

Potential Climate Change Impacts on the Bay of Green Bay – An Assessment Report

WICCI Green Bay Working Group

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Table of Contents

Executive Summary	6
Chapter 1 - Introduction and Background on Green Bay Ecosystem.....	13
Chapter 2 - History of Research on Green Bay/Fox River	14
Chapter 3 - Green Bay Today – Understanding the Present Condition	16
<i>Primary Stressors</i>	17
<i>Phosphorus</i>	18
<i>Sediment and Total Suspended Solids</i>	20
<i>Chlorophyll</i>	21
<i>Water Clarity and Secchi Depth</i>	22
<i>Dissolved Oxygen</i>	23
<i>Temperature</i>	24
<i>Beach Advisories and Closings</i>	25
<i>Coastal Wetlands and Littoral Zone</i>	28
<i>How have the coastal wetlands in Green Bay changed over time?</i>	29
Chapter 4 - Risk Assessment and Climate Change Impacts.....	30
<i>Defining and Identifying Risk</i>	30
<i>Process Overview</i>	31
<i>Variation of Expert Opinion</i>	33
<i>Current Risk Perspective</i>	34
<i>Climate Change Assessment</i>	36
Chapter 5 - Climate Change and Risk to Green Bay Conservation Targets	43
<i>Target Vulnerabilities – Present Conditions</i>	45
<i>Climate Change Analysis of Targets</i>	45
<i>Vulnerability of Targets under Climate Change</i>	48
<i>Conclusion</i>	49
Chapter 6 - Adaptive Management Strategies.....	50
<i>Guidelines for Developing Adaptation Strategies</i>	50
<i>Adaptive Management Strategies for Conservation Targets</i>	51
<i>Adaptive Strategies for Northern Pike</i>	51
<i>Northern Pike Strategies Itemized</i>	52

<i>Adaptive Strategies for Coastal Wetlands</i>	53
<i>Coastal Wetland Strategies Itemized</i>	53
<i>Adaptive Strategies for Littoral Zone Community</i>	54
<i>Littoral Zone Community Strategies Itemized</i>	54
<i>Adaptive Strategies for Lake Sturgeon</i>	55
<i>Lake Sturgeon Strategies Itemized</i>	55
<i>Adaptive Strategies for Benthic Community</i>	56
<i>Benthic Community Strategies Itemized</i>	56
<i>Conclusion</i>	57
References.....	58

Executive Summary

Over the next 100 years, climate change will have significant impacts in the Great Lakes region of North America; particularly affected will be the shallow bays identified as freshwater estuaries, which are more sensitive to increases in temperature, precipitation, and runoff than other regions of the Great Lakes. One such estuary, Lake Michigan's Green Bay, which is located in northeastern Wisconsin (Figure 1-1), is one of the largest freshwater estuaries in the world. Long term predictions for the Great Lakes include both warmer and wetter conditions, with mean summer temperatures in Wisconsin increasing by 4.7°-6.5° F by the middle of the 21st Century and an increase in precipitation during winter and spring months. In addition to warmer and wetter conditions, scientists expect an increase in the frequency of heavy rainfall events. By mid-century the probability of an April rainfall event larger than one inch in Green Bay is predicted to be 0.523. This is 12 percent higher than at present. By the end of the century, the probability of exceeding the one inch threshold is 0.613.

Green Bay is characterized as an estuary because it functions as a nutrient trap, has very high biological productivity, and because of the thermal and chemical difference between the water of the tributaries and that of Lake Michigan. The mixing processes in Green Bay are complex and driven by a wind induced seiche, a small lunar tide, and temperature differences in water masses. Warm water enters the bay in the south, and at depth, cooler water enters from the north through several channels from Lake Michigan. This layered system operates somewhat like a conveyor belt, with warmer nutrient-laden surface water moving north on the east coast and cooler Lake Michigan water moving south at depth on the west coast.

The head of Green Bay originates at the mouth of the Fox River, the largest tributary to Lake Michigan. While representing only seven percent of the surface area and 1.4 percent of the volume of Lake Michigan, the bay receives approximately one third of the total phosphorus loading within the Lake Michigan basin. The biogeochemical cycles in Green Bay are dominated by the nutrient inputs from the Fox-Wolf River watershed with an area of 6400 square miles, equivalent to one third of the Lake Michigan basin. Approximately 70 percent of the phosphorus and suspended sediment load to the southern bay enters from the Fox River, including an estimated 330,000 tons of sediment annually and 1210 tons of total phosphorus.

The large catchment and the shallow basin would result in nutrient rich waters even without human influence. However, Green Bay and the Lower Fox River have been severely polluted since as early as 1925. Even so, the existing abundance of the bay's habitats remains vital to commercial and sports fishermen, boaters, duck hunters, beachcombers, bird watchers, and many people in the region who depend on it, both culturally and economically.

Stakeholders, both public and private, have spent hundreds of millions of dollars in efforts to reduce pollution and restore habitat in the Green Bay ecosystem. Over the last forty

years or more, they have made progress in restoring the ecological integrity of the bay and the many uses it provides. Scientists and managers have recognized that the Fox River and the Green Bay ecosystem have become degraded because they are impacted by multiple stressors, not just one or two causal agents. Climate change poses a new kind of threat to the bay and its resources because it may alter the impact of the already existing stresses on the system. Consequently, as part of the Wisconsin Initiative on Climate Change Impacts (www.wicci.wisc.edu) a Green Bay Ecosystem Working Group formed; its mission is to develop a collaborative approach, utilizing applied research, modeling, and adaptive guidelines to generate management strategies that address future climate change impacts. Adaptive management approaches will be developed and shared with Wisconsin policy makers, stakeholders, and citizens. The essential step in developing adaptive strategies to address climate change impacts is to assess the potential risks to the resource or system of interest.

One of the primary objectives of all WICCI working groups is to assess the vulnerabilities of the particular resource or ecosystem to the potential impacts of climate change. The Green Bay Ecosystem Working Group has focused initially on valued components of the natural ecosystem and climate-caused changes that will likely occur over the next 30 to 50 years. It is our intent to consider the built environment at a later time. In any case, the ultimate outcome is to formulate adaptive management guidelines for the Green Bay ecosystem resources and the Green Bay community.

Assessing Risk and Vulnerabilities

Based on previous experience, the Green Bay Working Group assessed the potential consequence of climate change by evaluating the **risk** posed to the Green Bay Ecosystem from regional shifts in temperature, precipitation, and storm events. The relative magnitude of risk to valued components of the ecosystem can be estimated by examining the interaction among ecosystem stressors and the valued components of ecosystems using the mathematical tool of fuzzy set theory. Briefly, fuzzy set theory is an area of mathematics that provides a theoretical basis for making informed judgments and decisions when full precision is lacking. Fuzzy set theory enables one to draw logically valid conclusions based on sets whose memberships are specified in a tertiary manner or some other non-binary form. When used in conjunction with expert insight, group knowledge can be synthesized and priorities identified .

The Green Bay Working Group has conducted two separate workshops to assess how climate change may impact “The Green Bay Ecosystem.” The first workshop held in June of 2008 assessed the way in which climate change is likely to alter ecosystem stressors. The second workshop held in August 2009 assessed the potential impact of climate change on a select group of conservation targets of particular interest to the Nature Conservancy (TNC). Both workshops combined involved thirty scientists and resource managers with expert knowledge of the Green Bay ecosystem. The purpose of the workshops was to delineate the risk and vulnerabilities of the system to climate change impacts and thereby better inform

development of adaptive management strategies. Both reports are available on line at WICCI web page under the Green Bay Working Group.

An assessment of climate change impacts on the “Conservation Targets” for Green Bay reveals that the most vulnerable “Targets” (in descending order) are: Northern Pike, Coastal Wetland Community, Littoral Zone Community, and Lake Sturgeon. These are followed by Benthic Community, Migratory Diving Ducks and Colony Nesting Birds. The vulnerabilities reflect an increased risk to the targets due to the exacerbating impact of climate change on the existing threats. The threats in descending order of importance are: Agricultural Runoff, Invasive Species (Carp), Urban Runoff and Residential Development. These four are followed by Dams, the Invasive Species Phragmites, Industrial Waste and Zebra Mussels. The increased risk to a particular target derives from either the combined effects of the climate change components or from an individual climate change component. The six climate change components used in the analysis are:

- Increasing Air and Water Temperatures
- Seasonality (Decreasing Winters, Earlier Springs)
- Precipitation (Higher in Winter & Spring)
- Periodicity of storm events (more frequent)
- Lower Record and Average water levels
- Shifting Wind Fields during summer from SE

In addition to considering vulnerabilities of and threats to conservation targets when contemplating adaptive management strategies, we also considered how climate change may alter the existing stressors on the Green Bay Ecosystem. The analysis from our first workshop reveals that the most significant stressors to the Green Bay Ecosystem under climate change conditions are Nutrient Loading, Solids Loading, Aquatic Exotics and Wetland/Shoreline Filling. These top ranked stressors are followed by Pathogens, BOD, Hydrologic Modifications and Persistent Organics.

When we compare the most significant ecosystem stressors from the first workshop to the most important threats from the second workshop, runoff and related phenomena appear in common. Consequently, it was imperative that runoff and related phenomena (i.e. Nutrient Loading, Solids Loading, Residential Development, Pathogens, Biochemical Oxygen Demand, and Hydrologic Modifications) be given high priority when developing adaptive management strategies for conservation targets in Green Bay.

Expert opinion is consistent regarding runoff as the most significant impact associated with climate change. Consequently, further effort to quantify the magnitude of runoff under climate change conditions is warranted. Evidence to date reveals that nutrient and suspended solids

loading to tributaries and the bay are event driven. A significant change in future climate will likely affect amount and timing of phosphorus (P) and total suspended solids (TSS) flux to Green Bay. Scientists from the University of Wisconsin at Milwaukee and Green Bay are collaborating with WICCI in a project funded by NOAA to use downscaled climate data generated by the climate working group in a computer runoff model (the Soil and Water Assessment Tool) to predict the impacts of climate change on P and TSS inputs to lower Green Bay. The overall goal is to evaluate and develop methods to address the effect of climate change on nonpoint source phosphorus and TSS inputs to lower Green Bay, as well as changes in runoff.

Objectives are:

- To quantify the amount of P and TSS that are discharged to lower Green Bay from the lower Fox River sub-basin under several future climate scenarios, and to compare the amount to historical conditions.
- To evaluate changes in the effectiveness of P and TSS runoff control practices to determine if their relative efficacy is altered under future climate conditions.

This study is part of an ongoing effort by WDNR to develop a Total Maximum Daily Load (TMDL) for P and TSS for the Fox River and Green Bay. We will delay development of specific adaptive management strategies for P and TSS runoff until the related TMDL has been approved and the climate-related Soil and Water Assessment Tool modeling is completed. However, it is still possible and desirable to move ahead and develop adaptive management strategies for other threats (eg. Invasive Species, Residential Development, Dams and Industrial Waste) as they may impact the eight conservation targets. Runoff may also be considered in a general sense.

Adaptive Management Strategies

The Green Bay Working Group held its initial Adaptive Management Workshop on April 7, 2010. A mix of twenty professionals from academia, Wisconsin Department of Natural Resources, U.S. Fish and Wildlife Service, and The Nature Conservancy convened for a day at the University of Wisconsin Green Bay campus to identify potential adaptive management strategies for Green Bay Conservation Targets. Participants prepared for the workshop by reviewing previous results of the earlier risk assessment workshops and reading a published review of climate adaptation literature. Individuals were assigned to one of the five breakout groups to address the five most vulnerable Conservation Targets: Northern Pike, Coastal Wetland community, Littoral Zone Community, Lake Sturgeon, and Benthic community. The groups were prompted to keep in mind the five overarching principles of adaptive management identified in the literature review article. (New Era for Conservation) published by The National Wildlife Federation. These principles are:

- Reduce other non-climate stressors
- Manage for ecological function and protection of biodiversity
- Establish habitat buffer zones and wildlife corridors
- Implement proactive management and restoration strategies
- Increase monitoring and facilities management under uncertainty

Another way of envisioning adaptive strategies is from a conservation strategy perspective such as:

- Protection
- Land / water management
- Species management
- Education / awareness
- Laws and policies
- Economic incentives

Other general strategy categories include research, using existing laws or policies (mainstreaming), enhancing resilience and adaptive capacity and externality control.

The adaptive management strategies developed by the separate breakout groups are outlined below:

Northern Pike

- Review Chapter 30 WI Stat. (waterways and wetlands) and Chapter 31 (dams) for adequacy in protecting coastal wetlands and removing or modifying dams
- Continue closed season for northern pike on tributary streams and daily bag limits
- Examine zoning regulations for adequacy in protecting hydrologic integrity of both surface and groundwater of west shore coastal zone
- Support TMDL for phosphorus and total suspended solids
- Bank sloping channel restoration
- Dam removal management
- Manage water levels at restoration sites
- Continue emphasis on wetland acquisition and stream habitat and wetland restoration
- Manage age structure to create resiliency in face of interdecadal water level variability
- Determine minimum number of age classes needed for resiliency (see above)
- Assess the loss of submergent aquatic vegetation on predation and juvenile mortality
- Define relations between nutrient loading water quality and sustainable spawning

Wetlands

- Examine policies and regulations protecting lands below the ordinary high water mark policies need to be preemptive to protect.
- Inventory fragmentation and connectedness and identify critical habitat for protection
- Protect, restore integrity of hydrologic regime

- Consider seed bank manipulation to counter *Phragmites* invasions of exposed lakebed
- Control nonpoint runoff through TMDL and best management practices particularly stream bank buffers.
- Consider woody vegetation for stream buffers
- Assess effectiveness of conventional Best Management Practices and support development of new methods
- Assemble oral histories, photos, records, and studies to document previous conditions; present to the public.

Littoral Zone Community

- Use and support the ongoing TMDL effort
- Incorporate climate change scenarios in next modeling effort and engage community planning
- Examine adequacy of treatment systems and storm water infrastructure to accommodate climate change conditions
- Investigate the need for a separate BMP strategy for spring runoff
- Engage with comprehensive planning to encourage more concentrated development
- Target community lakeshore planning such as multiple landowners boat access under various water levels and least impact marina siting
- How do we protect unfragmented habitat in Northern Green Bay?
- How do we engage and build community capacity?

