

1. **Sorting Code** 200-STAR-B1
2. **Title** Development of Environmental Indicators of Condition, Integrity, and Sustainability in the Great Lakes Basin

**3., 4. Investigators and Institutions:**

*Principal Investigator:* Gerald Niemi, Center for Water and the Environment (CWE), Natural Resources Research Institute (NRRI), University of Minnesota (UMN)

*Co-Principal Investigators:* Richard Axler, JoAnn Hanowski, George Host, Lucinda Johnson, Carol Johnston, John Kingston, CWE/NRRI; Ronald Regal, Department of Mathematics and Statistics; Carl Richards, Minnesota Sea Grant; Deborah Swackhamer, Department of Environmental and Occupational Health, UMN; Robert Howe, Department of Natural and Applied Sciences; University of Wisconsin-Green Bay (UW-GB)

*Other Cooperators:* Barbara Bedford, Charles Smith, Cornell University; Jan Ciborowski, University of Windsor, Canada; Jeffrey Johansen, Gerald Sgro, John Carroll University, Ohio; David Mladenoff, Joy Zedler, University of Wisconsin-Madison (UW-M); Eugene Stoermer, University of Michigan;

*US EPA Office of Research and Development (ORD) Cooperators:* Steven Bradbury, Gerald Ankley, John Brazner, Philip Cook, Naomi Detenbeck, John Kelly, Russell Kreis, Mary Moffett, David Mount, Mid-Continent Ecology Division-Duluth (MED), MN and Grosse Ile, Michigan

5. **Project Period** October 1, 2000 to September 30, 2004

**6. Project Cost**

7. **Overall Summary** We propose a comprehensive cooperative agreement with the US EPA ORD to identify, evaluate, and recommend a portfolio of multi-scaled environmental indicators for the entire US Great Lakes basin. The major question to be addressed is “what environmental indicators can be developed to efficiently, economically, and effectively measure and monitor the condition, integrity, and long-term sustainability of the basin?” Our specific objectives include: 1) identification of environmental indicators that will be useful to define the condition, integrity, and change of the ecosystems within the basin, 2) testing these indicators with a rigorous combination of existing data and field data to link stressors of the basin with environmental responses, and 3) recommendation of a suite of hierarchically structured indicators to guide managers toward informed management decisions. The final product will allow managers to communicate with the public on the condition and integrity of the basin, to guide development of monitoring programs to measure change, to identify areas in need of restoration or conservation strategies, and use of key indicators as input for modeling efforts to predict the future condition and integrity of the basin.

Our research plan uses EPA’s ecological risk assessment paradigm as a broad framework to 1) illustrate the development of indicators, 2) test cause and effect between stressors and endpoints to develop diagnostics indicators, and 3) provide essential linkages with several EPA initiatives and programs [e.g. State of the Lakes Ecosystem Conference (SOLEC), Clean Water Act - Sections 305(b), 303(d)]. In this proposal we have formulated the problem (Objective 1) by defining the major human threats to the basin and identified the specific pressure indicators that affect the condition, integrity and change of the basin as measured by the state indicators (responses). The major threats to this system include stressors related to land use (e.g. agriculture, forestry, mining, lakeshore, urban, and other watershed development), climate change (expressed largely through water level fluctuations, tributary discharge, and habitat change), point and non-point source discharges, exotic species, atmospheric deposition, stratospheric/tropospheric ozone effects, and various hydrologic modification (e.g. dredging, breakwaters, harbors, docks). Examples of specific stressors

include chemical (e.g. contaminants, nutrients, salinity), hydrological (water table, stream flow), physical (sedimentation, temperature), habitat alteration (fragmentation, dredging), and biotic (predation, disease, over-harvest) factors.

Coastal ecosystems across the basin vary greatly in their structure and function. Thus, unique state indicators are included that reflect the characteristic condition and integrity of the basin; state indicators are linked with stressors with an ultimate use of monitoring change within these ecosystems as well as being diagnostics of endpoints of societal concern. We identified a suite of state indicators that represent individual, population, community, and landscape-level endpoints, thereby representing the range of spatial and temporal scales necessary to cover the immense area of the Great Lakes basin. They include 1) climate, land use, and landscape characteristics for the entire basin (associated with habitat alteration and physical stressors), 2) water quality contaminant levels, and relative abundance and diversity of amphibian, bird, diatom, fish, macroinvertebrates, and plant communities in estuaries/bays and nearshore coastal waters (linked with all stressors), and 3) amphibian, bird, and plant communities in the land margins (primarily linked with habitat alteration, biotic, and physical stressors).

The analysis phase (Objective 2) consists of using a combination of existing data and field experiments to test cause/effect relationships between pressure and state indicators. These indicators will be developed from a combination of existing data, Great Lakes dynamic models such as the Lake Michigan Mass Balance model, and newly collected data gathered at specific sampling sites. For example, land use, landscape characteristics, and point sources of contaminants can be quantified, to some extent, from existing data sources, while some exotic species or nutrient levels will require field sampling. The abiotic and biotic templates (e.g. substrate, temperature, turbidity, or patch size) of the specific ecosystems sampled will also be characterized by a combination of existing data and field sampling. We will employ a random stratified sampling design to select sample sites using ecological provinces, watersheds and shoreline reaches, and finally ecosystems as the basis for stratification. A total of 10 - 20 % of sites will be preselected. Data analyses will be completed using a variety of statistical and analytical approaches.

The risk characterization phase (Objective 3) will include integration of these data, uncertainty and sensitivity analysis, and ecological significance of the indicators. An important part of this phase is the assessment of redundancy among the indicators, cost effectiveness, environmental relevance, power of an indicator to detect environmental change, and recommendations on how the US Great Lakes basin can be improved in the management of human-induced stressors (e.g. prioritization and integration of Total Maximum Daily Loads-TMDLs). Since indicators are not static, an adaptive system capable of refining and updating the indicators must be in place for the ultimate success of this project and for the ultimate goal of protecting the integrity of the Great Lakes basin. Finally, to insure effective communication and interaction with management agencies, this project is integrated with EPA's-ORD and Minnesota Sea Grant whose mission within the Great Lakes Sea Grant network is to bring University-based research to the *“people of the Great Lakes to maintain and enhance both environmental and economic sustainability.”*

**8. Supplemental keywords:** Great Lakes, monitoring, EMAP, indicators, risk assessment, stressor, ecological effects, integrated assessment, surveys, monitoring, remote sensing, animal, plant, diatoms, toxics, stressor, PAH, scaling

## **D. OVERALL DESCRIPTION**

The major question to be addressed is “what environmental indicators can be developed to efficiently, economically, and effectively measure and monitor the condition, integrity, and long-term sustainability of the US Great Lakes basin?”

### **Objectives:**

- 1) Identify environmental indicators that will be useful to define the condition, integrity, and change of Great Lakes ecosystems at multiple spatial and temporal scales.
- 2) Test the relationships between anthropogenic stressors (pressure indicators) and environmental responses (state indicators) with a rigorous combination of existing data and field data across the Great Lakes basin.
- 3) Recommend to EPA and NASA a suite of hierarchically-structured, environmental indicators to guide managers toward informed management strategies.

