The Impact of Episodic Events on the Nearshore-Offshore Transport and Transformation of Biogeochemically Important Materials (BIMS) in the Great Lakes

This proposal is submitted in response to the NSF/OCE and NOAA/COP Joint Announcement of Opportunity for Coastal Studies in the Great Lakes (NSF Publication 97-38. This proposal has been developed to focus on a critical theme that was common to two workshops (NOAA 1992; Klump *et al*. 1995).: the importance of episodic events on nearshore-offshore transport and subsequent ecological consequences. Each of the components of this program is being led by a team of scientists with proven experience and long-term interest in coastal research. The episodic events study described in these proposals provides a unique opportunity to combine their talents in a comprehensive program directed toward the NSF-NOAA goals as defined in the Announcement of Opportunity:

1. to determine what processes control the cross-margin (inshore to offshore) transport of biological, chemical, and geological materials in the coastal margins of the Great Lakes, and
2. to develop and test scientific strategies for assessing, quantifying, and predicting the impacts of multiple stressors, both natural and anthropogenic, in the Great Lakes or selected sub-regions.

<u>**Issue**</u>: A tight coupling between contaminated sediments and overlying water exists in lakes and coastal ecosystems through the process of sediment resuspension. Recent satellite observations of suspended sedimentary material in Lake Michigan illustrate a unique opportunity to investigate an annually recurrent major episode of nearshore-offshore transport, a 10 km wide plume of resuspended material extending over 200 km along the southern shores of the lake (Fig. 1). The plume appears to be initiated by a major late winter storm after the melting of surface ice, and it eventually veers offshore along the eastern shore of the lake, coincident with the area of highest measured sediment accumulation in the lake. The inventory of particulate matter in the plume, on April 2, 1996, is approximately equal to the total annual load of fine sediments into the southern basin. Preliminary evidence indicates that this episodic event may be the major mechanism for cross-margin sediment transport in Lake Michigan. We believe this type of event is ideal for studying internal recycling of biogeochemically important materials (BIMS), ecosystem responses, and one of the major processes controlling cross-isobath transport in the Great Lakes. While we are

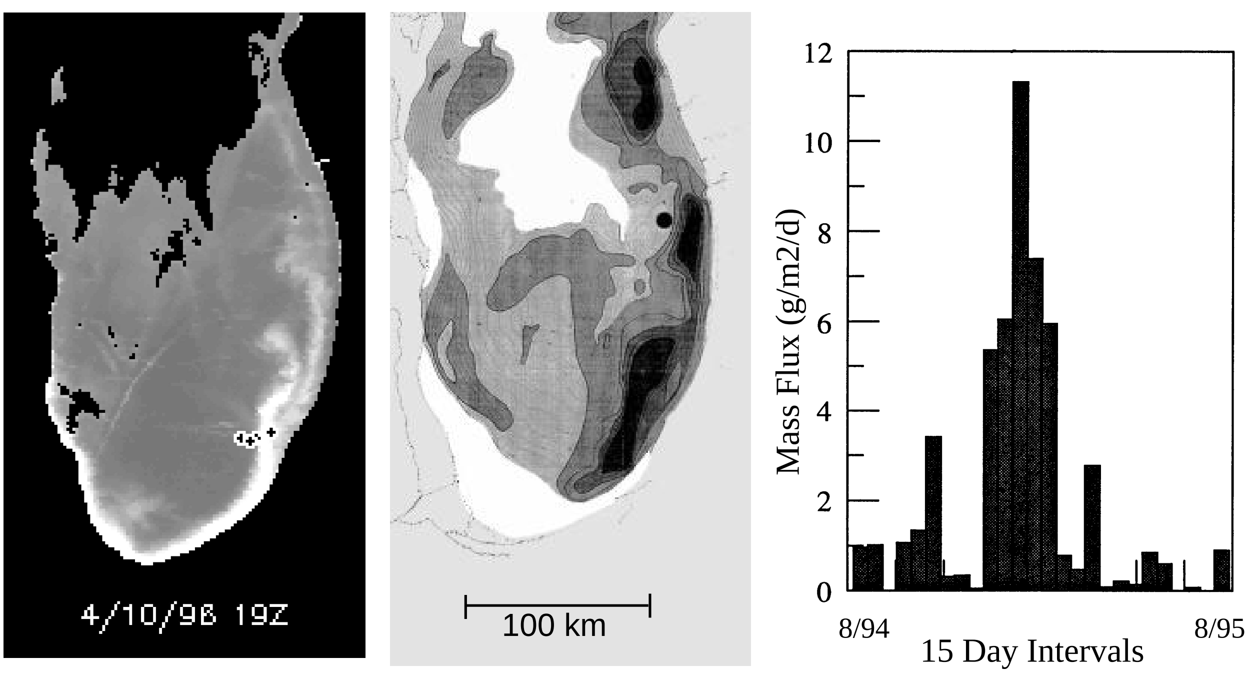

Figure 1. (a). AVHRR channel 1 (visible) imagery of the plume on April 10, 1996; clouds are masked out in black. The plume was initiated by a major storm on March 20 and appears to be an annually recurrent event. The offshore advection of major features on the eastern side of the lake coincide with the regions of maximum sediment accumulation. The plus symbols are locations of water sampling on this day (Eadie et al., 1996). (b). Thickness of post-glacial sediments; zero accumulation in the white region (non-depositional) and less than 1 meter in the lightest shade of gray (transitional). Subsequent contours are in 4 m thick intervals, with the black regions having greater than 14 m of total accumulation. (c). Mass fluxes recorded in a sequencing trap in the plume and high sediment accumulation region (near the easternmost + symbol in a). Fluxes are in 15 day intervals covering the period 8/94-8/95. The critical feature illustrated is that approximately 90% of the mass of particulate material delivered to this site arrived in less than 10 weeks during the winter-spring period.

focusing on a particular episodic process in southern Lake Michigan, the program results will be applicable to similar events in many coastal areas.