Lake Sturgeon

- Continue restricted harvest
- Ensure availability of spawning sites at dams under high and low water conditions through Federal Energy Regulatory Commission Licensing
- Protect hydrologic integrity of watershed for small rivers to maintain genetic diversity
- Reduce runoff of suspended solids
- Provide in-stream habitat improvement where possible and at critical sites
- Develop innovations on how to pass fish upstream without passage of aquatic invasive species
- Assess significance of egg predation
- Assess success of downstream migrants passing over dams
- Determine the restoration potential of macrophyte habitat for juveniles
- Develop census techniques for juveniles 3 to 10 years old
- Assess introduction of daughterless carp

Benthic Community

- Continue current and proposed regulatory controls for nutrient and solids loading, Biochemical Oxygen Demand, and non-persistent toxic substances
- Complete and implement the lower Fox River TMDL

- Update wasteload allocation rule (NR 212) to determine need for adjustment resulting from climate change
- Continue existing programs to restrict spreading of Dreissenids and encourage regulatory activities aimed at preventing future invasions of exotic and invasive species
- Develop rapid response planning and implementation methods to improve existing aquatic invasive species control programs
- Develop riparian guidance for west shore area to control amount and type of manmade modifications to shoreline and runoff conveyance mechanisms
- Establish a clear understanding of the ordinary high water mark
- Consider dam removal or flow manipulation of the lower Fox River and other Green Bay tributaries
- Continue existing programs for identification and remediation of legacy pollutants
- Encourage low-impact development for future development in the watershed
- Evaluate the potential benefits of a temporary Lake Winnebago drawdown
- Investigate the possibility of isolating the Great Lakes from ocean-going vessels via cargo transfer
- Encourage research and regulatory attention to compounds of emerging concern
- Repeat the Green Bay Mass Balance Study PCB fate, transport, and food web modeling for post-climate change conditions
- Explore the utility of increased biofuel production (eg. switchgrass) from marginal cropland
- Continue exotic and invasive species education/awareness programs for boaters, anglers, etc.

The list of adaptive management strategies that we identified by the separate conservation target focus groups are first cut raw ideas in need of sifting and winnowing and then refinement. It is interesting to note that many of the strategies refer to ongoing programs, laws, policies, practices, etc. This suggests that to a large degree we are already doing the right things but we need to either do it better or do more of it. The emerging, overarching adaptive principle appears to be "reduce other non-climate stressors and thereby increase the resilience and adaptive capacity of the system". While this is not new, it is consistent with the sustainability mantra and within our grasp to accomplish.

Chapter 1 - Introduction and Background on Green Bay Ecosystem

Over the next 100 years, climate change will have significant impacts in the Great Lakes region of North America; particularly affected will be the shallow bays identified as freshwater estuaries. One such estuary, Lake Michigan's Green Bay, which is located in northeastern Wisconsin (Figure 1-1), is one of the largest freshwater estuaries in the world. Long term predictions for the Great Lakes include both warmer and wetter conditions, with mean summer temperatures in Wisconsin increasing by 2.2°-5° C by the middle of the 21st century (Vimont 2009). Precipitation is likely to be higher in winter and spring. By mid-century the probability of an April rainfall event larger than one inch in Green Bay is predicted to be 0.523. This is 12 percent higher than at present. By the end of the century, the probability of exceeding the one inch threshold is 0.613.

Green Bay is characterized as an estuary because it functions as a nutrient trap, has very high biological productivity, and because of the thermal and chemical differences between the water of the tributaries and that of Lake Michigan. The mixing processes in Green Bay are complex and driven by a wind induced seiche, a small lunar tide, and temperature differences in water masses. Warm water enters the bay in the south, and, at depth, cooler water comes into it from the north through several channels from Lake Michigan. This layered system operates somewhat like a conveyor belt, with warmer nutrient laden surface water moving north on the east coast and cooler Lake Michigan water moving south at depth on the west coast (Figure 1-1).



Figure 1-1. Green Bay Watershed

Morphometric estimates for Green Bay yield a length of 193 km, a mean width of 23 km, and a mean depth of 16 m. The water surface area is 4,248 km² with a total catchment of 40,469 km². This yields a water surface area to catchment ratio of 9.5. The corresponding ratio for Lake Michigan as a whole is much less: about 2.10. There are six major tributaries (Figure 1-1) with a total mean discharge of 3033 m³/sec. The largest tributary, the lower Fox River, accounts for approximately 35% of the total discharge, thus it has a major influence on the estuary. The large catchment and the shallow basin would result in nutrient rich waters without human influence. However, Green Bay and the Lower Fox River were considered to be severely polluted as early as 1925. Even so, the existing abundance of the bay's habitats remains vital to commercial and sports fishermen, boaters, duck hunters, beachcombers, bird watchers, and many people in the region who depend on it, both culturally and economically.

Some progress has been made over the last forty years or more in restoring the ecological integrity of the bay and the many beneficial uses it provides. Hundreds of millions of dollars, both private and public, have been spent in an effort to reduce pollution and restore habitat in the Green Bay ecosystem. Scientists and managers have recognized that the Fox River and the Green Bay ecosystem have become degraded because it is impacted by multiple stressors, not just one or two causal agents. Climate change poses a new kind of threat to the bay and its resources because it may alter the impact of the already existing stresses on the system. Consequently, as part of the Wisconsin Initiative on Climate Change Impacts (WICCI) a Green Bay Ecosystem Working Group has been created; its mission is to develop a collaborative approach, utilizing applied research, modeling, and adaptive guidelines to generate management strategies that address future climate change impacts. Adaptive management approaches will be developed and shared with Wisconsin policy makers, stakeholders, and citizens. The essential step in developing adaptive strategies to address climate change impacts is to assess the potential risks to the resource or system of interest. A description of the work that has been done as part of this initial step is the main focus of this report. However, before addressing the risk assessment work, we provide a thumbnail sketch of the research activities that have been conducted on Green Bay over the last four decades and a section on the present conditions of the bay of Green Bay. This will help to put the climate change and risk assessment work in perspective.

Chapter 2 - History of Research on Green Bay/Fox River

Few studies were conducted on Green Bay and its main tributary, the Fox River, before the 1960s. One study conducted by the Wisconsin Board of Health in 1925-26 was undertaken because of the many complaints by citizens regarding the bad odors and unsightliness of the water (Wisconsin Board of Health 1926, Bertrand et al. 1976). The results of the study revealed that during conditions of low flow and high temperatures, the Fox River, at its downstream end and portions of the southern bay, were hypoxic or actually anoxic. A second study conducted by the Wisconsin State Commission on Water Pollution in 1938-39 revealed that the benthic fauna in the Fox River and lower Bay were either absent or dominated by pollution tolerant forms

(Wisconsin State Committee on Water Pollution, 1939). Additionally, pelagic algae composition was dominated by blue-green algae in the latter part of the summer. These conditions were believed to be due to nutrients and biochemical oxygen demand (BOD) entering the bay from the Fox River.

The period of the 1940s and 1950s was a time of continued decline in the “health” of the river and bay. See Harris et al. (1987) for more details. “Dead zones”, created by hypoxic conditions, impacted the fishery. Commercial fish populations declined and bacterial contamination closed swimming beaches. The awakening of the public to the deterioration of the Fox River and Green Bay was not immediately followed by a management response. Management initiatives require a statutory authority and prior to 1972 the State of Wisconsin had little authority to respond to water quality problems. The situation was changed in 1972 when the Congress of the United States passed an amendment to the Federal Water Pollution Control Act of 1965 (P.L. 92-500 FWPCA).

Following the landmark legislation of 1965, the Wisconsin Department of Natural Resources (WDNR), and the newly founded Wisconsin Sea Grant Program, began to focus research efforts on Green Bay and the Fox River. In 1969, the Wisconsin Sea Grant Program initiated research on Green Bay (Smith et al. 1988) and the WDNR turned attention to the Fox River and developed a management model for BOD reduction (Patterson et al., 1975). Based on data collected from the early research efforts, the WDNR imposed BOD wasteload allocations on industrial and municipal discharges. The wasteload allocation program was highly effective: by 1978 the BOD loading, which had been as high as 170,150 kg per day in 1971, was reduced to 15,870 kg per day by 1978. Summer average dissolved oxygen concentrations in the inner bay improved from 1.6 mg/l in 1970 to 8.1 mg/l in 1982. But this proved to be only the first and easiest step; much more difficult problems remained. WDNR continued to focus mainly on point source problems, particularly polychlorinated biphenyl pollution and remediation of contaminated sediments.

From 1978 to 1988, supported by Federal and State funds, the National Sea Grant Program, guided by a holistic perspective, undertook investigations on the chemical and physical characteristics, trophic structure, nutrient dynamics, and geology of the bay. This has led naturally to an ecosystem approach in developing and proposing management guidelines where the land-water interface, watersheds and non-point source pollution are the primary interest (Harris et al. 1988, The Lower Fox River Monitoring Program, 2009). The evolving ecosystem perspective for Green Bay parallels an unfolding interest in the same approach that is rising throughout the Great Lakes basin in the area of environmental policy. This perspective is characterized by several features: a premise of “environmental holism”; a systemic as, distinguished from a particularistic perception of the problems of ecosystem well-being; a primary focus on ecological concepts, as opposed to engineering, economics, or jurisdictional concepts; a perception of the existence of some self-regulating capacity on the part of an ecosystem; and a recognition of the marked responsiveness of many ecological systems to

natural or human activities (stressors). It is in this context that we have developed our approach to ecological risk assessment and applied it to the Green Bay ecosystem.

As stated earlier, a first step in developing adaptive strategies to climate change is to assess the potential risks to the resource or system of interest. Based on previous experience it was proposed that a way to assess the potential consequences of climate change is to evaluate the risk posed to the Green Bay Ecosystem by regional shifts in temperature, precipitation and weather events. The relative magnitude of risk to valued components of the ecosystem can be estimated by examining the interaction among ecosystem stressors and the valued components of ecosystems using the mathematical tools of fuzzy set theory and graph-theoretic analysis. An ecosystem stressor is defined as any physical, chemical or biological entity that is having an adverse impact on the system. Valued ecosystem components may be as specific as a particular species, a particular ecological service or as general as any beneficial use of the ecosystem. We will first identify existing impaired uses of the bay, the stressors causing the impact on uses, and then look at some indicators of the “health” of the bay.

Chapter 3 - Green Bay Today – Understanding the Present Condition

The bay as a natural ecosystem has provided a multitude of resources and processes for humans over centuries. Resources (water and food) may be viewed as natural capital. Processes such as, waste assimilation, nutrient cycling, and climate modification are ecological services that have “hidden” but real economic value as well. When the bay becomes degraded and “unhealthy”, some of these values are lost. Today we recognize a dozen impaired uses (Figure 3-1). Some impaired uses have multiple causes, while others may be due to a single pollutant. Regardless, if the bay is to remain a sustainable ecological and economic resource for future generations, the causes of impairment must be corrected and the bay restored to a healthy state.















 Restrictions of Fish and Wildlife Consumption	 Restrictions on Dredging Activities
 Tainting of Fish and Wildlife Flavor	 Eutrophication or Undesirable Algae
 Degradation of Fish and Wildlife Populations	 Degradation of Aesthetics
 Fish Tumors and Other Deformities	 Loss of Fish and Wildlife Habitat
 Bird or Animal Deformities or Reproduction Problems	 Degradation of Phytoplankton and Zooplankton Populations
 Degradation of Benthos	 Beach Closings
 = Impaired Use	 = Nutrient Impaired Use

Figure 3-1. Impaired Uses in the Area of Concern

Primary Stressors

Years of research have revealed that the bay is impacted by multiple stressors (Figure 3-2). From Figures 3-1 and 3-2, you can see that nutrient loading and solids loading are judged to be stressors that impact many desirable uses of the bay. We will first look at indicators related to these important stressors and then proceed to address other aspects of the “health” of the bay.

Criteria	Human Health	Aesthetic	Economic Costs	Energy/ Nutrients	Biota	Multiplier Effect
Stressors						
Nutrient Loading	0	3	2	3	3	2
Heavy Metals	1	0	1	1	1	1
Wetland and Shoreline Filling	0	2	1	2	3	1
Solids Loading	0	3	2	3	3	2
Persistent Organics	2	0	2	1	1	1
Biochemical Oxygen Demand	0	1	3	1	2	2
Exotic Invasions	0	1	2	2	3	1
Nonpersistent Toxics	0	0	2	1	1	1
Impact Scale						
0 No apparent impact	1 Minor Impact		2 Moderate Impact		3 Major Impact	

Figure 3-2. Primary stressors on the bay.

Phosphorus

It is most instructive to know how phosphorus levels have changed in Green Bay over time. Because of the Green Bay Metropolitan Sewerage District (GBMSD) monitoring program (Figure 3-3) and research efforts at UW-Green Bay, a record of total phosphorus concentrations covering a period of almost 40 years in Green Bay is available (Figure 3-4). The Remedial Action Plan (RAP) target set in 1993 for total phosphorus was set at 0.05 mg/l to 0.107 mg/l for the Area of Concern (AOC), which is essentially zone 1 plus the river up to the De Pere dam. Concentrations continue to far exceed the RAP target and, in fact, it appears that there has been little change in phosphorus concentrations since an initial decrease in the 1970s following improved sewage treatment required by the Clean Water Act and a ban on phosphorus detergents (Figure 3-4). It remains to be seen if the recent lower levels of phosphorus (2007-2008) continue.

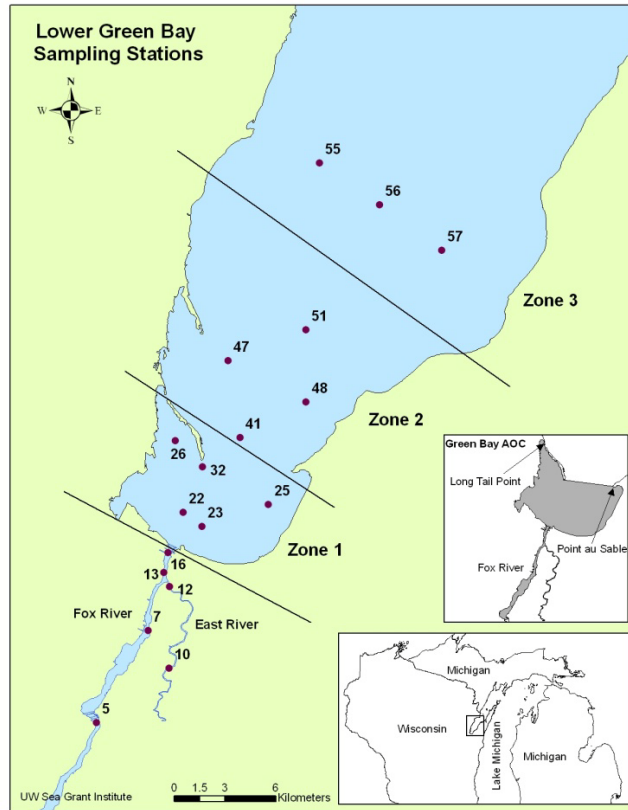


Figure 3-3. Sampling stations and the area of concern.