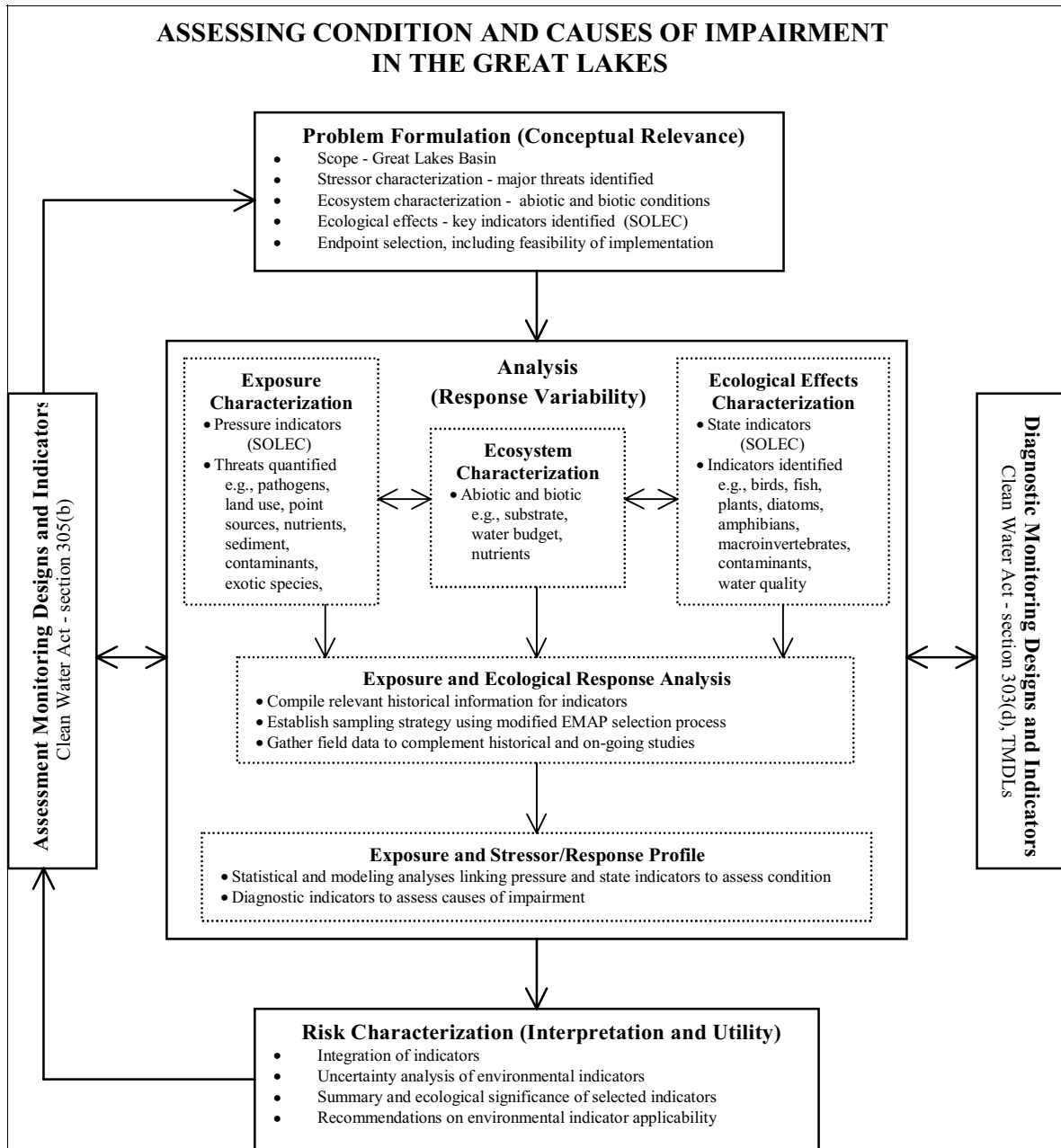
We use the general definitions described in the solicitation for condition, integrity, and sustainability. Briefly, condition refers to the overall health of the basin. Integrity is the degree to which an ecosystem demonstrates a balanced, resilient community of organisms with biological diversity, species composition, structural redundancy, and functional processes comparable to that of natural habitats in the same region. Sustainability refers to the ability of an ecosystem to maintain a defined/desired state of ecological integrity over time.

In the development of our research plan we use EPA’s ecological risk assessment paradigm (EPA 1992, 1996a) (Fig. 1) as a general framework to illustrate the development of these indicators, how the testing of cause and effect will occur, and finally how the problem formulation, analysis phase, and the risk characterization phase of the paradigm links with EPA programs for management of the US Great Lakes basin. The linkage with management issues is essential (Jackson et al. 1999) and results of this study would identify indicators necessary to define current status, extent, and geographic distribution of ecological resources as well as defining causes of adverse effects (<http://www.epa.gov/emap/>). The SOLEC (<http://www.epa.gov/glnpo/solec/88>, Bertram and Stadler-Salt 1999) process has identified a large number of pressure and state indicators for the Great Lakes basin through input from government agencies, non-government groups, universities, and the public. Yet, these indicators have not been thoroughly evaluated or tested. Finally, the Clean Water Act, especially Sections 305(b) and 303(d), includes essential needs for the rational development of environmental indicators. This includes the need for reporting on the condition, integrity, and trends in the nation’s water resources and for identifying waters that do not meet designated uses and require development of total maximum daily loads (TMDLs) for specific pollutants.

Both pressure and state indicators operate at a variety of temporal and spatial scales (Richards and Johnson 1998), so environmental indicators need to be developed in a hierarchical framework (Allen and Starr 1982, O’Neill et al. 1986, Hunsacker and Carpenter 1990, Hunsacker and Levine 1995). Furthermore, in our development of indicators we have considered the broad guidelines provided by EPA (Jackson et al. 1999). In particular we focus on Phase 1-Conceptual Relevance, which includes a) relevance to the assessment (Guideline 1) and b) relevance to ecological function (Guideline 2) and Phase 2-Feasibility of Implementation, which includes five additional guidelines a) data collection methods, b) logistics, c) information management, d) quality assurance, and e) monetary costs. This project will include analysis and development of Phase 3-Response Variability (years 1 to 3 of this study) and Phase 4-Interpretation and Utility (primarily years 2 to 4).

**Problem Formulation.** We chose the entire US Great Lakes basin as the focus of the study

Figure 1. Conceptual model for the development of Great Lakes environmental indicators using the EPA Ecological Risk Assessment framework to link the Environmental Monitoring and Assessment Program (EMAP), selected pressure and state indicators developed as part of the State of the Lakes Ecosystem Conference (SOLEC), and EPA indicator evaluation guidelines (Jackson et al. 1999).



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use the indicators ultimately selected must be applicable to the entire basin. The US Great Lakes basin is a massive area consisting of more than 30 million ha in the watershed, containing 23,000 km<sup>3</sup> of water, and 244,000 km<sup>2</sup> of surface area (18 % of the world's surface freshwater) (EPA and Government of Canada 1995) (Fig.2). The basin is within one of the most industrialized regions of the World, and has about 10 % of the US human population (EPA and Government of Canada 1995), including major US cities such as Chicago, Illinois; Detroit, Michigan; Milwaukee, Wisconsin; Cleveland, Ohio; and Buffalo, New York. The Great Lakes basin has been identified as an area of high significance because of the presence of 131 elements (100

species and 31 communities) that are critically imperiled, imperiled, or rare on a global basis (Nature Conservancy 1994). The basin exhibits a wide range of environmental variation from relatively pristine headwaters to highly perturbed ecosystems near the industrial regions and represents one large, interconnected watershed that ultimately empties into the St. Lawrence River. A substantial body of literature exists on the history and biota of the basin (e.g. <http://biology.usgs.gov/s+t/SNT/noframe/gl127.htm>).

