ICPMS & Ultra-Clean laboratory*** (390 ft²) contains a 81 ft² class 100 lab; 24 ft² class 1000 gowning lab; a 100 ft² class 100 ICPMS lab and a 185 ft² class 100,000 lab prep area. The inductively coupled, plasma, mass spectrometer (ICP-MS) is a Micromass ICP-HEX-MS with organic matrix system, high dissolved solids v-groove nebulizer, hydride generation, high efficiency nebulizer, direct injection nebulizer, and laser ablation. HEX stands for hexapole, which is a relatively new technology that allows for the determination of elements such as As, that have been a challenge to determine by traditional ICP methods. The Environmental Isotope and Geochemical Lab at Michigan State University is one of few institutes that has this technology available at this time. The laboratory is equipped with a Barnsted (Nano-Pure Infinity) water purification system.

3. The Center for Advance Microcopy at Michigan State University

The Center for Advanced Microscopy is a university facility. There are two scanning electron microscopes at the Center for Advanced Microscopy, a JEOL (Japan Electron Optics Laboratories) JEOL JSM-35CF and a JEOL JSM-6400V. The following services are available: Secondary Electron Imaging, Backscattered Electron Imaging, Energy Dispersive X-ray Microanalysis, Cryo Electron Microscopy, Digital Imaging, Analog Imaging. There are two transmission electron microscopes at the Center for Advanced Microscopy, a Philips CM-10 and a JEOL (Japan Electron Optics Laboratories) 100CXII. A National Science Foundation grant is pending for the purchase of a JEOL 2010F 200 kV field emission transmission electron microscope. The following services are available: Bright Field Imaging, Dark Field Imaging, Selected Area Diffraction, STEM (scanning-transmission electron microscopy) Imaging, EDS (energy dispersive x-ray microanalysis)

4. Center For Fundamental Materials Research

With National Science Foundation and MRSEC support, the Center was created as a university shared facilities. There are four main laboratories with the capabilities of the W. M. Keck Microfabrication Facility, related to this work. Hitachi S-4700II Field Emission Scanning Electron Microscope, JEOL 840A Scanning Electron Microscope and Electron Beam Lithography, Scanning Probe Microscope - Dimension 3100 SPM, EDAX Phoenix energy dispersive X-ray system (EDS), Kaiser Optical Systems HoloProbe Raman Spectrograph coupled to an Olympus BX-60 optical microscope.

5. General

Associated with the labs are large freezers for sample storage and a 15' x 20' cold room (4°C) for sample storage and cold temperature experiments. The laboratories are climate (temperature and humidity) controlled with filtered air in neutral-pressure rooms. The laboratories are equipped with hoods, benches, and clean hoods (class 100) appropriate for general and trace biogeochemical analyses. Field equipment includes two YSI multimeters; pH meters; DO meters; TDS meters; Ocean Instruments Multi corer (takes for replicated undisturbed sediment cores); sediment core extruders (these allow for precise sectioning with up to 0.25 cm resolution); a variety of plankton nets and water bottles (Lever-action Niskin) for collection of zooplankton and water samples, respectively; Teflon waters samplers for trace contaminants; field set ups for alkalinity, dissolved iron, etc.; low flow peristaltic pumps; and a SeaBird SBE25 CTD with temperature, conductivity, pressure, fluorescence, transmittance, pH, and O₂ sensors. We have built with in cooperation with the Department of Environmental Quality of the State of Michigan a boat capable of working in inland lakes as well as near coastal areas.. We had previously been using the EPA' vessel RV/ Mud Puppy.

Computational Ecology and Visualization Laboratory (CEVL) (www.cevl.msu.edu)

Stuart Gage directs and operates The Computational Ecology and Visualization Laboratory (CEVL). This newly developed facility operates an integrated Unix and PC environment to support advanced monitoring and data analysis application systems that interface with relational database management systems for multi-variate temporal and spatial data design, organization, management and analysis. Hardware include a Silicon Graphics Origin 200 server with 200 GB of on-line disk storage interconnected with 5 Unix workstations, 2 SGI-NT visualization workstations, and 6 Pentium class microcomputers. In addition, a Server has been added to the computation facilities to accommodated remote mapping and remote access to real-time measurements from distributed sites. The workstations are equipped with on-board cameras for digital image capture and video conferencing. Graphics hardware delivers high resolution rendering for special visualization processing. This facility can be accessed remotely through high-speed network communication.

Software includes geographic information systems and satellite image analysis (ArcInfo, ArcView, ERDAS Imagine, IDRISI); 3-D Scientific data mining, statistics and visualization processing (Data Explorer, MineSet, S Plus); Animation and video production (Adobe Premiere, Adobe Photoshop, Adobe Illustrator, WaveFront); Relational Database (Oracle); Automated web-cam and sound acquisition.

To accommodate new dimensions of biological monitoring focusing on environmental measurement an electronic workshop has been established. Facilities are under development to utilize wireless communications, capture remote sound and video, assemble hardware systems for field deployment and integrate sound and video into web-based technologies.

The CEVL anticipates that a major emphasis will be placed on the design development and deployment of environmental monitoring technologies and analysis in support of ecological assessment associated with the Muskegon River Watershed.

Algal Assay Laboratory

Stevenson's laboratory is equipped with 5 Leica® research-quality light microscopes and digital cameras for high-resolution observation and photography of algae. His library of more than 200 taxonomic references for algae, high resolution microscopy (with 1.36 NA objectives and condensor), and digital image storage enable high quality taxonomy and the ability to archiv photographic images of taxa for future reference. Routine algal pigment analysis (chlorophyll a) will be done with an Hitachi U-2001® uv-vis spectrophotometer. Data analysis is conducted on a suite of Pentium II and III microcomputers, networked throughout the laboratory

CURRENT AND PENDING SUPPORT

See CVs for Stevenson and Gage