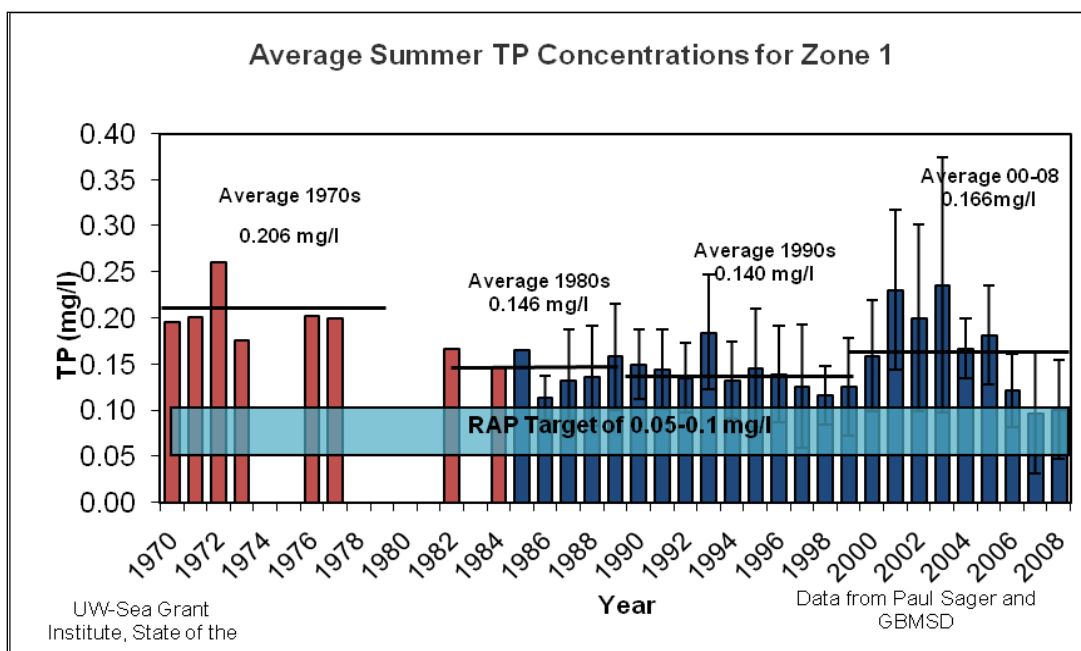


Figure 3-4. Graph of average TP concentrations for zone 1.

The higher average phosphorus concentration from 2000 to 2005 may be due to a combination of lower water levels, changes in algal composition, introduction of zebra mussels, and increased resuspension due to lower water levels and a change in prevailing wind direction. There was no apparent change in loading from the Fox River during this time.

Sediment and Total Suspended Solids

Total suspended solids (TSS) are all of the particles in the water that can be trapped on a filter. TSS includes a wide variety of material, such as soil, algae, decaying organic matter, and particles discharged in wastewater. Volatile suspended solids (VSS), a component of TSS, are the organic (biotic) solids, and are derived from algae, decaying plant and animal material, and organic wastes from sewage and industrial discharges. The remainder and majority of TSS consist of inorganic solids like silt, clay, and fine sand.

Suspended solids enter Green Bay mainly from the Fox River and its tributary streams. Suspended solids negatively affect tributary streams, Lake Winnebago, the Fox River, and Green Bay in a number of ways. TSS scatter and absorb sunlight, reducing the amount of light reaching submerged vegetation. In very murky, turbid water, photosynthesis is limited and submerged plants like water celery cannot survive. Reduced photosynthesis provides less oxygen to the water column and in combination with oxygen consumption by bacteria lowers dissolved oxygen. Occasional fish kills from depleted oxygen conditions have been reported in Green Bay, the Fox River, and Lake Winnebago. Decreased visibility caused by lowered water clarity can affect the ability of animals like fish and diving birds to find and capture food. Suspended solids foul gills and, therefore, increase stress in fish and invertebrates. As suspended solids settle to

the bottom sediments, they can bury fish eggs, fish nursery areas, and the micro-habitats used by invertebrates, such as amphipods and aquatic insects.

The suspended solids load at the mouth of the Fox River for the years 1995-1999 was 132,000 tons/yr (119,400 mt/yr⁻¹) (TMDL draft report 2005). This amounts to 360 tons per day (327 mt/day) in an average year which is equivalent to 24 dump truckloads per day of sediment deposited into Green Bay. However, approximately 40-60% of the annual load is delivered from tributaries in a much shorter period of time (approximately 4 days), primarily in the spring (www.uwgb/watershed). The RAP target for TSS set in 1993 is 7 mg/l to 14 mg/l. TSS concentrations in the AOC remain well above these target levels (Figure 3-5).

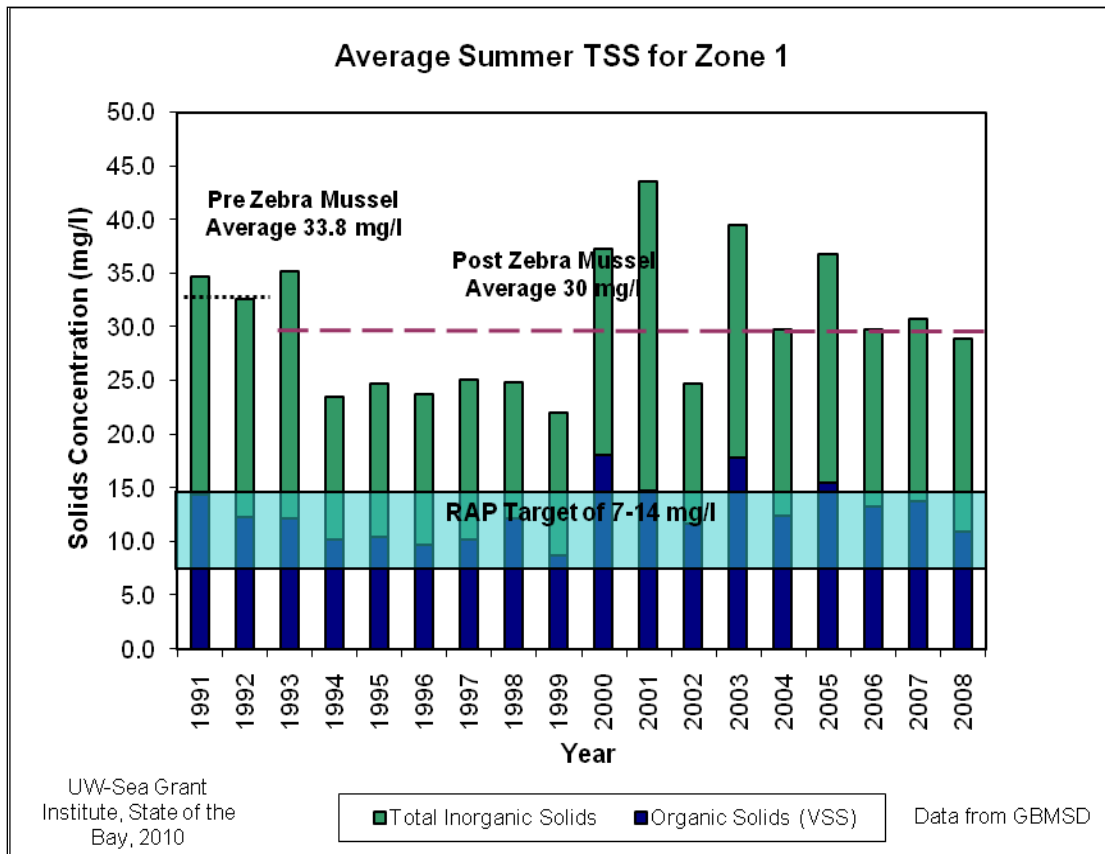


Figure 3-5. Graph of mean TSS concentrations for zone 1.

Chlorophyll

Chlorophyll *a* is a green pigment that plants use to convert sunlight, carbon dioxide, and water into sugars through photosynthesis. Therefore, chlorophyll *a* concentrations provide an indirect measure of the amount of living algae suspended in the water column. An increase in nutrients, especially phosphorus, stimulates an increase in algae production if sufficient light is available. Given an increase in phosphorus, algae populations will continue to increase and since algae are solids suspended in the water, water clarity and light penetration are reduced. Algal

blooms (abundant growths that cause the water to appear green or bluish green) can greatly reduce light penetration, and the decay of large amounts of algae can reduce dissolved oxygen concentrations.

Chlorophyll *a* concentration does not differentiate between the types or species of algae that are growing in a particular location. Cyanobacteria (blue-green algae) can become very problematic under high phosphorus conditions. Cyanobacteria are capable of fixing nitrogen directly from the air, unlike more desirable green algae, and are therefore limited only by the amount of available phosphorus. They readily use increased amounts of phosphorus and out-compete the more desirable green algae that form the base of the bay food chain. Chlorophyll *a* concentrations have only been measured in Green Bay on a routine monthly basis since 1990. The RAP target concentration for chlorophyll *a* of 13 ug/l to 32 ug/l is still being exceeded (Figure 3-6).

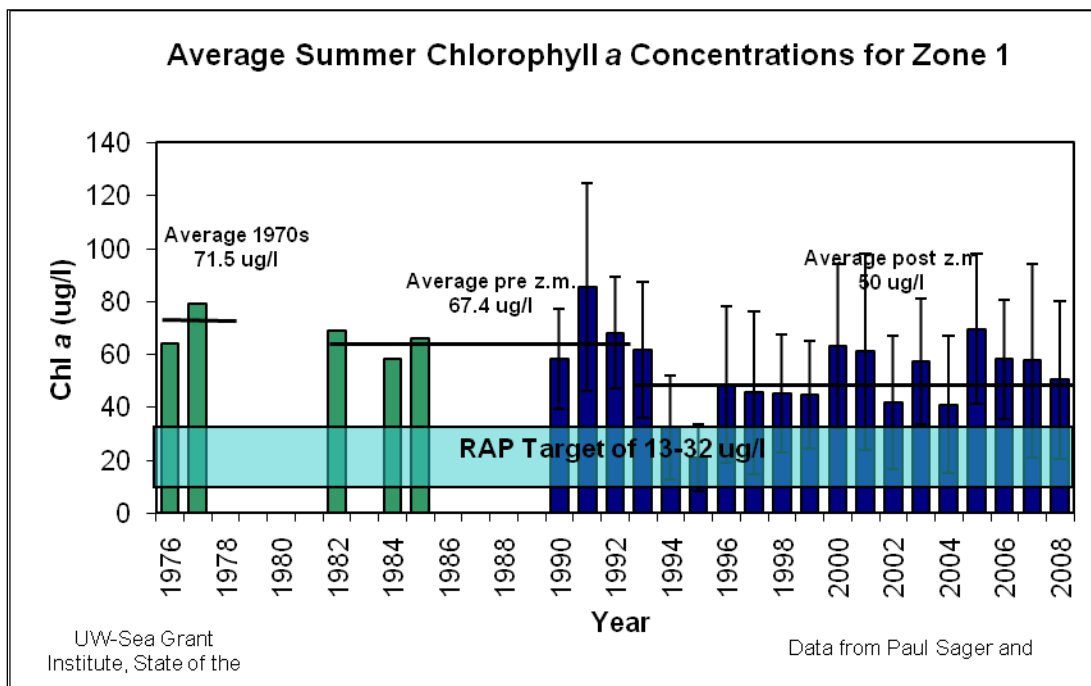


Figure 3-6. Graph of average chlorophyll *a* concentrations for zone 1. .

Water Clarity and Secchi Depth

One simple measure of water clarity is Secchi depth. A Secchi disk is a black-and-white disk that is lowered into the water until it is no longer visible. The point where it disappears from sight is the Secchi depth. Higher Secchi depths indicate clearer water and lower Secchi depths indicate more turbid water. Water clarity is impacted by algae, soil particles, and other suspended particles in the water. The RAP sets an objective range of average summer Secchi disk depth of 0.7 meters (2.3 feet) to 1.3 meters (4.0 feet) for the Fox River and inner bay (AOC).

Studies conducted in the early 1990s (McAllister 1991) defined the relationship between water clarity, light availability, and the maximum depth at which a particular submergent plants can colonize and persist. The 0.7 meter Secchi depth was set by RAP members as the minimum restoration target for the AOC. Secchi depth continues to fall short of desired levels (Figure3-7).

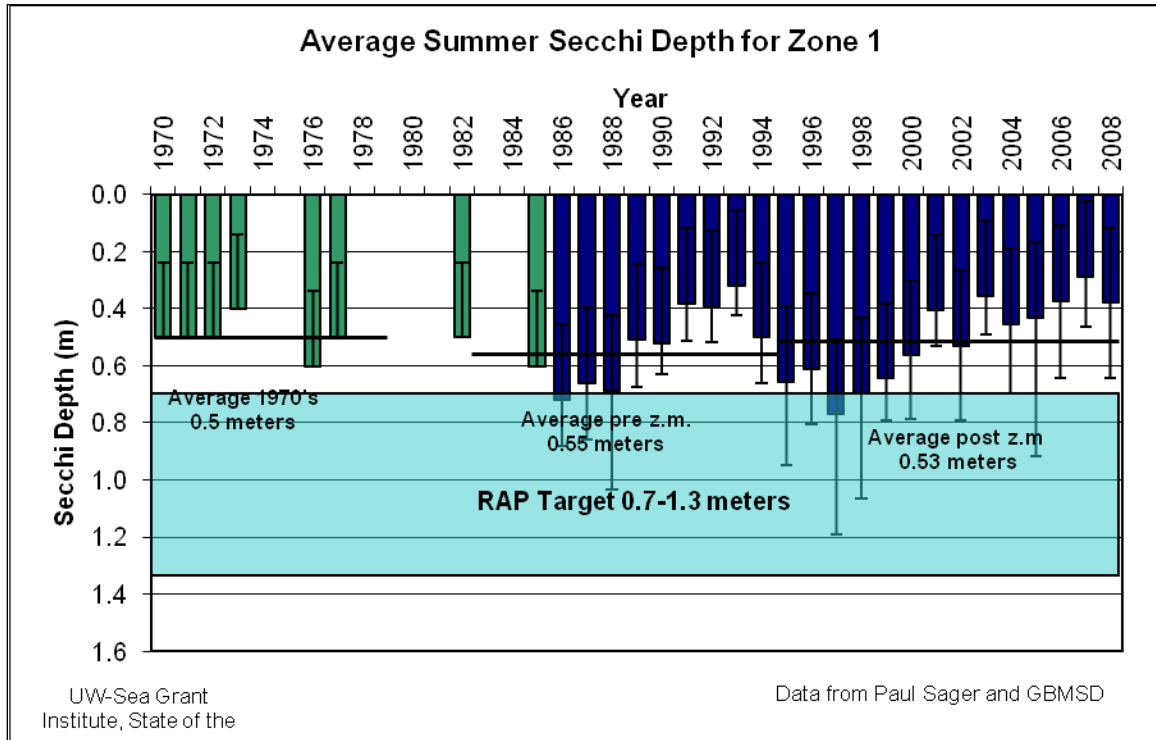


Figure 3-7. Graph of mean Secchi depths for zone 1.

Dissolved Oxygen

The amount of oxygen dissolved in lake water depends on wave action, water flow into the bay, water temperature, and photosynthesis by aquatic plants. It also depends on the biological oxygen demand (BOD). BOD is the amount of oxygen required by all organisms living in the lake, including algae and plants, bacteria, invertebrates like insects, and vertebrates like fish.