The major threats to the basin include land use and landscape change (Loehle and Li 1996, Robinson et al. 1995, Brazner 1997, Richards and Johnson 1998, Detenbeck et al. 1999) (e.g. agriculture, forestry, mining, and lakeshore, urban, and other watershed development), climate change (expressed largely through water level fluctuations, altered tributary flows, and habitat change; Hartmann 1990, Mortsch and Quinn 1996, Pastor et al. 1996, Lee et al. 1997, Magnuson et al. 1997, Kunkel et al. 1998, Mortsch 1998, Schindler 1998), point and non-point source pollution (Nature Conservancy 1994, Johnson et al. 1997), exotic species (Griffiths 1993, Brazner et al. 1998, Brazner and Jensen 1999), atmospheric deposition (Vitousek et al. 1997, Nichols et al. 1999), stratospheric ozone depletion (Ankley et al. 1998a, Schindler et al. 1996, Schindler 1998), and various hydrological modifications (e.g. dredging, breakwaters, harbors, docks).

These threats affect the ecological conditions of the Great Lakes basin in a variety of ways and, hence, we first linked human activities with specific pressure indicators (Table 1). Pressure indicators are stressors that actually cause change in ecological characteristics, yet they may arise from a variety of human activities. For example, land use change is a multi-faceted and complex problem that arises from agriculture, mining, silviculture, and other forms of human development. Land use results in changes to habitat (e.g. conversion from forest to agriculture) and landscape fragmentation (e.g. reduction in patch size of forests). Land use change can also result in increased hydraulic, sediment and nutrient loads to receiving water bodies, causing stress to biological, chemical, and physical systems downstream (Richards et al. 1996). Hence, we define human activities as the threats, but the specific pressure indicators include land use change, habitat fragmentation, sediment, and nutrients. These pressure indicators are further classified into habitat alterations, chemical, biotic processes, physical, and hydrological disturbances (Table 1) (Nature Conservancy 1994).

The state indicators are the specific ecological responses to the stressors (pressure indicators) that arise from threats. Land use change (e.g. wetland loss) results in shifts in the community composition of plants and animals (state indicators). Changes in flow, sediment, or nutrient loads of water result in shifts of macroinvertebrate and fish communities. We have identified the pressure indicators and have linked them with state indicators (Table 2). Our approach includes some redundancy in measurements of state indicators such as wetland plants, amphibians, and birds within wetland systems or diatoms, benthos, and fish within open water, but we believe it is essential to measure multiple communities within these systems “to develop

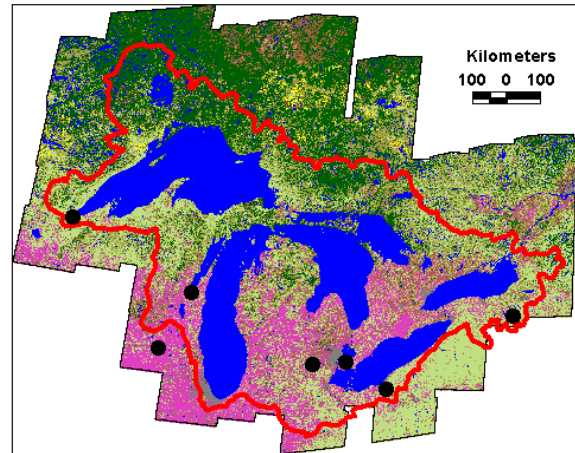


Fig. 2. Great Lakes watershed (red boundary) with four major habitat types (water-blue; agriculture-red; deciduous forest (lt green); and coniferous forest (dark green)) and locations (●) of study participants.

**Table 1. Human activities associated with individual stressors and examples of pressure indicators that will be quantified as part of this study.**

Agriculture	Energy	Mining	Recreation	Silviculture	Transportation	Urbanization	Stressor	Examples of pressure indicators
							<b>Habitat alterations</b>	
X			X	X	X	X	Fragmentation	land use/land cover area, patch density, edge density
					X	X	Dredging/filling	bathymetric surveys: US Army Corps databases
X		X	X	X	X	X	Erosion	land use/land cover, nonpoint sources
					X		Land conversion	change in land use over time
							<b>Chemical Disturbance</b>	
X		X	X		X	X	Contaminants	pesticide use lbs/acre, industrial point: non-point sources
X	X		X	X		X	Nutrients	N, P, TN, TP pathogens (NRCS National Inventory)
					X	X	Salinity (TDS)	measurements of specific electrical conductivity (e.g. EC25)
X			X	X	X	X	Sediments (TSS)	sediment delivered to streams by county (NRCS Natl. Resource Inventory)
X	X	X			X		Atmospheric	hydrogen, N, SO <sub>4</sub> , Hg deposition - kg/ha (national isopleth maps)
							<b>Biotic Processes</b>	
			X		X		Exotic species	distribution and abundance of nonindigenous plants or animals
X				X		X	Predation/grazing	food web disruption
			X	X			Over-harvest	fish and waterfowl population trends
							<b>Physical Processes</b>	
X		X	X	X	X	X	Sedimentation	sediment loads
X	X	X	X	X		X	Temperature	existing data and field data, climate models
							<b>Hydrologic Disturbance</b>	
					X		Hydrologic Alteration	impoundments, # dams on tribs, # groins
X				X	X	X	Stream flow	stream gauges
X	X		X	X		X	Water Table	lake levels

*indicators that would be most efficient, economical, and effective to measure and monitor the condition, integrity, and long-term sustainability of the US Great Lakes basin.*” Moreover, analyses of these diverse communities are necessary to tease apart the complexity of the interactions between pressure and state indicators.

The state indicators identified consist of a suite of population, community, and landscape-level endpoints that represent a range of spatial and temporal scales. They include 1) climate, land use, and landscape characteristics for the entire basin that are linked with habitat alteration and physical environmental stressors, 2) water quality and contaminant levels as well as relative abundance and diversity of amphibian, bird, diatom, fish, macroinvertebrates, and plant communities in estuaries/bays and nearshore coastal waters, which at varying levels are linked with all stressors, and 3) amphibian, bird, and plant communities in the land margins primarily linked with habitat alteration, biotic, and physical stressors.

### **Approach:**

**Analysis Phase.** This omnibus proposal includes the overall framework that links the threats, pressure indicators, and state indicators for the ecosystems of the Great Lakes basin. These indicators are divided into the following components, each represented with supporting subproposals: 1) birds and amphibians, 2) contaminants, 3) diatoms and water quality, 4) fish and macroinvertebrates, and 5) wetlands. We emphasize that these proposals are linked with broad overlap to insure coordination, integration, efficiency, and cost-effectiveness. This main proposal also includes descriptions and essential components common among the supporting proposals including: 3) field sampling design, 3) data gathering and management coordination, and 1) land use and landscape characterization. We have also requested funding for a separate remote sensing component that will advance our knowledge of water level fluctuations and habitat types in both coastal areas and throughout the Great Lakes watershed.