Significance: The episodic resuspension and subsequent transport of surface sediments profoundly influences biogeochemical processes in coastal ecosystems. Resuspension and transport of the large inventories of nutrients and contaminants deposited over the past few decades (e.g. P, ^{137}Cs, PCBs), presently results in much greater fluxes to the water column than from all external inputs. In addition, control of biological processes can occur as a result of effects on light and substrate availability and the introduction of meroplanktonic species. The magnitude and episodic nature of these processes in the Great Lakes has been poorly described from a few point measurements or as the residual term in mass balance models. This multi-disciplinary project will employ a comprehensive measurement and modeling approach to examine and compare effects of episodic physical forcing in relation to more persistent long-term (i.e., seasonal meteorological) forcing on nutrient inventories, fluxes and distributions, and on biological distributions and rate processes. The results of this proposed research will improve our understanding of critical processes and support the development of a resource management-oriented information and modeling system.

Background: Episodic events can exert major influences on ecosystems. Energy, sediment particles, and their associated nutrients, radionuclides, and exotic organic compounds, are predominantly transferred within the coastal zone of large lakes and enclosed seas in episodic pulses (e.g. storms, spring runoff). For many constituents in the Great Lakes, the resuspension of surface sediments, (which contain large inventories of certain nutrients and contaminants deposited over the past few decades) presently results in much greater fluxes than from external inputs (Eadie *et al*. 1984, Eadie *et al*. 1989; Eadie and Robbins 1987, Robbins and Eadie 1991, Brooks and Edgington 1994*).* In addition to their influence on nutrient, temperature and light fields, storms and turbidity fronts are recognized as important factors structuring planktonic communities (e.g. Mullin *et al*. 1985, Haury *et al*. 1992) determining whether primary producers remain in near-surface waters where solar irradiance is high or whether they are mixed into deeper waters. Resuspension of sediments may also inject resting stages of “meroplanktonic” diatoms into the water column (Schelske *et al*. 1995) and zooplankton resting eggs (Hairston 1996).

Circulation in the lake is also highly episodic; most energetic currents and waves occur during storms, which are generally more frequent in the spring and fall than during the summer. In the southern basin of Lake Michigan, alongshore currents are initially driven by these pulses of wind and steered by the bottom bathymetry, but can subsequently reverse direction as the forcing stops and the two gyre wind-driven circulation pattern begins to rotate around the basin as a two cell vorticity wave (Saylor *et al*. 1980, Schwab 1983). The relaxation time of this response is on the order of several days. When this type of circulation pattern is coupled with resuspended materials, large fluxes of BIMS may result across the coastal margin.

One major event, which appears to occur annually in southern Lake Michigan is the formation of a late winter-early spring coastal turbidity plume, first documented by Mortimer (1988) from satellite images obtained during the late 1970s and early 1980s. For the past four years, intermittent satellite coverage has revealed the presence of the plume in the visible band with a clear offshore projection that coincides with the region of maximum sediment accumulation in the lake (Lineback and Gross 1972, Edgington and Robbins 1990, Eadie *et al*. 1996), and with a bathymetric protrusion where topographically-steered, storm-induced currents frequently converge to produce significant offshore transport.

Lake Michigan is the sixth-largest lake in the world and has a hydraulic residence time of about 62 years (Quinn 1992). For particle-reactive constituents, internal removal through sedimentation is much more rapid than this. Radiotracer studies with ^{239}Pu ($t_{1/2}$ = 25,000 years) and ^{137}Cs ($t_{1/2}$ = 30.2 years) show that >95% of these tracers were removed from the water and transferred to sediments within a few years (Edgington and Robbins 1976; Wahlgren *et al.* 1980, Eadie and Robbins 1987). Although initial removal of particle-reactive tracers from the water is rapid (a few years), a small residual concentration remains in the water (either on particles, in biota or in solution) and now diminishes exponentially on a time scale of decades. Studies have shown that the small amount remaining in the system is primarily the result of an annual cycle of sediment resuspension and redeposition that releases constituents from sediments back into the water (Eadie *et al.* 1984, Robbins and Eadie 1991). The long-term decline of' ^{239}Pu and (decay-corrected) ^{137}Cs in the lake have about 20 year time constants (Wahlgren *et al*.1980), probably indicating the net rate of incorporation of these tracers into permanent sediments (Edgington and Nelson 1986, Robbins 1982).