Since the control of oxygen-demanding (BOD) organic wastes from sewage and industrial facilities in the 1970s and 80s, average dissolved oxygen (DO) levels in the inner bay and the river (AOC) have generally met the desired standard of five ppm. There are times, however, when the measured minimum concentration drops below this level (Figure 3-8).

Averages tell something, but as far as the organisms are concerned, it is the extreme conditions that make survival difficult. For example, there have been many instances in which the measured minimum oxygen concentration has fallen below the 5 ppm DO standard, while the average concentration remained above the standard (Figure 3-8).

The large variation in oxygen levels likely reflects the cumulative effects of upstream organic waste and algal production, sediment oxygen uptake, and bay water interactions. So, while the general oxygen picture looks good, the available data reveal that it can be marginal at times. Once again, high phosphorus loads and excess algae production contribute to these occasional problems.

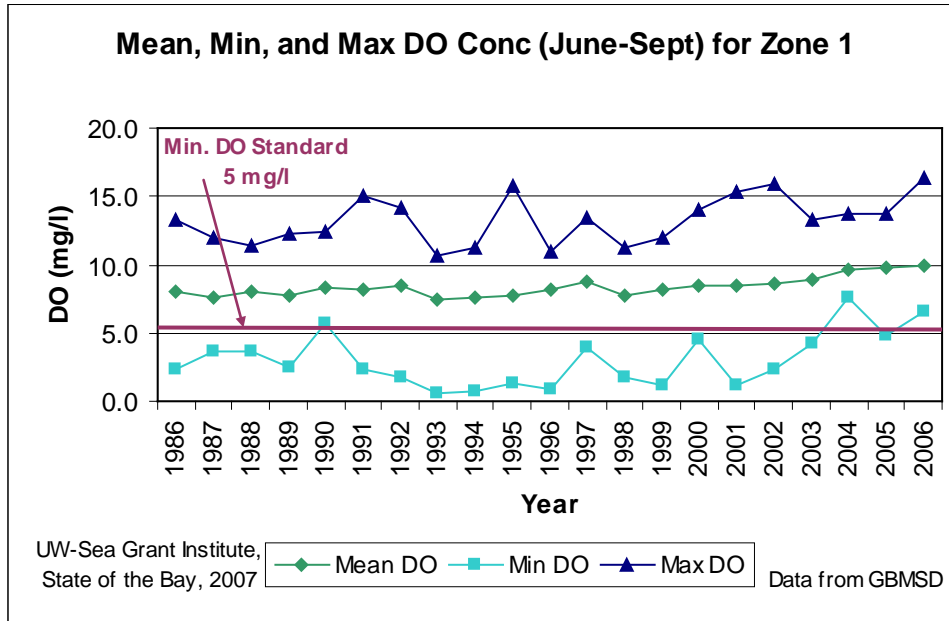


Figure 3-8. Mean, minimum, and maximum dissolved oxygen concentrations (mg/l) for zone 1. The purple line indicates the minimum dissolved oxygen standard of 5 ppm.

Temperature

Because of the bay’s depth configuration (bathymetry), with shallow waters in the south (≤ 15 feet) and deeper waters to the north (≥ 40 feet), the southern part of the bay supports a warm water fishery and the northern part supports a cool and cold water fishery. There is a clear temperature gradient from south to north (Figure 3-9).

Mean water temperatures in the bay and at the river stations are highest in July and August (Figure 3-9). The maximum water temperatures are important because of the relationship between temperature and dissolved oxygen. Colder water can hold more dissolved oxygen than warmer water. As water becomes warmer, the amount of dissolved oxygen it can hold decreases. Therefore, during the summer months, when the water temperature is warmer, temperature may limit the total amount of oxygen present. It is not clear how climate change will affect temperature, but it is quite likely we will see both seasonal and spatial changes during the coming decade.

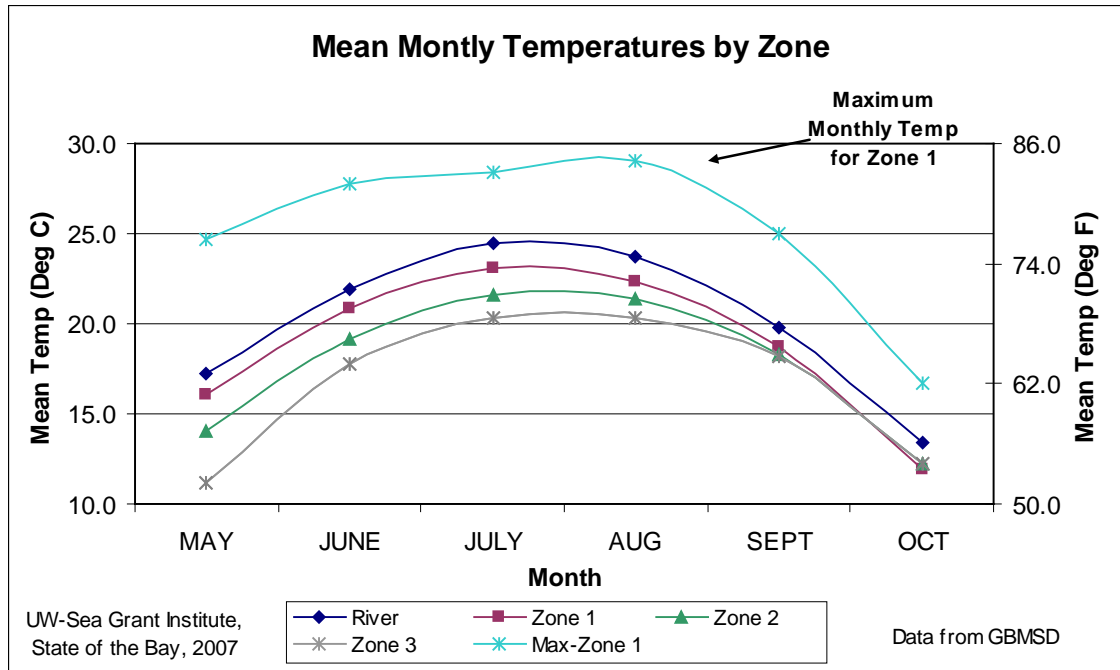


Figure 3-9. Mean monthly temperatures by zone and maximum monthly temperatures for zone 1. Zones 2 and 3 are north of zone 1. Zone 3 is north of Dykesville in about 10 meters (30 feet) of water.

Beach Advisories and Closings

Numerous swimming beaches are found along the Green Bay shoreline (Figure 3-10). However, beach closings have occurred at several of these beaches, primarily those in Door County. These beach closings have occurred due to elevated bacteria levels, and the source of bacterial contamination is not completely known, but much is attributed to fecal contamination from gulls. Beach closings negatively affect tourism and recreation.

The state of Wisconsin received grants from the federal BEACH (Beaches Environmental Assessment and Coastal Health) Act of 2000 for monitoring beaches. The BEACH Act requires all coastal states to adopt beach water-quality standards and to develop monitoring programs. Each beach was given a priority ranking for monitoring based on several factors, including how many people use each beach and its environmental status. A high-priority ranking means that a beach is monitored five times a week, medium-priority beaches are monitored at least two times a week, and low-priority beaches are monitored once a week. For Green Bay beaches in Wisconsin counties, only Brown and Door county beaches were given priority rankings; beaches located in Kewaunee, Oconto, and Marinette counties are not being monitored (Table 3-1).



Figure 3-10. Location of Green Bay Beache

Table 3-1. Door County beach closings/advisories for years 2003-2006.

Door County Beach Closings/Advisories										
Beach name	2003		2004		2005			2006		
	# Advisory	# Closure	# Advisory	# Closure	# Advisory	# Closure	# Wet Weather Advisory	# Advisory	# Closure	# Wet Weather Advisory
Egg Harbor Beach	3	0	8	1	2	1	0	2	0	8
Ellison Bay Town Park Beach	3	1	5	1	3	0	0	0	0	0
Ephraim Beach	0	1	0	0	2	1	0	0	0	8
Fish Creek Beach	3	1	5	1	3	3	0	1	2	8
Haines Park Beach	0	0	2	0	0	0	0	0	0	0
Murphy Park Beach	0	1	7	5	4	2	0	5	0	8
Nicolet Beach	1	0	4	2	5	1	0	1	0	0
Otumba Park Beach	5	2	6	2	4	2	4	11	1	7
Sister Bay Beach	4	0	3	1	3	0	0	0	0	0
Sunset Park Beach Sturgeon Bay	9	1	12	1	8	4	4	10	2	8
Total	28	7	52	14	34	14	8	30	5	47

Data Source: 2003, 2004, 2005, and 2006 monitoring data from Beach Health.

Advisory is the number of times the *E. coli* level is >235 and <1000 cfu/100 ml.

Closures is the number of times the *E. coli* level is >1000 cfu/100 ml.

Wet Weather Advisory is an advisory posted for 24 hours after all rain events of 1/4 inches within 24 hours, which results in increased run-off and increases potential for contamination.

Coastal Wetlands and Littoral Zone

Coastal wetlands and the littoral zone are very important parts of Green Bay, particularly because they serve as the functional link between uplands and open water. We discuss these features below.

Natural features of our landscapes, including forests, lakes, wetlands, are largely created by the geology of the region. This is certainly true for the coastal wetlands of Green Bay, which are mostly found on the gently sloping west shore of the bay. The east side of Green Bay has only a few wetlands in shallow east shore bays and at river mouths, due to a steep dolomitic outcropping called the Niagara Escarpment. In 1978, the Wisconsin State Legislature defined wetlands as

"An area where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic (water-loving) vegetation and which has soils indicative of wet conditions."

Coastal wetlands are typically characterized by transitional zones from aquatic to upland, and each of the zones can be recognized by the wetland vegetation present (Figure 3-11).

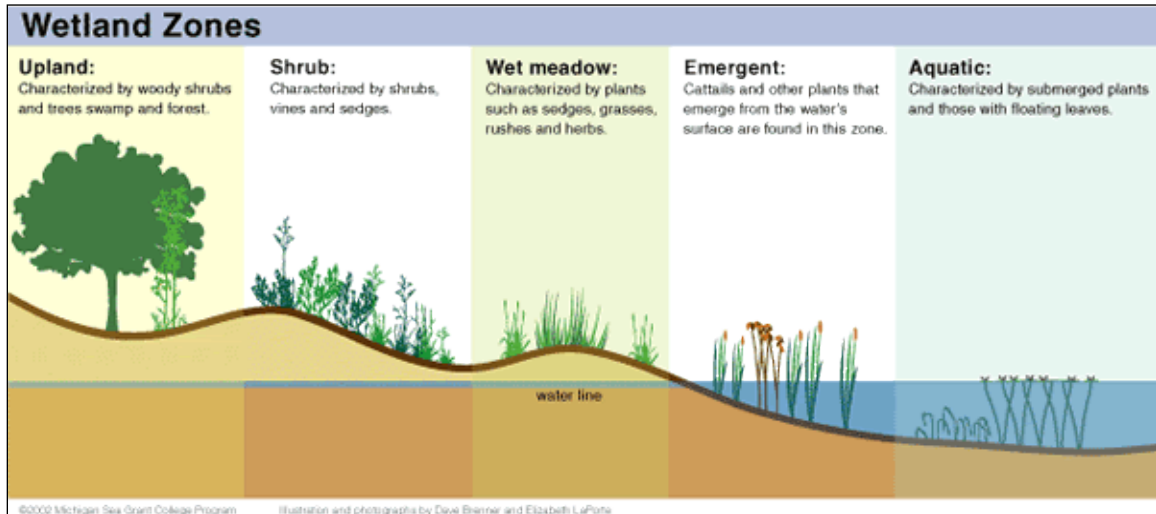


Figure 3-11. Diagram of a typical coastal wetland transition from lake to upland. Figure from Michigan Sea Grant.

The west shore of Green Bay is a major wetland complex for Lake Michigan. Approximately half of the coastal wetlands in Wisconsin are located along the west shore of Green Bay. Submerged aquatic vegetation (outermost zone Figure 3-11) is essential to the overall health of the Green Bay ecosystem. Submergents are important because they not only provide habitat and food but also anchor substrate, which helps to curtail resuspension of bottom sediments.

In the AOC, submerged aquatic vegetation populations have been all but eliminated. This loss is attributed to high water turbidity in lower Green Bay. One of the Green Bay RAP objectives is the re-establishment of aquatic habitat—in particular, submerged aquatic vegetation. In order to restore submerged aquatic vegetation, improved light conditions are necessary. *Vallisneria americana* (wild celery) is a submergent that was once abundant in Green Bay, and it was the dominant submergent plant along the west shore of Green Bay, south of Long Tail Point. A study conducted in Green Bay found that light is the primary limiting factor and that an average Secchi depth goal of 0.7 meters would just meet the limit for *Vallisneria* in the AOC (McAllister 1991).

An improved littoral zone, the zone nearshore where light penetrates to the bottom, and increased submerged aquatic vegetation are vital for the fish community. A study conducted in Green Bay concluded that fish diversity is high in the littoral zone (Brazner 1997). The study also found that undeveloped wetland sites had a higher fish diversity and abundance than developed wetland sites and developed and undeveloped beach sites (Brazner 1997). In addition, the undeveloped wetland sites contained the majority of sport fish species caught in the study (Brazner 1997).

Landward from the submergent zone, the emergent, wet meadow, shrub, and upland zones (Figure 3-11) are used for nesting and foraging by a wide variety of birds, reptiles and amphibians, and a few mammals.

How have the coastal wetlands in Green Bay changed over time?

Hydrologic conditions are of singular importance for the maintenance of a wetland's structural and functional characteristics. The water level of Green Bay has a history of dramatic change. The U.S. Army Corps of Engineers (USACE) has recorded water levels for Green Bay since the late 1800s, and it is clear that water level varies on several time scales, including [daily](#), [annually](#), and on roughly [ten- to twenty- year](#) cycles. Since 1964, the monthly mean water level of Green Bay has fluctuated by more than six feet! Changes in lake levels clearly impact the macrophyte communities of [coastal marshes](#) in Green Bay.

Although these wetland changes appear devastating, they are in reality a part of a longer submergence and emergence cycle. In order for some wetland communities to remain viable they must be subjected to periodic disturbances in water levels. Such communities are sometimes called “pulse stable” communities.

However, permanent changes in coastal wetlands have been caused by human activity. It is estimated that during the 1840s, 38.9 km² of coastal marshes and 186.5 km² of coastal swamps existed along Green Bay's west shore (Bosley 1976). Within the past century, however, 60% of the coastal marshes have been converted to agricultural land, filled with dredge spoils, or invaded by cottage settlements. Swamp forests of tamarack, alder, white cedar, and black ash have been harvested for timber—almost 155.4 km² of these forests have disappeared

altogether (Bosley 1976). Today, approximately only 15.5 km² of marsh and 31.1 km² of swamp remain at high water levels.