In general, our research timeline will be as follows. Year 1) Compilation of existing data for the selected indicators and conducting a pilot study to test methodologies, calculate variability, power to detect change, and cost-effectiveness to measure each indicator. Select areas for intensive sampling in future years. Years 2 and 3) Complete intensive sampling of sites to test hypotheses of linkages between pressure and state indicators. Years 3 and 4) Reexamine variability, power to detect change, uncertainty, and cost-effectiveness to measure each indicator. Conduct analyses of hypotheses relating pressure and state indicators. Recommend useful indicators and monitoring designs to EPA and NASA.

The ecological risk assessment process (Fig. 1) includes exposure characterization in which the “pressure indicators” of the Great Lakes are quantified. These pressure indicators must then be tested regarding their cause and effect relationship with the state indicators (ecological characterization). The hypothesized relationships among pressure and state indicators for each of the components of the study are described below and in more detail within each subproposal.

Ecosystem characterization of the abiotic and biotic environments is an extremely important phase of characterizing the template of the specific ecosystems to be sampled. The major components of this phase include: 1) landscape characterization, 2) water quality, and 3) physico-chemical characterization including quantification of attributes such as water budgets, flow regime, wave energy, geomorphology, bathymetry, substrate, surface/ground water discharge, sediment/nutrients levels, temperature, dissolved oxygen, and water clarity. These are important variables for providing the appropriate context for interpretations of exposure as well as ecological effects. In addition, sediment traps will be installed to measure within-wetland sedimentation rates (Gardner 1980, Fennessy et al. 1994, Johnston et al. *in press*). The remote sensing component included in this proposal will also provide state-of-the-art information on the habitat template of the study areas selected as will climate information that has already been

Table 2. Examples of state indicators to be measured or taken from existing databases for each of the five major study components with pressure indicators of the Great Lakes. ‘Community’ response refers to a variety of metrics including distribution, abundance, guild structure, diversity, richness, biomass, and derived indices such as the index of biotic integrity (IBI) modified from Karr (1981), Fausch et al. (1990), US EPA (1997), and Jackson et al. (1999).

Pressure Indicators	Birds Amphibians	Contaminant Responses	Diatoms Water Quality	Fish Macroinvertebrate	Wetlands
Habitat alteration					
Fragmentation	Community			Community	Plant community
Dredging/filling				Community	Wetland area
Erosion			Diatom community	Community	Plant community
Land conversion	Community		Water quality		Wetland area
<b>Chemical Disturbance</b>					
Contaminants – PAHs/UV-B – endocrine disruptors		Fish Benthic organisms		Community Toxicity	
Nutrients			Diatom community	Community	Plant community
Salinity (TDS)			Diatom community	Community	Plant community
TSS			Diatom community	Community	
Atmospheric	Community		Diatom community	Community	
<b>Biotic Processes</b>					
Exotic species	Community		Diatom community	% native spp	Plant community
Predation/grazing				Food web structure	Plant community
Over-harvest				Rel. abundance game fish/age structure	
<b>Physical Processes</b>					
Sedimentation			Diatom community	Community	Plant community
Temperature	Community			Community	
<b>Hydrologic Disturbance</b>					
Hydrologic Alteration				Community	Plant community
Stream Flow				Community	
Water Table	Community IBI				Plant

generated for the entire watershed (see <http://www.nrri.umn.edu/cwe>).

Land use and landscape change has been one of the most important threats to biological diversity across the basin (SOLEC) and the nation (NRC 1999). The land cover of the basin is dominated by agriculture and forests (Detenbeck et al. 1999) (Fig. 2). There have been tremendous changes in the land use and landscapes of the basin over the past 150 years (Stearns and Gundenspergen 1987). Hence, it is extremely important to incorporate both land use and landscapes as both pressure indicators that affect change in a variety of biota and as state indicators, so that mechanisms for quantifying change in condition or integrity are included as indicators. In addition, change in the land use in the watershed has effects on downstream systems such as coastal ecosystems (Johnston et al. 1990, Richards et al 1993, 1996, Johnson et al. 1997).

Many spatial data bases for the Great Lakes basin are already available at NRRI (Table 3). For example, full coverage of the Great Lakes watershed is available [e.g. Multi-Land Resolution Classification (MLRC), see <http://www.nrri.umn.edu/cwe>] and will be used to map land use and land cover (LU/LC) for the basin and calculate landscape parameters. The classification system used for this imagery was developed by a consortium of government agencies for use in programs such as Gap Analysis Program, EMAP, and National Water Quality Assessment Program. In addition, digital orthophotographs, recent aerial photography (where available), and

Table 3. Spatial data to be used to characterize landscapes in the Great Lakes basin. NRRI- indicates data are in place at the Natural Resources Research Institute; acquire - indicates data to be acquired from existing sources. USFWS = US Fish and Wildlife Service, USGS = US Geological Survey (<http://www.nrri.umn.edu/cwe>).

Data Set	Source	Status
Elevation	USGS digital elevation model	NRRI
Land use / Land cover (regional scale)	Landsat TM (classified from 1994,1995 images );	NRRI
Land use / Land cover (local scale)	orthophotographs, aerial photography	acquire
Hydrography	USGS, digital line graph	NRRI
Population Density	U.S. Census Bureau, Tiger	NRRI
Roads	USGS, digital line graph	NRRI
Soils - generalized	Soil Conservation Service- STATSGO	NRRI
Soils- series	County soil surveys	NRRI (most counties); acquire missing
Station Location	GPS readings; field notes; USGS topo	acquire
Quaternary Geology	MN Geol. Surv.; Hobbs and Goebel 1982;	NRRI
Wetlands	USFWS National Wetland Inventory, WI Wetland Inventory	NRRI
Reach Files	USE EPA	NRRI
Great Lakes Climate	Ontario Ministry of Natural Resources	NRRI
Great Lakes Watersheds	Canada Land Inventory, Level 1 and USGS	NRRI
Landcover 30m	MRLC 1992 Landsat TM	NRRI
Landcover 200m	Resampled MSS 1985	NRRI
Great Lakes BBS Research Ctr	Patuxent Wildlife	NRRI
Great Lakes Bathymetry	NOAA	Aquire

field data will be used to develop higher resolution spatial data sets for each sampling location. Although these data are currently available, we have included an additional request for a remote sensing component that would increase the resolution of satellite imagery for the whole watershed to the level shown by Wolter et al. (1995) as well as improved high resolution classification for the coastal regions, and aerial videography. To the extent possible we will also assess the utility of other remote sensing studies that are attempting to characterize near-shore

water quality (TSS, DOM, chlorophyll) via satellite imagery (e.g. <http://www.glerl.noaa.gov/eegle>).

We will use established spatial metrics and descriptors to quantify landscape structure within each watershed. FRAGSTATS (McGarigal and Marks 1994) and APACK (Boeder et al. 1993) statistical software will be used to compute these landscape descriptors. These programs have been used with success to quantify landscape structure in Saginaw Bay watersheds in Michigan (Johnson et al. in progress), Wisconsin (Crow et al. 1999), northern Lake States (Host et al. 1996), and basin as a whole (Niemi et al. 1998a). These metrics will be used to quantify fragmentation patterns, and other aspects of landscape structure as they relate to coastal ecosystem conditions and community structure. Example landscape variables that will be calculated from LU/LC include patch size, patch density (a measure of fragmentation), edge length, edge contrast, interspersion, contagion, lacunarity, population density, and road density (Forman and Godron 1986, O'Neill et al. 1988, Host et al. 1996, Mladenoff et al. 1997, O'Neill et al. 1997).