The patterns of long-term sediment accumulation in Lake Michigan are complex (Lineback and Gross 1972, Cahill 1980). The distribution of post-glacial sediment in the southern half of Lake Michigan is asymmetric with the greatest accumulations found in a band about 20 km from the eastern shore and decreasing towards the deepest sounding in the basin (Fig. 1). Approximately 30% of the bottom is non-depositional while an additional 40% is considered transitional. Sediments have been well characterized in all areas from which high-quality cores can be retrieved (e.g. Edgington and Robbins 1990). The few sediment cores from the transitional deposits which have been recovered and analyzed consistently reveal a veneer of ^{137}Cs laden material no more than a centimeter or two thick (Edgington and Robbins, *pers. com*.) compared with up to 25 cm of ^{137}Cs at sites in the depositional basins. It seems likely that non-depositional and transitional regions serve as temporary repositories for recently introduced particle-associated constituents, including radiotracers, contaminants and nutrients.

In 1996, exceptionally clear conditions provided a first opportunity to observe the initiation, development, and decay of this extensive coastal plume and to collect water samples for analyses. The rapid onset of the plume in 1996 appeared to coincide with melting of the last snowpack and shore ice in late March, and with the occurrence of a major storm. Within a few days, a 10 km wide plume of high reflectivity extending over 200 km along the entire shoreline of the southern half of the lake had developed. This feature persisted for over a month progressing northward along the eastern shore and dispersing offshore in complex patterns. Our preliminary results imply that the reflective substances in the plume represent a substantial fraction of the total annual particle load to the lake and have characteristics somewhere between silty-clay materials eroding from bluffs along the shore of Lake Michigan or from exposed glacial clay deposits in relatively shallow waters and recent surface sediments. As they progress through a series of resuspension-deposition cycles (Fig. 2) these easily resuspendable materials constitute the major non-point source of nutrients and contaminants to the pelagic system. For example, it is now well known that contaminants, such as PCBs, decline rapidly in fish after production/use has been halted but that after a few years a level is reached which is determined by sediment-water coupling. Although the processes of the coupling are poorly understood, the consequences are very important to lake management since this process has a long (ca. 20 y) time constant.

This resuspendable material also serves as a food source for surface deposit feeders, suspension feeders, and the microbial food web. The timing of the plume event, relative to lake warming and increased solar irradiance, will be critical in the development of the spring diatom bloom and subsequent production. Biological recycling of nutrients within the upper layer of the water column is very efficient. The inventory of nutrients present in this layer when the lake thermally stratifies is the fuel that determines the magnitude of annual productivity. The plume may also provide material to sustain the benthic nepheloid layer which plays a major role in the coupling of the inventory of constituents in surface sediments with overlying lake water throughout the year.

<u>Program Goal:</u> The purpose of this program is to create an integrated observational program and numerical model-

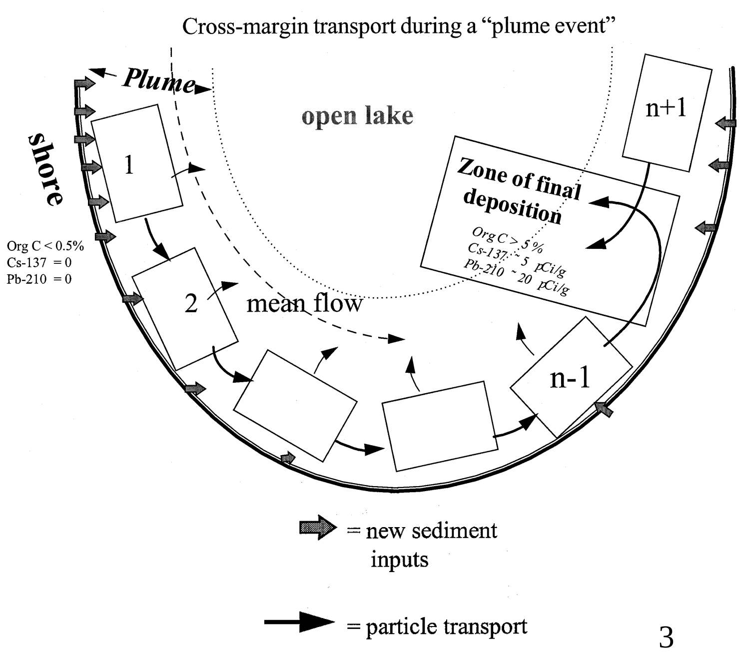

Figure 2. A simple conceptual model of the movement of particles in the coastal plume in the southern basin of Lake Michigan. Particles derived from the western shore move counter-clockwise in concert with the mean circulation. Major questions include how quickly these particles move from source to sink, the number of deposition/resuspension cycles that they undergo in transit, the transformations that occur in route, and offshore transport. An important parameter therefore is the residence time for particles within the plume, a function of both the inventory in each compartment and the flux “down stream.” Radionuclides may be used to “clock” the speed with which particles move and yield the “apparent age” of particles within the system.