The loss of these wetlands is permanent. An accurate assessment of the effect these wetland losses have had upon the Green Bay ecosystem can probably never be made. However, wetland losses have significantly influenced the decline of Green Bay and Lake Michigan fisheries as well as waterfowl populations and water quality.

The bay as a whole has experienced degradation beginning in the mid 1800s. The ecological integrity of the lower one third of the bay has been impacted the most. Loss of beneficial uses has followed. While restoration efforts are underway and appear promising, we must now consider the potential impacts of climate change and what they may mean to successful restoration of ecological integrity and beneficial uses.

Chapter 4 - Risk Assessment and Climate Change Impacts

One of the primary objectives of all WICCI working groups is to assess the vulnerabilities of the particular resource or ecosystem to the potential impacts of climate change. The Green Bay Ecosystem Working Group has focused initially on valued components of the natural ecosystem and climate caused changes that will likely occur over the next 30-50 years. It is our intent to consider the “built environment” at a later time. In any case the ultimate outcome is to formulate adaptive management guidelines for the Green Bay ecosystem resources and the Green Bay community.

Defining and Identifying Risk

Risk is formally defined as the probability of an event occurring x it’s consequence. In the context of climate change we may wish to know, for example, if there is an increased likelihood of a two inch rainfall occurring in the spring thirty years from now when compared with the present. The methods used to delineate these probabilities are described in the section of this assessment document containing the report of the Climate Change Work Group. The impact of an event (consequence) may be identified through an assessment of expert opinion using a defined mathematical procedure.

We outline a process for accomplishing this purpose in the next section and describe its application at a workshop held in June 2008. The focus of this workshop was the identification of those stressors that pose the greatest risk to the Green Bay ecosystem when evaluated from the perspective of a set of ecosystem values/services. After this baseline assessment was completed, the workshop participants moved on to an assessment of potential climate change impacts on the ecosystem. This assessment was conducted by evaluating the degree to which regional shifts in temperature and precipitation and frequency of storm events are likely to impact the ecosystem stressors.

The same methodology was used in a workshop that was held in August 2009. In this workshop the purpose was to assess climate change impacts on Green Bay conservation targets. The workshop procedures and results are described in Chapter 5. The results from these two workshops provide important insight to potential climate change impacts on the Green Bay ecosystem.

Process Overview

The methodology employed in the workshops is based on soliciting insights from those who have knowledge and expertise about the ecosystem that is being assessed. In a formal workshop setting the expert participants are asked to provide numerical values that represent their best judgment about the degree to which a given stressor is impacting the ecosystem. The numerical results are analyzed with the aid of a mathematical tool from fuzzy set theory. After identifying potential climate change impacts on the ecosystem stressors, again based on numerical values that represent expert judgment, the fuzzy set tool can be used once again to assess climate change impacts.

Briefly, fuzzy set theory is an area of mathematics that provides a theoretical basis for making informed judgments and decisions when full precision is lacking. Whereas traditional mathematics requires precise binary statements, such as “a given object is or is not in a set or collection”, fuzzy set theory does not require a binary statement for membership in a set. For example, when considering polluted rivers it might be reasonable to use 0 to describe a pristine river, .5 to describe a river that is somewhat polluted, and 1 to describe a river that is extremely polluted. Or, one could use the entire range of numbers between 0 and 1 as a scale for describing polluted rivers. Fuzzy set theory enables one to draw logically valid conclusions based on sets whose memberships are specified in a tertiary manner or some other non-binary form. When used in conjunction with expert insight, group knowledge can be synthesized and priorities identified.

This particular process and method of ecological risk assessment was developed and tested by faculty at University of Wisconsin-Green Bay and colleagues from the University of Wisconsin-Milwaukee, University of Minnesota, Wisconsin Department of Natural Resources, US Fish and Wildlife Service and US EPA during the 1990s. Three papers explain the process and methodology in detail (Harris et al., 1994; Wenger and Rong, 1987; Wenger et al., 1999). The process has the advantage of synthesizing expert opinion in a methodical manner and rigorously identifying priorities.

The first step at the 2008 workshop was to form an interdisciplinary work group whose members have a working familiarity (science and/or management) with the Green Bay Ecosystem. Twenty professionals participated in the assessment. The second step was to define the boundaries of the ecosystem. Because we were interested in comparing the results with a similar exercise carried out almost two decades ago (1991), the boundaries of the Green Bay Ecosystem were kept the same as in the earlier assessment. Consequently the ecosystem was

bounded as the entire Bay with an emphasis on the Lower Bay (Area of Concern). While the watershed was outside the boundary, the connection to the bay was acknowledged by way of connecting tributaries.

Once the system was bounded, the participants focused attention on identifying significant anthropogenic stressors affecting the ecosystem. Once again we used the earlier experience as a starting point. Eight of the identified stressors were the same as those in the group of stressors that formed the basis of the assessment that was done in 1991. Three additional stressors were identified: Hydrologic Modifications, Pathogens, and Biota Harvest (see Table 4-1). Following this, the participants identified a set of six ecosystem values and services of interest (see Table 4-2). Once workshop participants had identified a set of anthropogenic stressors affecting the ecosystem and a set of ecosystem values and services, they were then asked to assign risk values to each stressor/ecosystem value pair. The relative degree of risk reflects the degree to which a given stressor is contributing to ecosystem impairment as indicated by the impact of the stressor on the ecosystem from the perspective of the given ecosystem value or service. Participants used a scale of 0 – 3 with the following definitions: 0 – no impact, 1 – minor impact, 2 – moderate impact, 3 – major impact.

Table 4-1. Ecosystem Stressors

Stressor	Notation
Nutrient Loading	NL
Heavy Metals	HME
Wetland/Shoreline Filling	WSF
Solids Loading	SL
Persistent Organics	PO
BOD	BOD
Aquatic Exotics	AE
Non-Persistent Toxins (NH ₃ , microcystins)	NPT
Biota Harvest	BH
Hydrologic Modifications	HMO
Pathogens (VHS, botulism, <i>E.coli</i>)	P

Table 4-2. Ecosystem Values/Services

Ecosystem Value	Notation
Human Health	HH
Aesthetics, Culture, and Recreation	ACR
Biota (populations and health)	B
Natural System Function	NSF
Economic Impacts	EI
Habitat	H

The initial step in this exercise was carried out in four separate breakout groups with the members of each group compiling a matrix. The Risk Consensus Matrix was completed after a discussion in a plenary session was employed to resolve differences among the workgroup results. The resulting Risk Consensus Matrix can be referred to as the “baseline matrix” because it implies a risk assessment based on current conditions; i.e., before climate change impacts. A fuzzy set analysis was then conducted, the results of which provide a ranking of the stressors according to the severity of their impacts as shown in Figure 4-1.

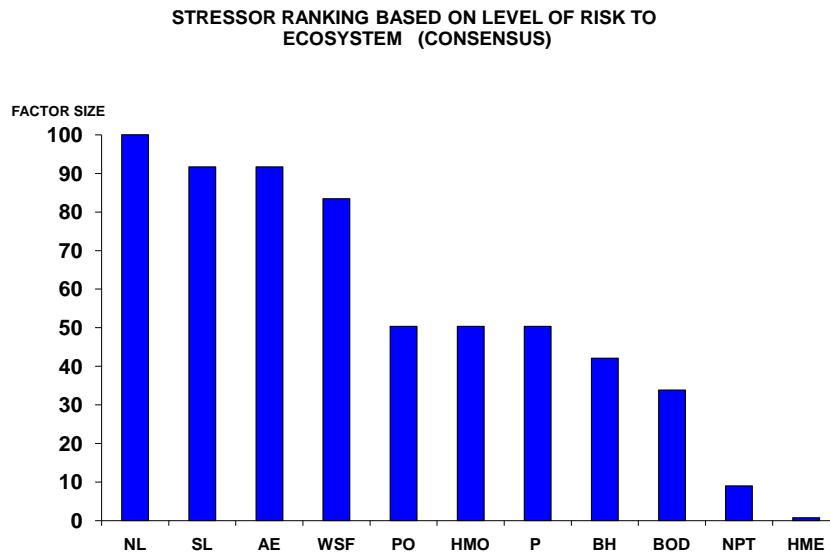


Figure 4-1. Stressor ranking.

The Risk Consensus Ranking under existing conditions shows that four stressors (Nutrient Loading, Solids Loading, Aquatic Exotics, and Wetland/Shoreland Filling) have a notably greater impact on the ecosystem than the others. A second group (Persistent Organics, Hydrologic Modifications, Pathogens, Biota Harvest, and BOD) consists of stressors which have a more moderate impact on the ecosystem than the first group. Finally, the two remaining stressors (Non-Persistent Toxins and Heavy Metals) have a significantly lower impact on the ecosystem.

Variation of Expert Opinion

To get a sense of the variation of the expert opinion, we analyzed the matrices resulting from the work of the individual teams. When the rankings of the four teams and the Risk Consensus Ranking are arrayed in a single bar graph, as shown in Figure 4-2, there is a strong clustering for Nutrient Loading, Solids Loading, Aquatic Exotics, and Wetland/Shoreland Filling in the top four places. For some of the other stressors there is a good deal of inconsistency, most notably, Hydrologic Modifications, Pathogens, Biota Harvest, and BOD. Said another way there is good agreement on the top four stressors and bottom two and less agreement with those in the

middle. We infer from this that there is strong agreement among professionals about the top four stressors and the bottom two. There is less agreement about those in the middle.

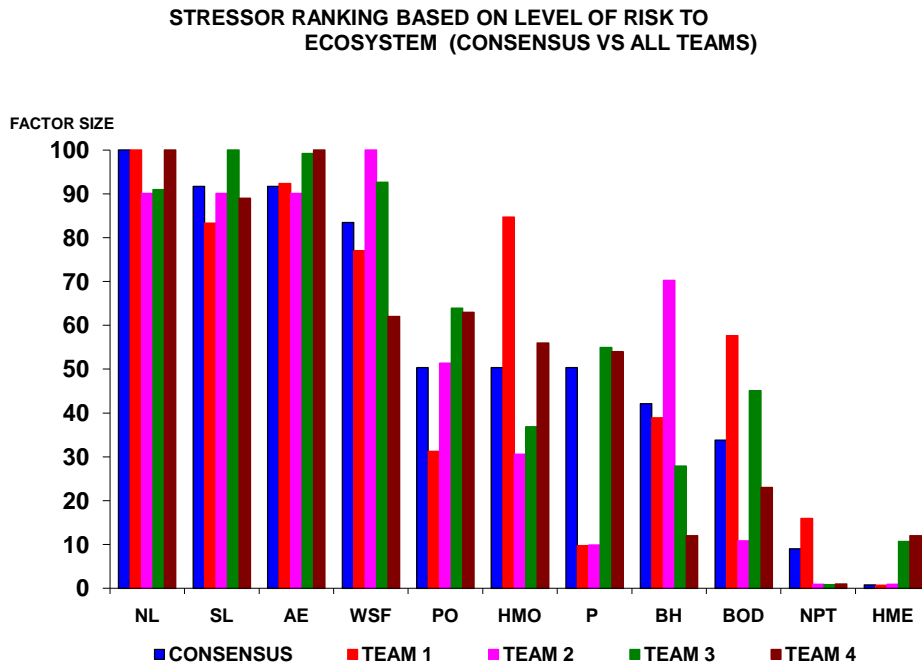


Figure 4-2. Stressor ranking between groups.

Current Risk Perspective

Workshop participants identified eleven stressors believed to be of particular importance because of their multiple impacts on six significant ecosystem values. Presently Nutrient Loading, Solids Loading, Aquatic Exotics and Wetland/Shoreland Filling, pose the greatest risk to the Green Bay Ecosystem. These four stressors jointly impact aesthetic, cultural, recreational and economic values, as well as natural system functions, biota and habitat.

Nutrient Loading, together with Solids Loading, reduces water clarity, creating unsuitable conditions for the growth and existence of desirable submergent aquatic vegetation. Underwater plants are essential for a productive littoral zone promoting a balanced and productive aquatic insect and fish community. The littoral zone is also an important habitat for aquatic birds and mammals. In essence much of the littoral zone in Lower Green Bay has been lost.

Nutrient Loading and Solids Loading also impact the pelagic and benthic areas of the Bay. High phosphorus concentrations stimulate excess algae production, particularly cyanobacteria, some of which produce toxins and most of which are undesirable as a food source for zooplankton. Consequently, food chain efficiency is reduced which is reflected in an unbalanced fish community favoring bottom feeding carp and resulting in fewer predator fish.

In summer months, excess algal growth also leads to low oxygen conditions below the thermocline, thereby creating areas of “dead zones”.

Wetland/Shoreland Filling compounds the loss of the littoral zone, further reducing an important habitat component of the Bay. For the Bay as a whole, sixty percent of the original wetlands have been lost to filling or hydrologic modification. In the Area of Concern (AOC) ninety percent of the wetlands have been destroyed, mostly by filling. These three stressors, Nutrient Loading, Solids Loading, and Wetland/Shoreland Filling, together have a profound effect on aesthetic, cultural and recreational values.

Aquatic Exotics, one of the four primary stressors, is a mounting problem in the Great Lakes System in general, and in Green Bay in particular. Presently over 180 exotic species have been introduced into the Great Lakes System, most of them through human activities. In Green Bay, three species – zebra mussel, quagga mussel and common reed (*Phragmites*) – are apparently changing the nutrient and energy pathways and dynamics of the Green Bay Ecosystem. The impact of mussels is seen in both the open water and near shore systems, while the *Phragmites* invasion alters the structure and function of diverse marsh ecosystems by changing species composition, nutrient cycling, and hydrologic regimes.

Workshop participants identified Persistent Organics, Hydrologic Modifications, Pathogens, Biota Harvest, and BOD as a second group of stressors exerting a more moderate impact on the Green Bay Ecosystem. Persistent organics include several chemicals of potential concern most notably DDT and its metabolites, dieldrin, dioxins and PCBs. Available studies identify PCBs as the toxic substance of greatest concern. While PCB-contaminated sediment remediation is underway, PCBs can be expected to be a risk for the next two decades. Exposure to other persistent organics will be reduced with sediment remediation as well.

Hydrologic modifications in the Green Bay Ecosystem and its tributaries have not been systematically studied or documented. There is evidence to support the impact of hydrologic modifications on coastal wetlands; regional studies in other locations link development and change in runoff patterns. Other studies reveal the importance of flow regimes on the health of fish communities in Green Bay tributaries and the impact of dams and habitat changes on the success of migratory fish species like the northern pike.

The importance of pathogens as a health risk to swimmers has systematically been addressed since 2003 for Green Bay swimming beaches. Numerous swimming beaches are found along the Green Bay shoreline. As noted earlier, beach closings have occurred at several of these beaches, most of which are located in Door County. Beach closings negatively affect tourism and impact recreational use. On another front, viral hemorrhage septicemia remains a real threat to fish in Green Bay.