Landscape fragmentation (e.g. habitat loss, altered habitat structure, microclimate changes, and disruption of dispersal corridors) has been associated with decreased fitness and a decreased probability of habitat occupancy by amphibians (Vitt et al. 1990, Blaustein et al. 1994, Vos and Stumpel 1995), birds (Robinson et al. 1995, Fenske-Crawford and Niemi 1997), and fish (Detenbeck et al. 1992, Brazner 1997, Brazner and Beals 1997). For example, recolonization of sites following local extinctions often relies on the "rescue effect" provided by nearby, occupied habitat patches (Gibbs 1993). Increased fragmentation and isolation of suitable habitat patches may decrease between-site migration rates to the point that species are unable to recolonize more isolated sites following local extinctions, resulting in extinction of metapopulations (Blaustein et al. 1994).

**Birds and Amphibians** (*Subproposal - "Development and Assessment of Environmental Indicators Based on Birds and Amphibians of the Great Lakes Basin"*). Breeding bird diversity, including neotropical migrants, in the US and Canada is highest in areas surrounding the Great Lakes (Robbins et al. 1986, p.126). Breeding birds are among the most well-studied organisms across the basin and their life histories are directly related to both aquatic and land cover types (habitats) and landscape characteristics (Freemark and Merriam 1986, Van Horne and Wiens 1991, Hawrot and Niemi 1996, Howe et al. 1997, Niemi et al. 1998b). For example, landscape changes in habitat patch sizes have direct and measurable effects on the relative abundance of breeding birds (Temple and Cary 1988, Robbins et al. 1989), while land use conversions such as residential development or wetland loss also result in direct and measurable changes to breeding bird communities (Dettmers and Bart 1999). As described in the subproposal, there are at least six extensive data bases on breeding birds and amphibians that already exist throughout the basin. These data are emerging as invaluable for the development of large-scale, predictive models on the distribution and abundance of birds within the basin (Venier et al. 1999, ms.) and can be used for the development of regional indices of integrity (Brooks et al. 1998).

Amphibians are of growing worldwide concern, and there is a large and growing network of volunteer-based sampling sites across the basin (North American Amphibian Monitoring Program). Because of their life history at the interface of both aquatic and terrestrial systems they are ideally suited as indicators of land use and landscape change (Demaynadier and Hunter 1998, Gibbs 1998). An extensive literature has documented the sensitivity of amphibian species to water quality, including negative effects of acidification (Clark 1986, Kutka and Bachmann 1990), pesticides (Johnson 1980), and other pollutants (Manson and O'Flaherty 1978). Amphibians are also being increasingly used to examine UV-B radiation (Long et al. 1995, Ankley et al. 1998a).

We will develop amphibians and birds as state indicators in estuaries/bays, nearshore coastal waters, and land margins to measure response to habitat, biotic (exotic species), chemical, physical, and hydrological disturbances (Croonquist and Brooks 1991, Brooks et al. 1998). A

variety of community (e.g. indices of biotic integrity, Karr 1981, O'Connell et al. 1998) and multivariate based indices (Bradford et al. 1998) of the breeding bird and amphibian biota will be linked with local and large-scale responses to disturbances.

**Contaminants** (*Subproposal - Development and Evaluation of Chemical Indicators for Monitoring Ecological Risk*). In contrast with other components that primarily focus on the response of state indicators to stressors, contaminants are pressure indicators in themselves. However, they justify consideration as a special component because of their importance and magnitude of problems that exist in the Great Lakes basin. The presence of organic chemical contaminants and heavy metals in the Great Lakes ecosystem has presented significant stress to benthic invertebrates (Canfield et al. 1996), fish communities and populations (Cook et al. 1997), colonial nesting birds (Kubiak et al. 1989), reptilian populations (Patnode et al. 1998), fish-eating mammals (Aulerich et al. 1986), and humans consuming large quantities of contaminated sport fish (Jacobson and Jacobson 1993). Contaminant classes include organochlorine chemicals, volatile organic compounds, combustion products, agricultural chemicals, and surfactants. Of the more than 1000 chemicals present in Great Lakes water, particular concern has been focused on those chemicals that are persistent, toxic, and bioaccumulate in the aquatic foodweb. Exposures to contaminants that bioaccumulate are greatly increased and pose a great risk to higher trophic levels of the foodweb. SOLEC has recommended that the exchange of contaminants between media (e.g. atmospheric deposition) and the concentrations of contaminants in water, sediments, and indicator species of fish, bird eggs, turtles, and mammals be included as indicators in the open waters, nearshore regions, and coastal wetlands of the Great Lakes. Most of these indicators have been implemented by federal or state/provincial monitoring programs so they will not be considered in detail here.

We propose to test two specific hypotheses regarding contaminants: 1) polycyclic aromatic hydrocarbons (PAHs) in combination with UV penetration are indicators of potential loss of vulnerable species within coastal fish and benthic communities (Malins et al. 1984, Ankley et al. 1994, Erickson et al. 1999) and 2) specific chemicals are indicators of endocrine disruption in fish via the estrogen receptor (Aulerich et al. 1986, Colborn et al. 1996, Ankley et al. 1998b). These indicators were selected because of current concerns raised about PAHs and emerging concern with contaminants related with endocrine disruption in biological communities. PAHs are carcinogenic (Baek et al. 1991) and acutely toxic to aquatic organisms (Newstad and Giesy 1987). The toxicity of PAHs to aquatic organisms is attributed to photoexcitation of the PAH molecule within the organism (Newstad and Giesy 1987) and toxicity is enhanced by several orders of magnitude (Erickson et al. 1999). A primary impact of the exposures to endocrine disrupting chemicals (EDCs) is reproductive impairment such as sex differentiation, sexual development and sexual dimorphism or reversal (Ankley and Giesy 1998). Vitellogenin expression in males or in juveniles has become a fairly consistent assay for estrogenic compounds (e.g., Folmar et al. 1996). For both indicators (PAHs and EDCs), we will compare contaminant concentrations across a gradient of non-degraded to highly degraded sites. We will measure and compare concentrations of both photoactive toxic and non-photoactive toxic PAHs in sediments, fish, and fish larvae across the gradient. Vitellogenin induction in male fish will also be measured and compared in fish tissue, sediment and/or water across the gradient of sites.

**Diatoms and Water Quality** (*Subproposal-Great Lakes Diatom and Water Quality Indicators*). Diatom community responses are closely linked to water quality related issues, especially chemical disturbances from nutrients, salinity, sediments, and acidification (e.g. NRCS National Resource Inventory, Fritz et al. 1993, Dixit et al. 1999). Although SOLEC has designated phytoplankton as an important state indicator only for open and nearshore waters, many significant EPA assessment programs such as the National Acid Precipitation Assessment Program (NAPAP) (Kingston et al. 1988; Sullivan 1990), EMAP-SW (Dixit and Smol, 1994; Dixit et al. 1999), EMAP-GL (Stoermer and Andresen 1995), and wetlands monitoring