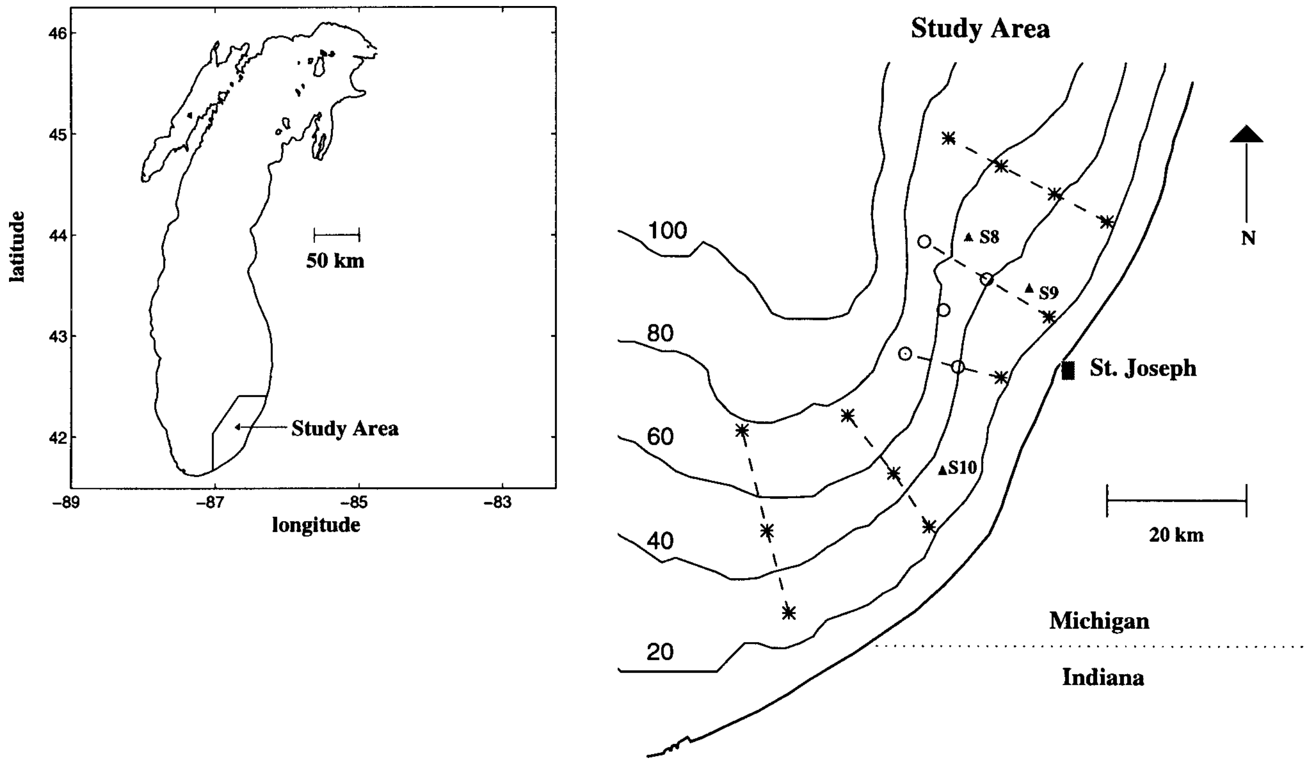

Figure 3. Moored arrays. Open circles are ADCP current meters, stars are VACM current meters.

ing effort to identify, quantify, and develop prediction tools for the winter-spring resuspension event and to assess the impact of this event on the transport and transformation of BIMS and on lake ecology. Three fundamental hypotheses focus this program:

1) that the plume is a result of the first winter-spring storm after ice-out and represents the resuspension of particulate materials (and associated constituents) that have been stored in the lake as surface sediment ‘floc’ for a distribution of times, during which they have undergone differential diagenesis,

2) that the forced, two-gyre vorticity wave response of the lake to episodic wind events, occasionally modified by stratification, is a major mechanism for nearshore-offshore transport of particulate matter and associated constituents in the Great Lakes, and

3) that physical processes, (e.g. resuspension, turbulence) associated with the plume event are important in determining the nutrient and light climate, and in structuring the biological communities throughout the spring isothermal period, and in setting the conditions for the critical ‘spring bloom’ period.

Approach: Our program is designed to test these hypotheses through the implementation of an integrated field program and the application of numerical models. The program consists of the following components:

Observation Strategy: Our observation strategy will consist of three components: (1) moored arrays of current meters, thermistors and sequencing traps, (2) interdisciplinary Lagrangian measurements, and 3) shipboard surveys. Several types of cruises are planned to support: a) moored instrument deployment/retrieval, b) ROV and particle transformation measurements, c) surveys, and d) process measurements. The time series and survey data will be supplemented by synoptic coverage from satellite imagery and multi-frequency HF radar observations. Three years of field activities are planned with the first year being a pilot study. Plans for Survey and Process cruises are for one in the first year during the event, and three cruises in years 2 and 3. All cruises will be approximately 2 weeks long. In years 2 and 3 the cruises will be before during and after the plume event. Each cruise will consist of a transect survey (in areas A, B, and C ; Figure 4), followed by intensive sampling at 5 master stations (two in area A, one in MIAA, one in area B, and one in area C), then followed by a 5-7 day Lagrangian experiment that starts in area A. During years 2 and 3 the same major state variables will be monitored biweekly or monthly (as ice and weather permit) at Site A to put effects of the plume in perspective with other events and ongoing changes in the plankton. ROV and particle transformation measurements will be made primarily on the western side of the southern basin, since the main particle source is the region between transect C and E (Figure 4), although some work will be done at the ‘receptor site’ (A).