Biota harvest of both commercial and sport fishery is regularly assessed and records compiled and maintained. There is no doubt that biota harvest has the potential to adversely affect the fishery of Green Bay; however, regulatory management actions appear to provide

protection for most important fisheries. There are suggestions that recreational and commercial harvest has impacted the perch fishery in recent times. Biota Harvest is viewed as a manageable stressor; the workshop experts saw this stressor as having a lesser impact than Persistent Organics, Hydrologic Modifications, or Pathogens.

Prior to 1980 biological oxygen demand (BOD) was an extremely significant stressor for the Green Bay ecosystem. Remediation efforts after passage of the Clean Water Act largely rectified this problem. Even so, continuous monitoring at the mouth of the Fox River and in the Bay reveals oxygen levels below the standard of 5 ppm at times during the summer. The continuous monitoring regime shows a distinct flux of cold, nearly anoxic water in the lower water column. The large variation in oxygen levels likely reflects the cumulative effects of upstream organic waste and algae production, sediment oxygen uptake, and Bay water interactions.

The remaining two stressors, Non-Persistent Toxins and Heavy Metals were judged to pose considerably less risk than the other nine stressors. Non-Persistent Toxins consist of ammonia and microcystines. Average concentration of ammonia (NH₃) during the growing season in the Area of Concern has averaged less than 0.10 mg/l for the years 1994 through 2005. This level is well below the 30-day chronic criterion of 0.59 mg/l. Microcystines are cyclic nonribosomal peptides produced by cyanobacteria (blue-green algae). Their hepatotoxicity may cause serious damage to the livers of mammals. Little work has been done on microcystines in Green Bay. However, in other water bodies the concentration of chlorophyll *a* has been significantly correlated with the concentration of toxic microcystines. The Area of Concern has a high level of chlorophyll *a*. A more definitive assessment of the risk posed by microcystines in Green Bay awaits further investigation.

Sediments in the Lower Fox River are known to contain high concentrations of mercury. Despite the high sediment concentrations, the bioaccumulation factor (BAF) from sediments to forage fish is very low (0 to <1). Somewhat more expected is the level of total mercury found in walleyes captured below the DePere dam where the BAF is 2.5×10^2 . The high level of total mercury in the sediments of the Fox River exceeds the Ontario Sediment Quality Guidelines for "lowest effect level" (0.2 µg/g (ppm)) by a factor of 10 to 35. The concentration of total mercury in the Fox River water exceeds the Wisconsin Water Quality Standard (2ng/l (ppt)) by fourteen times. Some members of the workgroup believe Heavy Metals have been underrated as a stressor. With the exception of mercury there are no other heavy metals known to pose a threat. Lead and cadmium were discounted during the Green Bay Mass Balance Study.

Climate Change Assessment

As stated earlier, an important goal of the 2008 risk assessment project was to seek insights into potential climate change impacts on the Green Bay Ecosystem. A methodological basis for assessing climate change impacts was suggested by the approach employed in the Time-Duration perspective that was part of the 1991 risk assessment. The use of a weighting

system, similar to that employed in the Time-Duration perspective, has been used successfully in other ways as well. For example, two different types of management perspectives that were part of the 1991 risk assessment also employed weighting schemes (Harris et al. 1994).

Originally the thought was that we would derive one set of weights to apply to the list of 11 stressors that would reflect climate change judgments. However, as noted earlier, the workshop participants felt a more nuanced approach was needed. Instead of considering climate change in aggregate form it was proposed that a set of climate change components or characteristics be identified. During a plenary discussion the six climate change components shown in Table 4-2 were agreed upon. An 11 X 6 matrix was then constructed with the rows consisting of the original list of stressors and the climate change components assigned to the columns. Four breakout groups were then convened with the purpose of entering values into the matrix. The ij^{th} entry was determined according to the following scale:

- 1 – climate change component in column j has little or no impact on stressor i
- 2 – climate change component in column j has a moderately exacerbating impact on stressor i
- 3 – climate change component in column j has a major exacerbating impact on stressor i
- 1 – climate change component in column j has a moderately diminishing impact on stressor i
- 2 – climate change component in column j has a major diminishing impact on stressor i

When the results of the workgroups were compiled a consensus number existed in 82% of the cells. The definition of consensus is the following. When a cell meets one of the following conditions it is defined as a consensus cell: 1) agreement exists among all four teams, 2) one team had a value that differed by one from the common value of the other three teams, and 3) two teams have a common value and the other two teams have a common value that differs by one from the value of the first two teams. In the second case the majority number is chosen and in the third the larger of the two numbers is chosen. The rationale for the latter is the desire to err on the side of the “worst case”. A plenary discussion was employed to resolve the differences and arrive at a number for those cells for which a consensus did not exist. The results of the four teams are displayed in Table 4-4 and the Climate Change-Stressor Consensus Matrix is shown in Table 4-5.

Table 4-4. Composite Results of Impacts on Stressors by Climate Change Components

STRESSOR	Climate Change Components					
	Air and Water Temperature	Seasonality	Precipitation	Periodicity of Extreme Events	Lower Record and Average Water Levels	Shifting Wind Fields during Summer from SE
Nutrient Loading	1 1	2 2	2 2	3 3	1 1	1 1
	3 1	2 1	3 2	3 3	2 2	2 2
Heavy Metals	1 2	2 1	2 2	3 3	2 1	2 2
	2 1	2 1	2 2	2 2	1 1	1 1
Wetland/ Shoreline Filling	1 1	1 1	1 2	1 2	3 2	1 1
	1 1	1 1	1 -1	2 -1	3 2	1 1
Solids Loading	1 1	3 2	2 2	3 3	1 1	1 1
	1 1	2 2	3 2	3 3	3 2	1 1
Persistent Organics	1 1	1 1	2 1	2 2	2 2	1 1
	1 -1	1 -1	2 2	3 2	2 1	1 1
BOD	2 2	2 2	2 2	2 3	1 1	2 3
	3 2	2 2	2 1	3 2	2 2	2 2
Aquatic Exotics	2 3	2 1	1 1	1 2	2 2	1 1
	2 2	3 2	1 1	2 2	2 2	2 1
Non-Persistent Toxins	2 3	2 2	2 2	2 3	1 1	1 1
	3 2	2 2	3 2	3 2	2 1	2 1
Biota Harvest	2 -1	2 1	1 1	1 1	2 1	1 1
	1 1	3 2	-1 1	2 -1	1 1	1 1
Hydrologic Modifications	1 1	1 1	2 2	3 3	2 1	1 1
	1 1	1 2	2 3	3 3	1 2	1 1
Pathogens	2 -1	1 1	2 1	2 2	2 1	1 1
	2 2	2 2	2 1	3 2	2 1	1 1

Scale:

-2 Major diminishing impact
-1 Minor diminishing impact
1 No impact
2 Minor exacerbating Impact
3 Major exacerbating Impact

Team Entries:

A	B
C	D

Indicates No Consensus:



Table 4-5. Climate Change-Stressor Consensus Matrix

Stressors	Climate Change Components					
	AWT	S	PR	PE	LWL	SWF
NL	2	2	2	3	2	2
HME	2	2	2	3	1	2
WSF	1	1	1	1	3	1
SL	1	2	2	3	2	1
PO	1	1	2	2	2	1
BOD	2	2	2	3	2	2
AE	2	2	1	2	2	1
NPT	3	2	2	3	1	1
BH	1	2	1	-1	1	1
HMO	1	1	2	3	2	1
P	2	2	2	2	2	1

As noted earlier, to analyze the climate change impacts on the Green Bay Ecosystem, a set of weights is needed. The workshop participants decided that the average of the values in each row of Climate Change-Stressor Consensus Matrix should be used as the weights. Thus, the weight for a stressor is the average of the six impacts from the individual climate change components. The weights are displayed in Table 4-6.

Table 4-6. Weights for Climate Change Perspective

STRESSOR	WEIGHT
Nutrient Loading	2.2
BOD	2.2
Heavy Metals	2.0
Non-Persistent Toxins	2.0
Solids Loading	1.8
Pathogens	1.8
Aquatic Exotics	1.7
Hydrologic Modifications	1.7
Persistent Organics	1.5
Wetland/Shoreland Filling	1.3
Biota Harvest	0.8

After the weights were applied as multipliers of the row entries in the Risk Consensus Matrix (Table 4-5), the Climate Change-Ecosystem Risk Consensus Matrix was obtained. This matrix is displayed in Table 4-7. We emphasize here that the development of the Climate Change-Stressor Consensus Matrix (Table 4-5) was an intermediate step in the climate change analysis. The Climate Change-Ecosystem Risk Consensus Matrix (Table 4-7) provides the basis for assessing the climate change impacts on the Green Bay Ecosystem. The stated conclusions that follow are all based on the Climate Change-Ecosystem Risk Consensus Matrix.

Table 4-7. Climate Change-Ecosystem Risk Consensus Matrix

STRESSORS	ECOSYSTEM VALUES					
	HH	ACR	B	NSF	EI	H
NL	2.2	6.6	6.6	6.6	6.6	6.6
HME	2.0	2.0	2.0	0	2.0	0
WSF	0	3.9	3.9	3.9	2.6	3.9
SL	0	5.4	5.4	5.4	5.4	5.4
PO	3.0	3.0	3.0	1.5	4.5	0
BOD	0	2.2	4.4	4.4	2.2	4.4
AE	0	5.1	5.1	5.1	5.1	5.1
NPT	2.0	2.0	2.0	2.0	2.0	0
BH	0	1.6	1.6	1.6	2.4	0
HMO	0	1.7	3.4	5.1	3.4	3.4
P	3.6	3.6	3.6	3.6	3.6	0

The first step in the assessment is to perform a fuzzy set analysis on the Climate Change-Ecosystem Risk Consensus Matrix. The ranking results from this analysis are displayed in Figure 4-3. This ranking is referred to as the Climate Change Consensus Ranking.

**STRESSOR RANKING BASED ON RISK TO ECOSYSTEM
WHEN CONSIDERING CLIMATE CHANGE COMPONENTS
(CONSENSUS)**

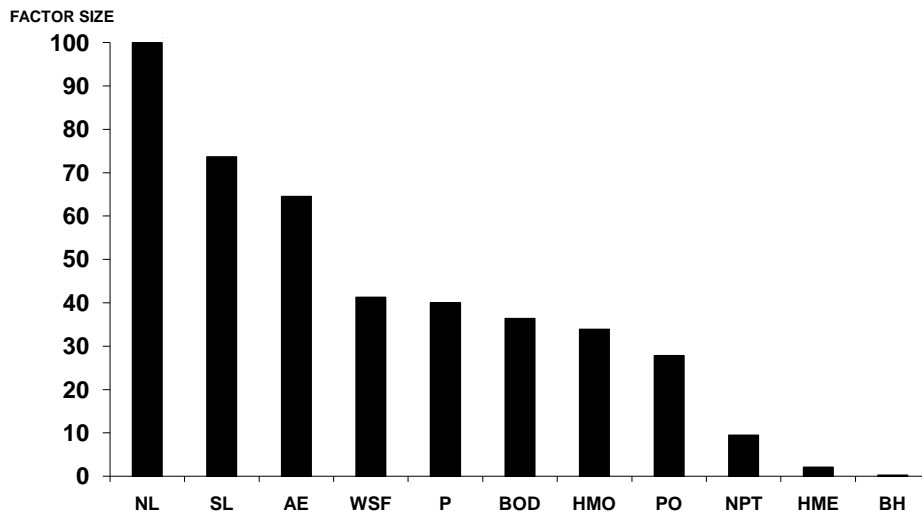


Figure 4-3. Stressor ranking and risk to ecosystem.

What is most noticeable about the ranking of the stressors based on ecosystem impacts when climate change components are taken into account is that Nutrient Loading has a notably greater impact than any of the other stressors. After that, at a relatively consistent rate of decline, Solids Loading, Aquatic Exotics and Wetland/Shoreland Filling follow. Pathogens have nearly the same level of impact as Wetland/Shoreland Filling, and BOD, Hydrologic Modifications, and Persistent Organics are not far behind. Non-Persistent Toxins, Heavy Metals, and Biota Harvest are the three lowest-ranked stressors.

When comparing the Risk Consensus Ranking with the ranking when climate change components are considered, there are a number of differences (see bar graph in Figure 4-4). While Nutrient Loading, Solids Loading, and Aquatic Exotics are the top three stressors in both rankings, the levels of impacts in the Risk Consensus Ranking are much more consistent. Said another way, climate change considerations seem to suggest that Nutrient Loading emerges as the dominant stressor and Solids Loading and Aquatic Exotics decline in their relative impacts. Wetland/Shoreland Filling, Pathogens, BOD, Hydrologic Modifications, and Non-Persistent Toxins constitute a mid-range level of impact under climate change considerations. BOD and Pathogens have moved up somewhat in the Climate Change Consensus Ranking when compared to the Risk Consensus Ranking. Biota Harvest has declined significantly under climate change considerations.

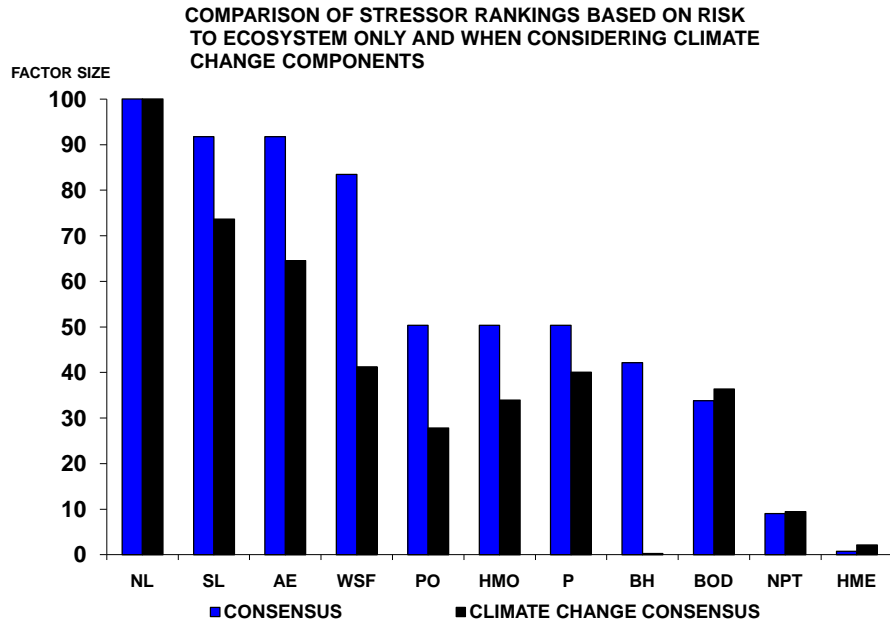


Figure 4-4. Stressor ranking and risk to ecosystem – climate change.

Chapter 5 - Climate Change and Risk to Green Bay Conservation Targets

In this section we report the results from a workshop held in August 2009 for the purpose of assessing climate change impacts on Green Bay conservation targets (see appendix B for names and affiliations). This workshop was supported by The Nature Conservancy, the Wisconsin Sea Grant Program and UW-Green Bay.