(Stevenson 2000, *in press*) have used diatom periphyton, sedimented diatom phytoplankton, and phytobenthos as the indicators to interpret state or condition. The Lake Michigan Mass Balance model is another major EPA effort that has increasingly used diatoms as a major coastal zone component of this time and space resolution model (EPA 1994). Data generated in this project can be entered into the Mass Balance model or used for post-audit validation. Periphyton diatoms have also been widely and successfully used in major stream assessment programs (Lowe and Pan 1996; Sgro and Johansen 1995; Stevenson and Pan 1999) and in Great Lakes estuaries (Sgro and Johansen 1998; Sgro and Johansen, *in review*). Diatom algae are abundant and diverse in all Great Lakes aquatic systems including wetlands, and they are known to integrate stressor information with great fidelity. We propose using diatom periphyton, sedimented phytoplankton, and phytobenthos to develop and refine state indicators to measure the ecological responses to nutrient loading and soil erosion stressors. We will use structural characteristics (species composition, species environmental optima, autecological indices) because of their known efficiency (Lange-Bertalot 1979; Stevenson and Pan 1999). For example, condition of Lake Erie estuaries can be effectively assessed using the Erie Diatom Index (Sgro and Johansen 1998; Sgro and Johansen *in review*) and strong diatom-based calibrations and reconstructions exist for nutrients (Fritz et al. 1993; Reavie et al. 1995), salinity loading and water transparency (Dixit and Smol, 1994; Dixit et al. 1999). We will use shallow- and deepwater periphyton assemblages in the nearshore waters of the Great Lakes to provide comparative state indicators throughout the basin (Kingston et al. 1983; Stoermer 1975).

We have not proposed specific indicators for water quality (WQ) such as phytoplankton community structure, chlorophyll-a, measures of clarity, trophic state indices, or for specific nutrients such as nitrogen, phosphorus, or for pathogenic microbes for several reasons. We are proposing to measure many of these variables and even create some of these indices, but mainly as measurements of stress or as environmental gradients for diatoms. Because of the enormous scale of the Great Lakes basin, coupled with the extreme temporal (seasonal, diel, event-based) and spatial variability of these WQ parameters due to the flashy nature of the nearshore zone in response to storm events, makes a cost-effective sampling with adequate explanatory power impossible. Also, numerous assessments of the suitability of suites of WQ indicators have previously been developed for marine and fresh coastal waters including the Great Lakes basin (Paulsen et al. 1991, Hedtko et al. 1992, Klemm et al. 1993, Chaillou et al. 1996, EPA 1996b, SOLEC, Simon and Stewart 1998). These have been nearly uniformly accepted by federal and state resource and regulatory agencies; further a variety of WQ monitoring programs already exist, some conducted by volunteers, and are accepted for the same purposes as are driving this research effort. Nevertheless, we will need contemporaneous water quality data for several of the component studies, most importantly the diatom indices, and to ensure that we can characterize WQ and overall ecological condition at each of the sites.

**Fish and Macroinvertebrates** (*Subproposal-Testing Indicators of Coastal Ecosystem Integrity Using Fish and Macroinvertebrates*). These two biota have been used extensively as state indicators in streams and rivers (Plafkin et al. 1989, Barbour et al. 1995, Karr and Chu 1997), and are being developed for wetlands (Minns et al. 1994) and lakes (O'Connor et al. 2000). Macroinvertebrate communities in near shore areas of the Great Lakes have been shown to respond to sediment characteristics (Mozley and Garcia 1972, Barton and Hynes 1978, Cole and Weigman 1983, Johnson et al. 1987), eutrophication (Cook and Johnson 1974, McLaughlin and Harris 1990, Schloesser et al. 1995, Nalepa, et al. 1998, King and Brazner 1999), macrophyte community structure (McLaughlin and Harris 1990, Cardinale et al. 1998), contaminants (Wildhaber and Schmitt 1996), and exotic species such as the zebra mussel (Dermott et al. 1993, Griffiths 1993, Stewart and Hayes 1994, Thayer et al. 1997). Although less is known about coastal Great Lakes fish communities, they have been shown to respond to eutrophication, macrophyte community structure, and shoreline development (Jude and Pappas 1992, Brazner and Beals 1997, Wilcox, et al. 1999). In inland lake habitats, fish communities have similarly

responded to eutrophication (Schindler et al. 1971, Persson et al. 1991), as well as heavy metals (Somers and Harvey 1984) and acid deposition (Schindler et al. 1985, Tremblay and Richard 1993). Although numerous species of fish inhabit the coastal waters of the Great Lakes and feed on invertebrates (Duffey and Batterson 1987, French 1988) little is known about the interaction between these two groups (Gathman et al. 1999). There is concern that several recently introduced benthivorous fish may cause changes in the macroinvertebrate community. Eurasian ruffe may potentially cause declines in the abundance and biomass of several macroinvertebrate groups and may indirectly affect phytoplankton production and nutrient cycling (Peterson et al. 1999, Schuldt et al. *in prep*). Other disturbances, such as habitat alteration from recreational activities (e.g. boating, docks), and development, can potentially modify macrophyte communities which will have a direct impact on invertebrate and fish community structure and productivity. The concurrent examination of macroinvertebrates and fish, along with macrophytes (see wetlands), will be valuable because these communities respond to stressors at different time scales and integrate ecosystem-level responses such as primary and secondary production, nutrient cycling, and predator prey relationships.

**Wetlands** (*Subproposal-Vegetative Indicators of Condition, Integrity, and Sustainability of Great Lakes Coastal Wetlands*). These ecosystems are among the most severely impacted within the Great Lakes. Wetland plants form the underpinnings of the habitat structure while also influencing water quality. Birds, amphibians, fish, macroinvertebrates, algae, and bacteria utilize plant material for food and structural habitat. Particulate and dissolved organic matter released by macrophytes forms an important component of the trophic structure within wetlands. The composition and distribution of the macrophyte community in coastal regions is closely linked to water levels; therefore, this community is especially sensitive to hydrologic alterations due to climate change, geomorphic alterations (dredging and filling), and water diversion (Keough et al. 1999, Detenbeck et al. 1999). In coastal regions, the vegetated zone behaves as an effective filter, trapping sediments, organic matter, nutrients, and contaminants. Four wetland plant indicators proposed by SOLEC (Bertram and Stadler-Salt 1999) will be tested: coastal wetland area by type; gain in restored coastal wetland area by type; presence, absence, and expansion of invasive plants; and habitat adjacent to coastal wetlands. In particular, distribution and abundance of exotic species such as purple loosestrife (*Lythrum salicaria*), reed canary grass (*Phalaris arundinacea*), and giant reed grass (*Phragmites communis*) (Apfelbaum and Sams 1987, Cross and Fleming 1989, Haslam 1971, Helling and Gallagher 1992, Rawinski 1982, Stuckey 1980, Thompson et al. 1987, Wilcox 1989) are important pressure indicators of the Great Lakes. Distribution will be assessed and responses of other wetland plants measured. Three other indicators defined by SOLEC (coastal wetland area by type, gain in restored wetland area by type, and habitat adjacent to coastal wetlands) will be assessed using remote sensing and existing GIS data, supplemented by ground checking (Johnston 1984; Johnston et al. 1988a,b; Sersland et al. 1995, Williams and Lyon 1991). These data will be analyzed to assess species composition of plants and, especially the presence of species with narrow environmental tolerances (Reed 1988, Maynard and Wilcox 1997). Although we will use existing data to the extent possible and supplemented with available aerial photograph, funding of the remote sensing proposal will greatly improve the data resolution with low-level aerial imagery. This would be especially be useful to map dominant and invasive plant species.

**Study Site Selection.** In general, both pressure and state indicators will be quantified using existing data sources and through the field sample design. Efforts among the various study components will be coordinated with other on-going efforts in the basin and among the proposed study components to minimize sampling costs.