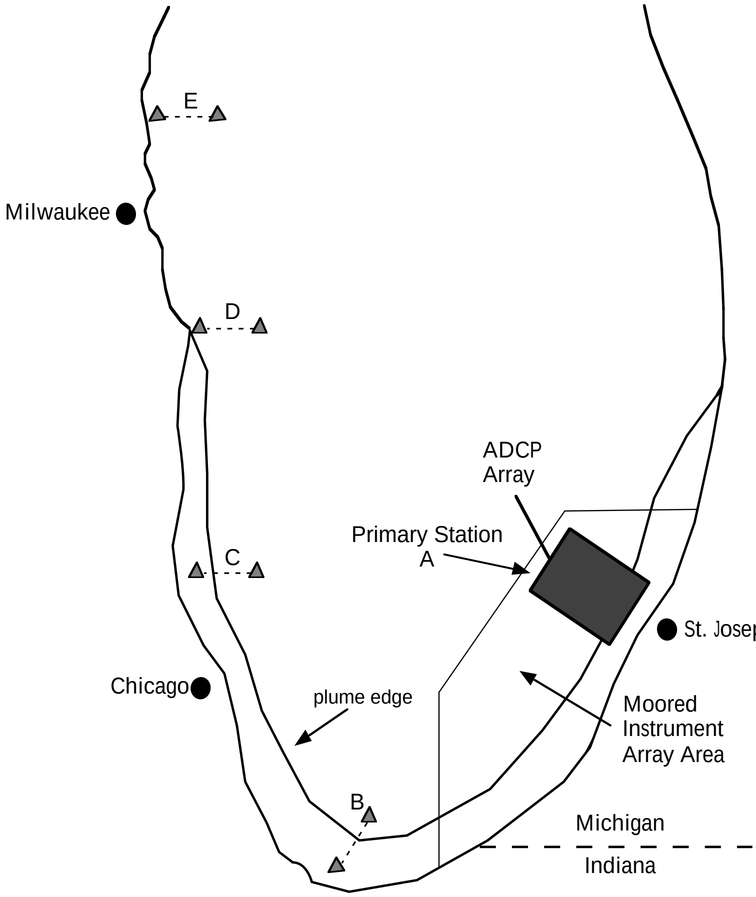

Figure 4. Schematic cruise tracks. Master stations will be located at transects a, b, and c. Lagrangian experiments will be in region a.

<u>**Modeling Strategy**</u> This collaborative Lake Michigan study provides an ideal framework for model testing and development. The modeling objectives of our proposal are to create a numerical modeling framework and use the extensive observational programs to identify, quantify, and develop prediction tools for the primary physical processes responsible for nearshore-offshore transport and transformation of BIMS in Lake Michigan. A lake-scale hydrodynamic circulation model (the Great Lakes version of the Princeton Ocean Model) will be coupled with ice and wave models and applied to Lake Michigan for selected periods in 1992-1997 during which the springtime turbidity plume has been observed, and for the program's field years. In collaboration with other components of this program the hydrodynamic model will be coupled with sediment transport and lower food web models in order to assess the impact of internal nutrient recycling and nearshore-offshore transport on sedimentary and biological processes. Overall, the program is designed to provide the most comprehensive insight into the hydrodynamics of cross-margin transport, transformation and ecological consequences of BIMS ever accomplished on the Great Lakes.

<u>**Program Organization:**</u> An integrated program has been developed to test the program hypotheses. **NOTE:** ***Proposal PIs are in bold italics***

H1. The plume is a result of the first winter-spring storm after ice-out and represents the resuspension of particulate materials (and associated constituents) that have been stored in the lake as surface sediment 'floc' for a distribution of times, during which they have undergone differential diagenesis.

A detailed retrospective analysis of archived satellite imagery (***Budd, Kerfoot and Stumpf***) will be examined to acquire a history of plume events. The primary objective of this work is the understanding of inter-annual variation in the timing, magnitude, duration and spatial extent of the spring turbidity plume. Archived satellite imagery represents a largely untapped source for long-term comparative studies of seasonally varying surface water variables. Remotely sensed data provide 1) truly synoptic surveys, and 2) the spatial and temporal detail necessary for describing seasonal and interannual changes in surface temperatures and total suspended material (TSM). A combination of *in situ* data (e.g. water intake turbidity, archived TSM) and Advanced Very High Resolution Radiometer (AVHRR) visible and thermal infrared satellite imagery will be used to "reconstruct" events from 1987-1996 in southern Lake

Michigan. Single images can estimate the aerial extent of surface plumes, whereas sequences of images can provide qualitative visualization of events (e.g., movement of river discharges, surface currents).

The changing inventories of unconsolidated surface sediment resuspendable materials will be characterized by ROV (***Eadie, Robbins, Edgington, Klump, Lesht, and Nealson),*** including measuring a suite of short-lived radionuclides to estimate particle residence times at various locations, and measuring the transformation of particle surface chemistry, both for information on in-lake residence times and for geochemical sorption substrate characteristics. Our conceptual model is that temporary deposits of flocculent particles in a thin layer at the sediment-water interface serve a very important function in modulating the movement and characteristics of particles, nutrients and contaminants between their source and their ultimate sink, and during this transition have a major impact on the ecosystem. This material is recharged by erosional inputs, biogeochemically transformed within the lake, redistributed throughout the year by a spectrum of energetic events, and massively redistributed by major storms and the recurrent coastal plume.