The workshop was based on work that had been done by The Nature Conservancy prior to the convening of the workshop. The outcome from this previous work (Wisconsin Coastal Management Program 2007) provided the list of threats and the conservation targets for establishing a baseline for the climate change assessment. The conservation targets of The Nature Conservancy represent essential structural and functional components of the Green Bay ecosystem; which, if unthreatened would insure essential ecological integrity of the system. Also, provided were descriptors of the impacts of the threats on the conservation targets. The descriptors used for the impact of a given threat on a given target were: no threat, low threat, medium threat, and high threat. By assigning the numbers 0, 1, 2, and 3 to these descriptors, respectively, the Baseline Matrix was in hand. The list of threats is shown in Table 5-1, the list of conservation targets in Table 5-2, and the Baseline Matrix in Table 5-3. A fuzzy set analysis on the rows of the Baseline Matrix produced the ranking of the threats shown in the bar graph in Figure 5-1.

Table 5-1. Threats to Green Bay ecosystem

Threats	Notation
Agricultural runoff	AR
Invasive species (Carp)	IVC
Residential Development	RD
Dams and dikes	DD
Invasive species (mussels)	IVM
Invasive species (phragmites)	ISP
Transportation infrastructure	TI
Urban runoff	UR
Industrial waste	IW
Sewage effluent	SE
Dredging	DR

Table 5-2. Conservation targets

Targets	Notation
Northern Pike	NP
Littoral Zone Community	LZC
Coastal Wetland Complex	CWC
Lake Sturgeon	LS
Benthic Community	BC
Migratory Diving Ducks	MDD
Colonial Nesting Birds	CNB

Table 5-3. Baseline matrix

Threats	Targets						
	CNB	LS	BC	LZC	MDB	CWC	NP
AR	1	2	2	3	3	3	3
IVC	0	2	3	3	2	0	3
RD	1	1	0	2	1	3	3
DD	0	3	0	0	0	2	3
IVM	1	0	3	3	1	0	0
ISP	3	0	0	0	0	3	2
TI	0	0	0	0	0	2	3
UR	0	1	1	2	1	2	2
IW	1	1	1	2	0	2	1
SE	0	1	0	2	0	0	2
DR	0	0	1	2	0	2	0

Figure 5-1 shows that Agriculture Runoff is not only the top ranked threat, but is a substantially greater threat than any of the others. A steady decline occurs in the level of the next three threats – Invasive Species (Carp), Residential Development, and Urban Runoff. After that, a leveling off occurs over the next four threats, followed by another set of three threats at yet a lower level.

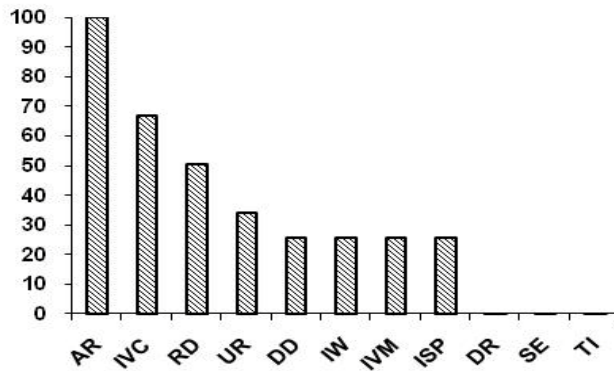


Figure 5-1. Baseline assessment of threats

Target Vulnerabilities – Present Conditions

A fuzzy set analysis was also performed on the columns of the Baseline Matrix displayed in Table 5-3. This provides a ranking of conservation target vulnerabilities. The results of this analysis, displayed in Figure 5-2, show that the Northern Pike is the most vulnerable of all the conservation targets. Also, three targets – Northern Pike, Coastal Wetland Complex, and Littoral Zone Community – stand out from the remaining four. The Migratory Ducks and Colonial Nesting Bird targets are the least vulnerable.

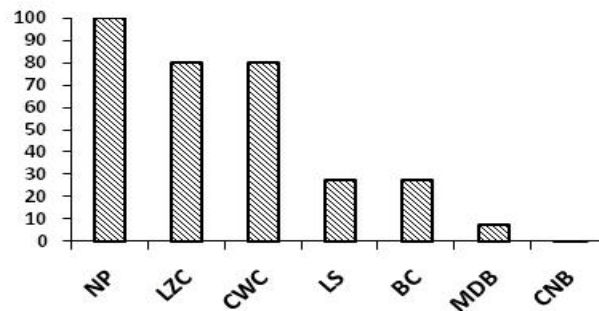


Figure 5-2. Baseline assessment of targets

Climate Change Analysis of Targets

These baseline results provided the backdrop for the main purpose of the workshop: an assessment of climate change impacts on the Green Bay ecosystem. The approach used for the climate change assessment was the same as used previously. Rather than considering climate change as a generic concept, six climate change components were identified at this earlier workshop. The participants in the August 2009 workshop agreed to use the same set of climate change components. The set of climate change components is shown in Table 5-4.

Table 5-4. Climate change components

Component	Notation
Increasing Air and Water Temperature	AWT
Seasonality (Shorter Winter, Earlier Spring)	S
Changing Precipitation Patterns	PR
Periodicity of Storm Events	PE
Lower Record and Average Water Levels	LWL
Shifting Wind Fields	SWF

An 11 x 6 matrix was constructed with the threats assigned to the rows and the climate change components to the columns. Four subgroups were assigned the task of entering values into the matrix. The ij^{th} entry was determined according to the following scale:

2 – climate change component in column j has a major augmenting impact on the threat in row i

1 – climate change component in column j has a moderately augmenting impact on the threat in row i

0 – climate change component in column j has little or no impact on the threat in row i

-1 – climate change component in column j has a moderately diminishing impact on the threat in row i

-2 – climate change component in column j has a major diminishing impact on the threat in row i

Using the consensus criterion mentioned in the previous section, a compilation of the results from the four workgroups revealed a consensus in 79% of the cells. For those cells that that did not have a consensus number, a discussion involving all workshop participants was employed to resolve differences and arrive at an agreement on consensus numbers. The end result was the Climate Change Matrix shown in Table 5-5.

The weights used in the overlay to determine the rankings of threats and target vulnerabilities were obtained by increasing the entries in the Climate Change Matrix by one and then computing the average of the resulting values in each row. This calculation adjustment provides an outcome consistent with the scale used in the 2008 workshop. These weights are displayed in Table 5-6.

Table 5-5. Climate change matrix

	AWT	S	PR	PE	LWL	SWF
AR	1	1	2	2	1	1
ISC	2	1	0	1	0	0
RD	1	1	0	1	1	0
DD	0	0	2	2	1	0
ISM	1	1	0	0	0	0
ISP	0	1	0	0	2	0
TI	0	0	1	1	1	0
UR	1	1	2	2	0	1
IW	0	0	1	1	0	1
SE	1	0	1	2	0	1
DR	0	0	1	1	2	0

Table 5-6. Weights for climate change analysis

Threat	Weights
AR	2.3
ISC	1.7
RD	1.7
DD	1.8
ISM	1.3
ISP	1.5
TI	1.5
UR	2.3
IW	1.5
SE	1.8
DR	1.7

When the rows of the Climate Change Matrix are multiplied by these weights and the fuzzy set analysis performed on the rows of the new matrix, the result is shown in Figure 5-3. In Figure 5-4, the bar graph displays a comparison between the baseline results and the climate change results. The most noticeable impact of climate change is that runoff from land sources is the greatest threat. Agricultural Runoff stands out at the top of the set of threats even more strongly than was the case in the ranking prior to the climate change analysis. In addition Urban Runoff has moved from the fourth position to the third position, and is almost equal to Invasive Species (Carp) in the second position. A more minor change is that the Invasive Species (Phragmites, Buckthorn) threat has moved down a bit in comparison to its baseline position. In addition, the Sewage Effluent and Dredging threats are no longer tied with the Transportation Infrastructure threat in the bottom position. Instead these three threats show the following descending order at the bottom of the list: Sewage Effluent, Dredging, and then Transportation Infrastructure.

To further assess the climate change impacts, fuzzy set analyses were performed for each climate change component. For a given climate change component, the weights that were used are those that appear in the column of the Climate Change Matrix associated with the given climate change component. While some changes in rankings occur when examining results from the individual climate change components, they provide no evidence for reinterpreting the conclusions obtained from the composite analysis. Due to lack of space these results are not listed here.

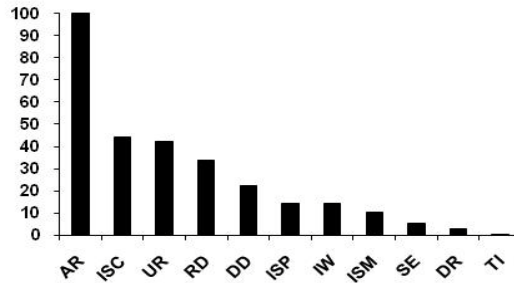


Figure 5-3. Impacts of climate change on ecosystem threats

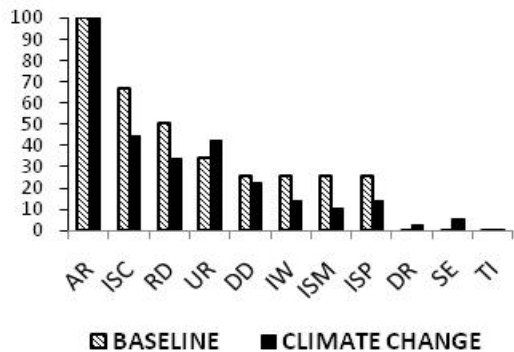


Figure 5-4. Comparison of climate change impacts with baseline

Vulnerability of Targets under Climate Change

By performing a fuzzy set analysis on the columns of the Climate Change Matrix, impacts on the vulnerabilities of the conservation targets can be assessed. The results are displayed in Figure 5-5 and Figure 5-6. In the latter figure the climate change impacts on the ranking are compared with the baseline ranking. When viewing the climate change impacts on the target vulnerabilities, only small changes occur when compared with the baseline ranking. Northern Pike, Coastal Wetland Complex, and Littoral Zone Community still stand out as the most vulnerable conservation targets. Climate change is seen to have a comparatively modest effect on the Lake Sturgeon, Benthic Community, and Migratory

Diving Duck targets. As in the baseline case, Colonial Nesting Birds are distinctly below the other targets on the vulnerability scale.

Fuzzy set analyses were also performed for each individual climate change component. In every case Northern Pike, Coastal Wetland Complex, and Littoral Zone Community remained as the top three most vulnerable targets. In all cases except one, Northern Pike is the most vulnerable of the top three. The exception occurs for the Lower Record and Average Water Level component; in that case the Coastal Wetland Complex is the most vulnerable target.

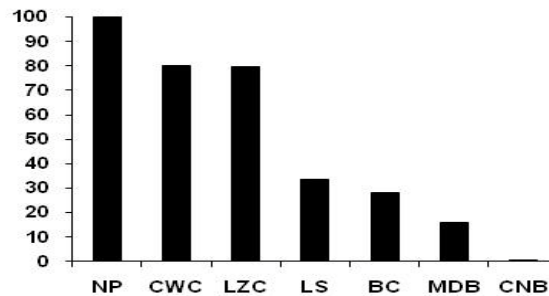


Figure 5-5. Impacts of climate change on targets

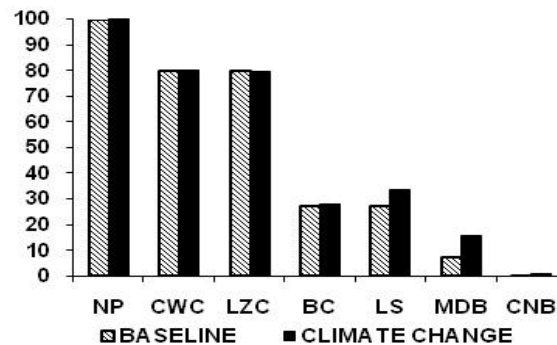


Figure 5-6. Comparison of climate change impacts with baseline

Conclusion

The most important impact of climate change on the Green Bay ecosystem is that runoff from land sources is exacerbated. Agricultural Runoff was the greatest threat under the baseline scenario but it was even more pronounced as the top threat when climate change impacts are considered. In addition, Urban Runoff becomes a more serious threat from climate change. In the baseline scenario, Urban Runoff is the fourth most serious threat, but when climate change impacts are considered, it moves up to the third position ahead of Residential Development and is almost tied with Invasive Species (Carp) at the second position.

The ranking of the target vulnerabilities is not changed from the baseline scenario when the climate change impacts are considered. Northern Pike, Coastal Wetland Complex, and Littoral Zone Community are the three most vulnerable conservation targets under every climate change scenario

considered in the assessment. These three conservation targets are considerably more vulnerable than any of the four remaining conservation targets.

Taken together, the climate change impacts on the threats and conservation targets send a strong message that managerial initiatives are needed that forcefully address runoff from land sources. This message was also the primary one from the June 2008 workshop that was described earlier. When the most significant ecosystem stressors from the first workshop are compared to the most important threats from the second workshop, runoff and related phenomena appear in common. Consequently it is imperative that runoff and related phenomena (i.e. Nutrient Loading, Solids Loading, Residential Development, Pathogens, BOD and Hydrologic Modifications) be given high priority when developing adaptive management strategies for conservation targets in Green Bay.

Chapter 6 - Adaptive Management Strategies

Guidelines for Developing Adaptation Strategies

The National Wildlife Federation has proposed a framework for developing and implementing adaptation strategies (Figure 6-1). The Green Bay Working Group in conjunction with The Nature Conservancy has completed the first two steps as described above. We now need to identify and evaluate management options.

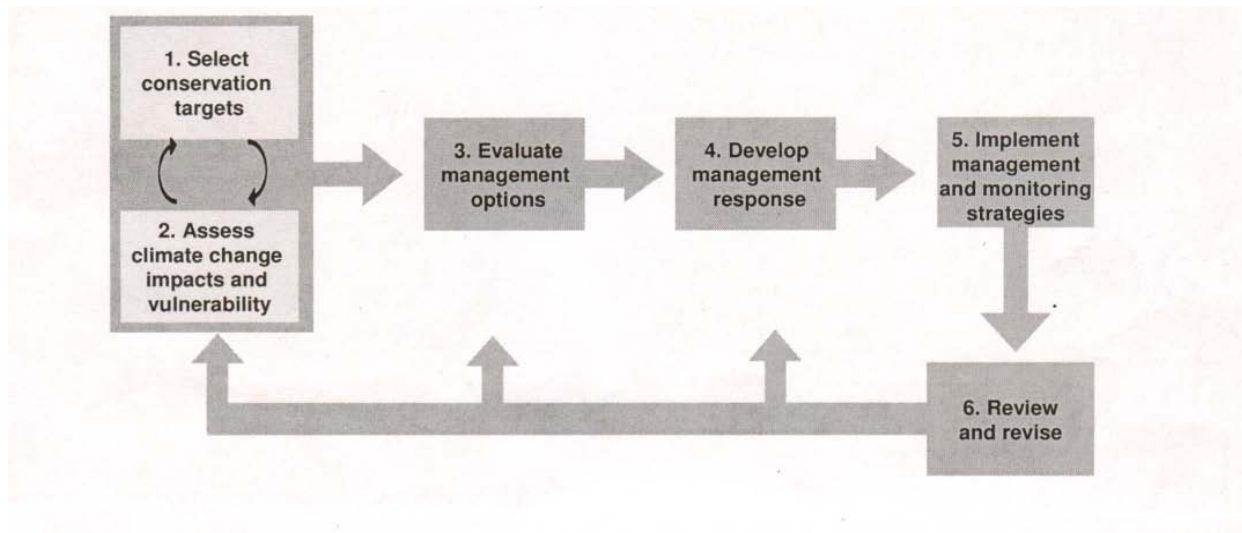


Figure 6-1. Framework for developing and implementing adaptation strategies.