We will employ a random stratified sampling design to select sample sites using ecological provinces, watersheds and shoreline reaches, and finally ecosystems as the basis for stratification. This strategy will allow broad sampling of the entire Great Lakes basin, allow representative

areas to be sampled that may be missed by a purely random design, and will be useful for input to important government programs of relevance to the Great Lakes (e.g. Sections 303(d), and 305(b) of the Clean Water Act). Selection of specific study areas will be developed during the first year and field sampling will be completed during years 2 and 3. The first level of stratification will be based on ecological provinces of the US Great Lakes basin (Keys and Carpenter 1995). These ecological provinces represent 100 % of the watershed and cover each of the Great Lakes. They include the following ecological provinces: 1) 221 - Eastern Broadleaf Forest (Oceanic) Province, 2) 222 - Eastern Broadleaf (Continental) Province, and 3) 212 - Laurentian Mixed Forest Province. These ecological provinces represent a broad gradient of land use, climatic conditions, anthropogenic disturbances, human density, and water quality (EPA and Government of Canada 1995).

The second level of stratification will be defined on the basis of watersheds and shoreline reaches (NOAA 1997). There are **113** watersheds and **437** shoreline reaches within the basin. Watersheds represent functional landscape units that allow for the analysis and integration of land use, land/water interactions, and effects on both land and aquatic systems relevant to the scales of pressure and state indicators. Watersheds are also a functional management unit (Johnston et al. 1990, Hunsacker et al. 1992, Detenbeck et al. 1990, 1993, Richards et al. 1996, Johnson and Gage 1997). For example, watersheds are increasingly becoming the basis for management of anthropogenic stress (e.g. TMDLs, Section 303(d)). However, if watersheds were the only stratification used within ecological provinces, then important near coastal lands and waters may be excluded. Hence, at this second level of stratification, we will also include reaches (NOAA 1997) for the US Great Lakes shoreline areas.

The third level of stratification includes selecting study areas on the basis of ecosystems within the watersheds and reaches. Each subproposal describes important ecosystems for their respective components of the study. Important coastal regions of the Great Lakes basin include (based on the solicitation, also Minc and Albert 1998, Keough et al. 1999, Detenbeck et al. 1999, SOLEC): 1) estuaries and bays (defined as high water mark and landward to first riffle of incoming lotic system), 2) near coastal waters - (defined as non-estuarine/bay areas from high water mark to depth of water where summer thermocline meets bottom), and 3) land margins - (defined from high water mark to 1 km inland). Hence, our sampling will focus on these three coastal regions and their associated ecosystems. We will also assess LU/LC, landscape characteristics, and climate for the entire US Great Lakes watershed because a) these data are readily available, b) we have already calculated a wide variety of land use and landscape characteristics for the watershed, and c) watershed characteristics are important stressors as well as explanatory variables for the endpoints of concern. Major ecosystems include agricultural, forest, water, wetlands, and urban/residential. Among the criteria to be included in this stratification include gradients of disturbance, proportions of ecosystems within watersheds and reaches, and data availability.

The final phase of study site selection includes the selection of individual study sites within these ecosystems, watersheds/reaches, and ecological provinces. A similar process has been applied in other areas (e.g. South Florida, EPA 1998; Savannah River basin, EPA 1999). The basic concept, called a random tessellation stratified (RTS) design, will be utilized to randomly locate specific study sites within ecosystems (Bellhouse 1977, Overton and Stehman 1993, Stevens 1997). Specific sampling points selected at random may also need to consider logistics in the event that randomly selected points are inaccessible or have other problems (e.g. landowner permission denied). This sampling design will result in a framework that will vary depending on the variability of the specific indicator, effort required, and monetary restrictions of various components of the study. The range of actual sampling sites can be summarized as follows: 1) three ecological provinces, 2) 2-10 replicates each for watersheds and reaches within each ecological province depending on the indicators of interest, and 3) a range of sample sites within each ecosystem which will depend on the indicator of interest and the pilot study planned for year 1. Hence, the number of sites to be sampled will be imbedded in a hierarchical framework;

some indicators will be available for the entire basin (land use and landscape characteristics), some for a majority of the ecosystems (e.g. breeding bird), and others for specific ecosystems (e.g. diatoms).

Finally, a purely stratified, random sample may not include all aspects of stressor regimes, ecosystems of concern, or a myriad of other factors that should be considered in a sampling framework. We will reserve 10-20 % of sampling sites for targeted sampling to insure that the broad range of pressure and state indicators within ecosystems of the Great Lakes basin will be sampled. These sites will be selected from such information as “list frames” of wetlands (Hedtke et al. 1992), reach files (NOAA 1997), and other information (e.g., Minc 1998).

**Pilot Study.** During year 1 we will conduct a pilot study to gain a more thorough understanding of the indicator response variability (e.g. Phase 3 of Jackson et al. 1999, EPA 1996c). Sources of variability that need to be considered include a) estimation of measurement error (e.g. errors associated with collecting, transporting, or equipment), b) temporal variability - within field season due to daily, weekly, or monthly variation in data collection, c) temporal variability - across years, d) spatial variability, and e) discriminatory ability (Jackson et al. 1999). Obviously among-year temporal variability cannot be considered during a one year pilot study, but we will use historical data and data gathered during subsequent years to assess this issue. These data will then be evaluated prior to study site selection for the major sampling during years 2 and 3.

**Risk Characterization.** This phase encompasses data quality objectives (uncertainty and sensitivity analyses), assessment thresholds, and linkage to management action (Jackson et al. 1999), but also includes integration of these data among indicator components and general interpretation of ecological or societal significance of the indicators. An important part of this phase is the assessment of redundancy among the indicators, cost effectiveness, environmental relevance, power of an indicator to detect environmental change, and recommendations on how the Great Lakes basin can best be improved by management of human-induced stressors. This phase requires clear recommendations for the establishment of basin-wide monitoring programs, SOLEC for review of environmental indicators, reporting requirements of the Section 305(b), and information for determination of the success of TMDLs as required by Section 303(d) (fig. 1). Finally, indicators are not static and so an adaptive system capable of refining and updating the indicators must be in place for the ultimate success of this project and for the ultimate goal of protecting the integrity of the Great Lakes basin.

**Expected Results and Benefits:** The final product will allow managers to communicate with the public on the condition and integrity of the Great Lakes, to guide development of monitoring programs, to identify areas in need of restoration or conservation strategies, and to provide input on key indicators that are or will be incorporated into modeling efforts (e.g. Lake Michigan Mass Balance model) to predict the future condition, integrity, and sustainability of the Great Lakes basin.

**Management Connection.** Effective indicators must have the ability to be used and translated into understandable management strategies and goals (Jackson et al. 1999). As an example of this need we have included a letter from the Minnesota Pollution Control Agency as an attachment. The letter indicates that a major limitation in achieving the goal of protecting and restoring water resources on a watershed basis (e.g., TMDLs) is the lack of consistent, affordable, effective indicators of system health. The Great Lakes are managed by a complex interwoven network of federal, state and province, local, municipal, and watershed-based entities. Effective, cooperative management strategies require that all stakeholder groups, including regulatory agencies, elected bodies, nonprofit organizations, educational institutions, businesses and industries, and citizen groups accept and understand the validity of the chosen indicators as accurately representing the state of the Great Lakes basin.