Transect (survey) cruises will measure near-continuous concentrations of nutrients (***Cotner and Johengen***), light climate (***Fahnenstiel, Lohrenz, Schoefeld, Millie, and Goad***). An optical plankton counter, CTD, and fluorometer mounted on a V-fin will be towed in an undulating mode to give vertical and horizontal distributions of chlorophyll, zooplankton, and suspended solids, and temperature, along transects across the plume (***Vanderploeg and Bundy***). Vertical closing net tows will give species distributions of zooplankton and water bottle casts will give distributions of phytoplankton and microbial food web taxa. These data, in conjunction with all of other observational data will enable us to define and track the evolution and decay of the offshore and coastal plumes with high precision, estimate the magnitude of internal recycling and will be critical to both algorithm development (***Kerfoot and Budd; Lesht, et al.)*** and coupled biological-physical model calibration (***Chen***).

H2. The forced, two-gyre vorticity wave response of the lake to episodic wind events, occasionally modified by stratification, is a major mechanism for nearshore-offshore transport of particulate matter and associated constituents in the Great Lakes.

Moored instrument arrays and Lagrangian experiments will provide a detailed description of the flow field (currents, vorticity, patterns of convergence, plume dynamics, and the net offshore transport of water) and an understanding of its physics during the winter/spring transitions in southern Lake Michigan. Instruments along five coastal cross sections configured will be deployed (Fig. 3) to measure alongshore and cross-shore currents and temperature distributions (***Saylor, McCormick, and Miller***) in the southeastern region of the lake where offshore transport is most apparent from the satellite imagery (Fig. 1). Seventeen moorings will be deployed using presently available ADCP (number = 5) and VACM (number = 24) current meters. A 1200 kHz ADCP will be purchased with funds requested by this proposal and deployed near one of the 600 kHz ADCP. The combination of backscatter data from both instruments will enable ***Bedford*** to calculate near-continuous particle concentration profiles. This dense array will complement a current meter mooring which has been maintained for several years in the center of Lake Michigan's southern basin by GLERL, a station known to be key to the observation of vorticity wave excitation and propagation (Saylor *et al.* 1980). The moorings will provide the density of instruments necessary to determine wave generation and propagation along the coast and its possible arresting at the bathymetric protrusion into Lake Michigan near St. Joseph. Maintaining the moorings through the spring warming cycle will also provide detailed observations of the offshore translating spring thermal front. High frequency radar will be used to make regional scale observations of winds, surface currents, and waves within the reach of the moored array (***Vesecky***). These measurements will cover the near surface flow on scales not observable with the moored instrumentation or drifting buoys.

Sequencing traps (***Edgington, Klump, Nealson, Eadie, Robbins, and Lesht***), specially modified for the very high particle fluxes observed in the plume, will be co-located with approximately half of the current meter moorings. These samples will provide particle flux information to constrain the models and will be analyzed for a suite of radionuclides, for source tracing, 'particle in-lake aging', and nutrients (***Cotner and Johengen***). Single VACMs will also be located within the transect C through F (Fig. 4), along with a benthic tripod, for extended circulation information and in support of the biological and particle transformation components of the program.

A lake-scale hydrodynamic circulation model (the Great Lakes version of the Princeton Ocean Model, Blumberg and Mellor 1987, Schwab and Bedford 1994) (***Schwab and Beletsky)*** will be coupled with the dynamic ice model of Stubblefield and Bennett (1984), modified by incorporation of thermodynamic effects to account for ice growth and melting. The ice-circulation model will calculate the three-dimensional current, temperature, and ice fields in the lake on a 2 km horizontal grid in order to be able to resolve both coastal boundary layer and currents within the plume. Fine resolution of the coastal boundary layer is important because the majority of resuspension occurs within 10-15 km distance from a coast (Fig. 1). Therefore, some experiments will also be carried out with higher (1 km) horizontal resolution, to study how improved horizontal resolution will influence velocity field and eventually sediment resuspension and transport during episodes of strong wind forcing. Retrospective analysis of visible imagery (***Kerfoot et al***.) will be used to help to select periods for model simulations

For these simulations, meteorological data from National Weather Service surface observing stations and two mid-lake weather buoys will be used to synthesize overwater momentum flux and heat flux fields to drive the model. Previous applications of the circulation model have shown that the accuracy of the results is often limited by the accuracy of the forcing fields (Schwab 1983, Schwab and Bennett 1987, Schwab 1989, O'Connor and Schwab 1993). Therefore, we will use output from the fine resolution meteorological model MM5, (Dudhia, 1993) (***Roebber***) to determine the influence of mesoscale atmospheric dynamics on the circulation and development of the plume. High resolution wind observations by the multifrequency HF radar in the study area (***Vesecky***) will be assimilated into MM5 output. By studying specific atmospheric conditions associated with nearshore-offshore transport events, it will be possible to address the question whether the plume occurrence represents a response to the aggregate effects of a season of individual storm events, an episodic response to a single large storm event or a complex interaction between the low-frequency (seasonal) preconditioning of the lake and a single storm event that occurs at a critical time.

Surface water temperature fields calculated by the model for the field seasons will be compared to satellite-derived surface temperature fields available through the NOAA CoastWatch program (Schwab *et al.* 1992) and program measurements. We will also compare surface currents calculated by the model to those derived from a multifrequency HF radar observations (***Vesecky***), and those derived from drifter buoys (***Saylor et al***.). To refine existing model parameterizations, model results will be compared to observational data from ship surveys, current meters, and thermistor arrays deployed during the field years as part of the program (***Saylor et al***). A parametric wave model for the Great Lakes developed by Schwab et al. (1984) will be used to provide estimates of wave characteristics for use in sediment resuspension calculations.

The ice-circulation model and the wind wave prediction model will be linked with a sediment resuspension/transport and particle tracking models (***Bedford***), in order to quantify the cross-isobath transport of resuspended material in the lake. Given the importance of episodic resuspension events to the functioning of the lake ecosystem, numerical models that predict three-dimensional concentration fields of suspended material as well as track the path of particles in the flow can provide a very useful management and analysis tool for these lake systems. Currently, estimates of concentrations and particle residence times resulting from these episodic events are obtained primarily from limited field measurements, tracer studies, and simple mass balance models. Development of a fully three-dimensional sediment resuspension and transport model, together with the detailed field measurements of hydrodynamic variables and suspended particulate concentrations will allow us to test the ability of these models to reproduce and predict onshore-offshore exchanges of sediments in large lakes. However, since conventional Eulerian-based transport models cannot provide information about particle trajectories and residence times, concurrent development and testing of a Lagrangian-based particle tracking model is critical for predicting the path that particles take as they travel cross-shore and for identifying transient and permanent particle sinks along this path.

H3. Physical processes, (e.g. resuspension, turbulence) associated with the plume event are important in determining the nutrient and light climate, and in structuring the biological communities throughout the spring isothermal period, and in setting the conditions for the critical 'spring bloom' period.

The evolution of the annual biotic community in Lake Michigan starts in the winter-spring period, when the lake is isothermal and nutrients are mixed throughout the water column. Physical processes, (advection, transport) are hypothesized to be a major factor controlling abundance and composition of microbial communities in the vicinity of the plume and that these physical factors influence the more long term biological structuring that takes place. The dominant role that physical factors play in explaining phytoplankton community composition and abundance in Lake Michigan during the spring period has been illustrated by Sell et al. (1984), and by Scavia and Fahnenstiel, 1987. These physical events appear to be important in seeding and setting the stage for biological interactions that follow, the spring diatom bloom, and then the associated impacts on secondary production. The plume event precedes the initiation of the spring diatom bloom and linkages between these two episodic events have been postulated, but not verified. The duration and intensity of the plume and the prominent role of light availability in regulating phytoplankton growth during the spring isothermal period, makes Lake Michigan an ideal locale to assess the impact of these variables at both the species and community levels. Moreover, the concurrent physical and biological events provide a unique opportunity to examine and compare forcing factors (particularly light) and their relation to phytoplankton rate processes.

We expect that the plume will affect the dynamics of secondary production in the region by changing the composition, production rates, and fate of organisms in the plume and at its edge relative to offshore waters. Identification of taxon-specific and community responses to environmental forcing is important to understanding the variations in coastal phytoplankton biomass, growth, and production that, in turn, will affect the structure and function of the micro-food web and other heterotrophic organisms. Field and laboratory experiments, with natural plankton assemblages, will examine community grazing rates, species-specific growth rates and species-specific copepod grazing rates. The winter-spring transition is also important to mesozooplankton and higher trophic levels throughout the year because much of the reproduction and early life stage (nauplii and copepodites) development of copepods, the dominant zooplankton of Lake Michigan, occur during this period.

Factors making phosphorus (P) available to phytoplankton, the composition and growth rates of phytoplankton, the trophic dynamics of zooplankton and microbial food web (MFW) secondary consumers will be measured and these factors will be incorporated into the mathematical modeling of these different processes as they relate to the formation, movement, and dissipation of the plume The transfer and transformation of nutrients and biochemical energy are affected by plume dynamics will be examined in detail (***Cotner and Johengen***). The P research will examine the influence of major episodic events on P availability and dynamics in the southern basin of Lake Michigan. Understanding the impact of episodic events on P availability has important implications for ecosystem structure and function because primary productivity in this system is P-limited.

Phytoplankton research (***Fahnenstiel, Lohrenz, Schoefeld, Millie, and Goad***) will aim to quantitatively assess the growth and ecophysiological requirements and characteristics of Lake Michigan phytoplankton. Synoptic cruises coupled with detailed site-specific process experiments and proven, state-of-the-art, bio-optical instrumentation/ methods will allow us to comprehensively examine the taxon-specific and community responses to distinct physical forcing factors in the plume and adjacent waters. The proposed research will greatly improve understanding of ecophysiological mechanisms controlling phytoplankton and community structure during episodic, physical forcing events within the Great Lakes. Lagrangian experiments will be mounted on satellite-tracked drifters launched within region A (Fig. 4). Interdisciplinary process studies will be conducted along the drifter transect (***McCormick, Saylor, and Miller -*** dispersion***; Eadie, Robbins, Edgington, Klump, Lesht, and Nealson -*** particle transformation***; Cotner and Johengen -*** phosphorus kinetics, ***Fahnenstiel, Lohrenz, Schoefeld, Millie, and Goad -*** light absorption, photosynthesis, and growth as well as characterization of the optical fields and phytoplankton distribution). During each survey cruise, drifter(s) will be launched in the primary research area (A in Fig. 4) and samples collected several times per day for up to a week. The drifters will incorporate a CTD system, a sequencing sediment trap and sequential water sampler (24 pre-timed, 1 liter samples) a spectral radiometer and solar stimulated fluorometer.