We will engage the existing seven state Sea Grant programs involved in the Great Lakes Sea Grant Network to provide links between the research community and the multi-level management community. The mission of Sea Grant (NOAA) is to bring University-based research to the “people of the Great Lakes to maintain and enhance both environmental and economic sustainability.” Because Sea Grant is strategically represented across the basin, it is mandated and positioned to transfer information from university research to government organizations and to the public. Sea Grant is the only federal government program that works with most of these entities. Dr. Carl Richards, Director of Minnesota Sea Grant, is a co-investigator on this project and will facilitate this interaction. In addition, EPA’s MED is a major cooperater on this project. This group also has a mandate for research on the Great Lakes, but also strong working relationships with the regulatory community of the Great Lakes.

**Management Plan and Milestones:** The project will be organized into a number of teams that correspond to the major elements and indicators of the study, but interaction and input among the teams will be essential for the success of the project and this will be facilitated. The overall management of this project is the responsibility of the PI, Niemi. The Co-Investigators, Axler, Hanowski, Howe, Host, Johnson, Johnston, Kingston, Regal, Richards, and Swackhamer, will be closely associated with all aspects of the project. This group will meet on a monthly basis or as needed to insure continued progress and communication on the project. In addition, each of the subproposals have various cooperators that have actively participated in the development of this project. They include the University of Wisconsin at Green Bay and Madison; Cornell University; University of Windsor, Canada; John Carroll University, Ohio; and the University of Michigan, (fig.2). At EPA-MED, the Director, Bradbury, will be the primary contact for coordination with PI Niemi. In addition, a variety of additional scientists at MED are associated with this omnibus proposal and with subproposals in which they have expertise. These individuals have all had a number of past and current projects dealing with the Great Lakes and other systems (see resumes attached).

The teams are described in detail within each subproposal, but are summarized here:

- 1) Overall Management and Coordination - Niemi (25 % time @ 12 months) and Bradbury;
- 2) Experimental Design, Statistical Analysis - Niemi (10 % @ 12 months), Regal, Host, Detenbeck;
- 3) Landscape Characterization, Remote Sensing, and GIS - Niemi (5 % @ 12 mos), Johnston, Johnson, Mladenoff, Wolter, Bolgrein, Detenbeck;
- 4) Birds and Amphibians - Howe, Hanowski, Niemi (10 % @ 12 mos), Smith,
- 5) Contaminants - Swackhamer, Simcik, Ankley, Burkhard, Cook, Diamond, Erickson, Mount;
- 6) Diatoms and Water Quality - Kingston, Axler, Johansen, Sgro, Stoermer, Kreis, Thompson;
- 7) Fish and Macroinvertebrates - Johnson, Richards, Brazner, Detenbeck, Kelly, Moffett;
- 8) Wetlands - Johnston, Bedford, Zedler, Kelly, Moffett.

A Senior Advisory Group has been established that will meet once a year to provide critical review, constructive criticism, and advise on the overall study. These individuals have all agreed to participate (resumes are attached): Dr. Steven Bartell, Principal at Cadmus Group, Oak Ridge, TN; Dr. Robert Brooks, Professor, Pennsylvania State University; Dr. Sushil Dixit, Sr.Res. Scientist, Queens University, Canada; Dr. Robert Hughes, Reg. Aquatic Scientist, Dynamac Corp., Corvallis, OR; Dr. Larry Kapustka, Sr. Ecotoxicologist and President, Ecological Planning and Toxicology, Inc., Corvallis, OR; Dr. Janet Keough, Res. Ecologist, USGS, Patuxent, MD; Dr. Daniel McKenney, Chief-Landscape Analysis and Appl., Canadian Forest Service; Dr. Daniel Simberloff, Professor, University of Tennessee. These individuals were selected based on a combination of their expertise, experience, and knowledge about the indicators being developed.

**Milestones:**

A summary of the major outcomes of our approach (by year) include:

- 1) Compilation of existing data for the indicators selected for measurement, recognizing other data gathering efforts in the Great Lakes to avoid duplication (all investigators, year 1, summary report on 31 October 2001).
- 2) Pilot study of selected indicators to estimate response variability including measurement error, temporal variability within season, and spatial variability (all investigators, year 1, summary report on 31 December 2001).
- 2) Calculation of variability, power to detect change, and cost-effectiveness to measure each indicator (all investigators, year 1, summary report on 31 December 2001).
- 3) Selection of areas for intensive sampling of indicators using a hierarchical, stratified random approach along with targeted sites defined for the appropriate scale of each indicator (all investigators, years 1 and 2, summary report on 28 February 2002).
- 4) Coordination of new data gathering at intensive study sites selected for each indicator (all investigators, years 2-3, summary of year 2 activities on 30 November 2002, year 3 on 30 November 2003).
- 5) Reexamination of variability, power to detect change, uncertainty, and cost-effectiveness to measure each indicator (all investigators, years 2-3, summary of year 2 activities on 31 January 2003, summary of year 3 activities on 30 November 2003).
- 6) Relate condition and change in state indicators with threats (pressure indicators) (all investigators, years 3-4, summary report on 30 August 2004).
- 7) Recommend a framework to US EPA and NASA on the most appropriate environmental indicators based on ability to define condition, integrity, power to detect change, and match with threats to the Great Lakes system (all investigators, year 4, final report on 30 September 2004).

#### **General Information:**

CWE/NRRI, UMN, the major organization involved in this project is directed by the PI, Niemi. The major mission of NRRI is to “*promote private sector employment in the use of Minnesota’s natural resources in an environmentally sound manner.*” CWE’s primary focus on the environmental component of the mission to insure sustainable use of natural resources. CWE has an annual budget of \$3.5 - 4.5 M, an average of 30 active projects per year, a staff of about 60 FTEs including 12 PhDs, technicians, graduate and undergraduate students, and support staff. CWE has completed more than \$13 M in projects during the past 12 years directly related to the Great Lakes, indicators, and issues related with this proposal (<http://www.nrri.umn.edu/cwe>). All of the staff are full time research personnel that are supported on a combination of University and grant funds. The CWE/NRRI facility has more than 25,000ft<sup>2</sup>, with 12 laboratories, a modern GIS facility, and modern computer equipment and networks.

The major EPA/ORD cooperator on this project is the Mid-Continent Ecology Division in Duluth, MN (<http://www.epa.gov/med/>) which has a field station in Grosse Ile, MI. The Division is part of the Office of Research and Development’s National Health and Environmental Effects Research Laboratory. Bradbury, the Division Director, will serve as the major liaison with Niemi on the overall technical coordination of the project. The Division’s research focuses on ecotoxicological and freshwater ecosystem effects and is designed to improve techniques for assessing biological and ecological condition, to reduce uncertainties in ecological risk assessment, and to support the selection of restoration options. The Division has an annual budget of \$18 M and 104 federal positions, including 34 PhDs, of which 17 are focused on the Great Lakes. Within the basin, the Division has developed large scale effects models (e.g., the Lake Erie Eutrophication and Green Bay Mass Balance Models); establishment of the EPA/ORD Great Lakes Environmental Monitoring and Assessment Program (Great Lakes - EMAP); and development of Great Lakes watershed classification and diagnostic monitoring approaches. The Division has over 90,000ft<sup>2</sup> with a wide array of analytical, wet, and GIS laboratories. The Division also operates the RIV Lake Explorer, an 82ft Great Lakes research vessel with a wide variety of sampling gear.

## 6. IMPORTANT ATTACHMENTS

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