The spatial variability in population structure, species composition and reproductive potential of mesozooplankton, before, during, and after plume formation will be measured (**Vanderploeg and Bundy**), and relations to the distribution of their prey and measured 3D fluid velocities in the water column will be examined. Community and species specific grazing rates of adult and juvenile copepods will be measured in relation to the plume and other conditions during the winter-spring transition. The abundance and growth rates of protists, N-cycling rates ***(Gardner and Lavryentov)*** and the dynamics of secondary production, in the plume region will be examined for changing composition, production rates, and types of organisms in the plume and at its edge relative to offshore waters. For example, by making conditions conducive to the production of small rather than large diatoms that are often associated with winter-spring transition conditions, the plume event may enhance conditions for the microbial food web (MFW) and mesozooplankton.

A lower food web model (***Chen***) (nutrients, phytoplankton, and zooplankton) will be coupled to the full three-dimensional hydrodynamic model (***Schwab and Beletsky***). This coupled model will be used to (1) integrate the results of physical and biological investigations (***Vanderploeg, Cotner, Eadie, Fahanenstial,*** and ***Gardner)*** and (2) interpret the field observations by model-guided mechanism studies of a coupled physical, chemical, and biological ecosystem. Numerical experiments will be focused on nonlinear interactions of biological, chemical, and physical processes associated with strong wind mixing, ice-melting, upwelling/downwelling, and eddy formation within and at edge of the plume. The response of phytoplankton, zooplankton, and MFW organisms to large scale episodic events is important at the ecosystem level because these organisms play a pivotal role in energy transfers and nutrient transformations in the Great Lakes and other aquatic environments.

Data Management and Great Lakes Forecasting System

Lake Michigan Information and Data Analysis System (LAMIDAS): Using the network and communication links already developed for the Great Lakes Forecasting System (Bedford and Schwab 1994; Schwab and Bedford 1994), we plan to create a distributed environment to provide access to a database of the research data generated by this program and to implement analysis tools by which two- and three-dimensional data can be rapidly accessed and analyzed. The Lake Michigan Information Data Analysis System (LAMIDAS) will be based on the GLOBEC (GLOBal ocean ECosystem dynamics) system for data archiving. A key component of the GLOBEC project is the sharing of the field, retrospective, modeled, and derived data collected by scientific investigators in different fields. The JGOFS (U.S. Joint Global Ocean Flux Study) data management software was developed to serve data and information to the involved scientists. This system will serve as the model for LAMIDAS.

The first step in LAMIDAS will be to create a database description for the data products expected to result from this research program. Results from field programs, retrospective studies, and numerical model studies will be stored in the database. Access will be provided on the program file server by date, data type, and location. Web browsers will be used as the standard user interface because of their platform-independent functionality and general availability. Scientists will be able to extract, browse, and/or visualize data. There will be a data base server at GLERL which will be maintained by GLERL personnel, and it will allow 24hr access to all archived data. The data to be included in the data base and the procedures and formats by which data are posted in LAMIDAS will be agreed to by the group at the first project meeting; again, the JGOFS Data System will serve as the model.

Great Lakes Forecasting System (GLFS): The Great Lakes Forecasting System (GLFS, Bedford and Schwab 1994; Schwab and Bedford 1994) has been developed by OSU and GLERL to provide short range operational (regularly scheduled) predictions of environmental conditions in the lakes. The Lake Erie portion of the system has been in operation at OSU since 1994. Predictions from the system include every-six-hour nowcasts and twice-a-day short range (36 hr) forecasts (Kelley *et al*. 1996) of the three-dimensional velocity field, the three-dimensional temperature field, the water level distribution and the wind wave height, length, period, and direction.

The Lake Michigan experiment proposed in this program is a timely opportunity to extend the scope of the GLFS. The sediment transport model, the ice model, and the lower food web model proposed in this program are all designed to operate in the GLFS framework. If it can be shown that accurate methods for predicting sediment movement, ice, and basic nutrients are possible, then for the first time credible real-time short range forecasts of these parameters will be possible. The results of the proposed program, particularly from the modeling components, will ultimately be incorporated into the GLFS framework to extend the prediction system to include sediment transport, ice, and trophic status. The experimental data gathered in this program will be used as validation for the modeling constructs.

Program Management The PI team of Brian Eadie (Director NOAA-GLERL Biogeochemical Sciences Division, NOAA-GLERL), Wayne Gardner (Director, Marine Science Institute, U TX), Val Klump (Director, Center for Great Lakes Studies, U WI-Milwaukee), and David Schwab (Senior Scientist, NOAA-GLERL) will serve as program managers; organizing PI meetings, briefings to NSF-CoOP and NOAA-COP, and logistics. Annual PI meetings, seen as critical to maintaining and fostering the interdisciplinary nature of this work, will be held and coordinated publications (i.e. synthesis in a dedicated journal) are foreseen in addition to primary research manuscripts in peer-reviewed journals. This team has extensive experience in the research being proposed and in managing programs of this magnitude. In addition Prof. C.H. Mortimer will provide his expertise on internal wave dynamics, sediment resuspension and biological impacts in the Great Lakes as a consultant to the program. NOAA-GLERL has a joint institute, the Cooperative Institute for Limnology and Ecosystem Research (CILER), with universities in the Great Lakes area. Any funding received can be transferred to PIs from GLERL through CILER without overhead.

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<u>Overall Program Budget Summaries</u>

<u>Attached individual/team proposals</u> (13)