Having a common understanding of what is meant by the term adaptation is essential. Here we propose to use the definition of the fourth assessment of the IPCC which defines adaptation as initiatives and measures designed to reduce the vulnerability of natural or human systems against actual or expected climate change effects. It implies adjustments in ecological, social, or economic systems in response to actual or expected climate stimuli. Applying this definition to the Green Bay Ecosystem our task then is to develop adaptive strategies to reduce the vulnerabilities of the conservation targets to actual or potential climate change effects.

Adaptive Management Strategies for Conservation Targets

The Green Bay Working group held its initial Adaptive Management Workshop on April 7, 2010. A mix of twenty professionals from academia, Wisconsin Department of Natural Resources, U.S. Fish and Wildlife Service and The Nature Conservancy convened for a day at the University of Wisconsin-Green Bay campus to identify potential adaptive management strategies for Green Bay Conservation Targets. Participants prepared for the workshop by reviewing previous results of the earlier risk assessment workshops and reading a published review of climate adaptation literature. Individuals were assigned to one of the five breakout groups to address the five most vulnerable Conservation Targets: Northern Pike, Coastal Wetland community, Littoral Zone Community, Lake Sturgeon, and Benthic community. The groups were prompted to keep in mind the five overarching principles of adaptive management identified in the literature review article. (New Era for Conservation) published by The National Wildlife Federation. These principles are:

- Reduce other non-climate stressors
- Manage for ecological function and protection of biodiversity
- Establish habitat buffer zones and wildlife corridors
- Implement proactive management and restoration strategies
- Increase monitoring and facilities management under uncertainty

Another way of envisioning adaptive strategies is from a conservation strategy perspective such as:

- Protection
- Land / water management
- Species management
- Education / awareness
- Laws and policies
- Economic incentives

Other general strategy categories include research, using existing laws or policies (mainstreaming), enhancing resilience and adaptive capacity and external control.

Adaptive Strategies for Northern Pike

The northern pike group(David Rowe, Erin Hanson, Kevin Fermanich) identified existing regulations that address several non climate stressors and thereby enhance resilience and adaptive capacity (Table 6.1).

Table 6.1 Existing regulations reducing non-climate stressors

Stressor	Existing Regulations
Biota Harvest	Closed season on tributary streams; 5 fish daily bag limit
Hydrologic modification, wetland shoreland filling	Chapter 30 waterways and wetlands, Chapter 31 dams
Nutrient and solids loading	Local/County Planning and Zoning TMDL Clean Water Act

The group recognizes the importance of the Green Bay west shore coastal wetlands and associated tributaries as spawning and rearing areas for the Northern Pike. While ongoing restoration projects are laudable there is continued concern about hydrologic modification associated with rapid residential development of the west shore. The interrelationship of ground water and surface water is poorly understood and needs clarification to assess the adequacy of existing zoning regulations. This is particularly urgent in light of potential declining lake levels associated with climate change. The Northern Pike group recognized several species management opportunities through habitat modification. These include, bank slopping channel restoration, dam removal and active management of habitats and water levels thru water control structures at restoration sites. The Northern Pike group also recognized that projected increased spring rainfall may work to the advantage of spawning pike but that potential increased variability of spring highs and lows could create problems as well. Age structure of the population is seen as an important adaptive factor. Having adults of varying ages would make the species more resilient to variation associated with climate change. A research question associated with this observation arises; what is the minimum number of age classes needed based on predicted variability in water levels and spring rain? Two other research needs were identified by this group. One is how the loss of submergent aquatic vegetation affects production and juvenile mortality and the other is the need to define the relationship between nutrient loading, water quality and suitable spawning habitat.

Northern Pike Strategies Itemized

- Review Chapter 30 WI Stat. (waterways and wetlands) and Chapter 31 (dams) for adequacy in protecting coastal wetlands and removing or modifying dams
- Continue closed season for northern pike on tributary streams and daily bag limits
- Examine zoning regulations for adequacy in protecting hydrologic integrity of both surface and groundwater of west shore coastal zone
- Support TMDL for phosphorus and total suspended solids
- Bank slopping channel restoration
- Dam removal management
- Manage water levels at restoration sites
- Continue emphasis on wetland acquisition and stream habitat and wetland restoration
- Manage age structure to create resiliency in face of interdecadal water level variability

- Determine minimum number of age classes needed for resiliency (see above)
- Assess the loss of submergent aquatic vegetation on predation and juvenile mortality
- Define relations between nutrient loading water quality and sustainable spawning

Adaptive Strategies for Coastal Wetlands

The Coastal Wetland Group (Joel Trick, Joe Henrey, Rebecca Smith, and Scott Thompson) and the northern pike group offered some similar management strategies. This is not surprising given the importance of wetlands to the northern pike as a species. Both groups recognized the importance of protecting and restoring the integrity of the hydrologic regimen of the west shore. The need to work with Regional Planning Agencies to address this issue was emphasized. Both groups also recommended an inventory of fragmentation and connectedness of the coastal wetlands of the west shore with the identification of critical habitat for protection. The wetlands group suggested that a current project under the Nature Conservancy to address wetland system functions and prioritize restoration potential may fill this need.

The wetlands group paid particular attention to the possibility of continued decline in average and extreme low water for Lake Michigan. They saw a very real need to examine policies and regulations protecting lands below the Ordinary High Water Mark (OHWM). Riparian landowners will likely lobby to lower the OHWM. Policy needs to be preemptive to protect lands below the existing OHWM.

The group also pointed out that lower lake levels will expose more lake bottom. From experience it is known that phragmites (giant reed) will quickly colonize these areas and exclude more ecologically functional native plants. The group suggested that seeding using seed bank materials may help to reestablish exposed areas with native species. They also were concerned whether seed banks would be available and if so how they could be preserved. The group also emphasized the importance of controlling nonpoint source runoff (nutrients and suspended solids) and assessing the effectiveness of conventional BMP's. Stream bank buffer initiatives should be strengthened and woody species should be given strong consideration. Woody species would not only trap nutrients and sediments but would also provide shade and woody debris to the streams. Lastly, this group suggested collecting oral histories of the bay along with photos, records, and studies to document previous conditions and changes.

Coastal Wetland Strategies Itemized

- Examine policies and regulations protecting lands below the ordinary high water mark policies need to be preemptive to protect.
- Inventory fragmentation and connectedness and identify critical habitat for protection
- Protect, restore integrity of hydrologic regime
- Consider seed bank manipulation to counter *Phragmites* invasions of exposed lakebed
- Control nonpoint runoff through TMDL and best management practices particularly stream bank buffers.
- Consider woody vegetation for stream buffers

- Assess effectiveness of conventional Best Management Practices and support development of new methods
- Assemble oral histories, photos, records, and studies to document previous conditions; present to the public.

Adaptive Strategies for Littoral Zone Community

The Littoral Zone Community groups (Paul Sager, Christine Deloria, Jim Hurley, Sally Kefer and Dave Web) identified agricultural and urban run-off, residential development, and dredging as the most significant threats to the LZC. For runoff issues they made a number of recommendations

- Use and support the ongoing TMDL effort which proposes realistic values based on sound science and can facilitate a credible amount of reduction in phosphorus and total suspended solids.
- Incorporate the next draft of the TMDL into community planning and incorporate climate change scenarios in the modeling effort to assess the adequacy of reduction allocations.
- Examine the adequacy of treatment systems and storm water infrastructure to accommodate climate change conditions.
- Investigate the need for a separate agriculture best management practice for spring which is when most loading occurs.
- Provide education to communities on climate change and influence community decision making and planning by working with engineers, mayors, etc.

For the threat Residential Development the group saw an opportunity to engage with comprehensive Planning to encourage more concentrated development and associated transportation corridors. They also posed two questions which need to be addressed through research and planning.

- How to protect unfragmented habitat in northern Green Bay from residential development that is dispersed and creates habitat fragmentation.
- How do we engage and build community capacity? There may not be comprehensive plans to engage in.

Community Lakeshore Planning was seen as a way to reduce the impact of dredging by providing:

- Access locations that allow multiple landowner boat access and can facilitate use under various water levels
- New marinas to be placed in least environmentally sensitive areas and capable of use at varying water levels.

Littoral Zone Community Strategies Itemized

- Use and support the ongoing TMDL effort
- Incorporate climate change scenarios in next modeling effort and engage community planning
- Examine adequacy of treatment systems and storm water infrastructure to accommodate climate change conditions
- Investigate the need for a separate BMP strategy for spring runoff

- Engage with comprehensive planning to encourage more concentrated development
- Target community lakeshore planning such as multiple landowners boat access under various water levels and least impact marina siting
- How do we protect unfragmented habitat in Northern Green Bay?
- How do we engage and build community capacity?

Adaptive Strategies for Lake Sturgeon

The Lake Sturgeon group (John Magnusson, Phil Moy, Mike Grimm and Bud Harris) identified dams, hydrologic modifications, egg predation by round gobies, carp, great lakes water levels and agricultural runoff as potential threats to Lake Sturgeon. Extremes in interdecadal lake levels, dams and hydrologic modification of streams are likely the most significant. Even with these threats the Lake Sturgeon may be quite well adapted to lake level changes and availability of spawning sites since resilience of long life does not require a top spawn every year. One Adaptive strategy is to insure availability of spawning sites under different flow and water level conditions. This may be facilitated through mainstreaming with Federal Energy Regulatory Commission (FERC) licensing.

Dam barriers prevent migrating fish from reaching upstream spawning habitat. Innovations to allow fish upstream without allowing lamprey, gobies, etc. upstream are needed. Such an example already exists at a Menominee River site. Even with such innovations there could be a possible mismatch between water levels and temperature in wetter springs which may disrupt normal the spawning and development of sturgeon.

Several research questions were identified.

- Is egg predation significant?
- How well do downstream migrants pass over dams?
- What is the restoration potential for saprophyte habitat for juveniles?
- How can juvenile stock 3-10 years old be estimates?

Lake Sturgeon Strategies Itemized

- Continue restricted harvest
- Ensure availability of spawning sites at dams under high and low water conditions through Federal Energy Regulatory Commission Licensing
- Protect hydrologic integrity of watershed for small rivers to maintain genetic diversity
- Reduce runoff of suspended solids
- Provide in-stream habitat improvement where possible and at critical sites
- Develop innovations on how to pass fish upstream without passage of aquatic invasive species
- Assess significance of egg predation
- Assess success of downstream migrants passing over dams
- Determine the restoration potential of macrophyte habitat for juveniles
- Develop census techniques for juveniles 3 to 10 years old
- Assess introduction of daughterless carp

Adaptive Strategies for Benthic Community

The Benthic Community workgroup consisted of Tina Ha., Victoria Harris, John Kennedy and Paul Baumgart. For the stressors of nutrient and solids loading, BOD and non persistent toxins the group identified several strategies involving the continuation of existing programs:

- Continue current and proposed regulatory controls for these pollutants
- Complete and implement Lower Fox River TMDL
- Update waste load allocation regulation (NR212) to determine need for adjustment resulting from climate change

With license to be creative the group proposed an evaluation of a drawdown of water level in Lake Winnebago which would aerate sediments decrease water column BOD, improve benthic habitat and provide a northerly migration corridor. Similarly explore the utility of increased biofuel production from marginal cropland in the Green Bay Watershed.

For the stressor Aquatic Exotics the group again identified the importance of continuing existing programs to restrict spreading of dreissenids and encouraging regulatory activates aimed at preventing current and future invasions of exotic species. This may include an investigation of the possibility of complete isolation of the Great Lakes from marine transportation vectors. In addition, they recommended rapid response planning implementation tools be developed to improve existing exotic control programs and the establishment of education / awareness program for aquatic resource users.

As part of overall rationale for improved treatment technologies, emphasize use of technologies that result in broad improvements in effluent quality (i.e. treatment for reduced solids discharge will likely reduce BOD discharge as well). Finally, evaluate the potential for significant prevailing wind direction shift for the Bay area which may lead to longer water residence times in the Bay and subsequent decreases in water quality.

Benthic Community Strategies Itemized

- Continue current and proposed regulatory controls for nutrient and solids loading, Biochemical Oxygen Demand, and non-persistent toxic substances
- Complete and implement the lower Fox River TMDL
- Update wasteload allocation rule (NR 212) to determine need for adjustment resulting from climate change
- Continue existing programs to restrict spreading of Dreissenids and encourage regulatory activities aimed at preventing future invasions of exotic and invasive species
- Develop rapid response planning and implementation methods to improve existing aquatic invasive species control programs
- Develop riparian guidance for west shore area to control amount and type of manmade modifications to shoreline and runoff conveyance mechanisms
- Establish a clear understanding of the ordinary high water mark

- Consider dam removal or flow manipulation of the lower Fox River and other Green Bay tributaries
- Continue existing programs for identification and remediation of legacy pollutants
- Encourage low-impact development for future development in the watershed
- Evaluate the potential benefits of a temporary Lake Winnebago drawdown
- Investigate the possibility of isolating the Great Lakes from ocean-going vessels via cargo transfer
- Encourage research and regulatory attention to compounds of emerging concern
- Repeat the Green Bay Mass Balance Study PCB fate, transport, and food web modeling for post-climate change conditions
- Explore the utility of increased biofuel production (eg. switchgrass) from marginal cropland
- Continue exotic and invasive species education/awareness programs for boaters, anglers, etc.

Conclusion

The list of adaptive management strategies that we identified by the separate conservation target focus groups are first cut raw ideas in need of sifting and winnowing and then refinement. It is interesting to note that many of the strategies refer to ongoing programs, laws, policies, practices, etc. This suggests that to a large degree we are already doing the right things but we need to either do it better or do more of it. The emerging, overarching adaptive principle appears to be "reduce other non-climate stressors and thereby increase the resilience and adaptive capacity of the system". While this is not new, it is consistent with the sustainability mantra and within our grasp to accomplish. These actions are not only prudent of the context of a changing climate, but will result in a healthier ecosystem in any event.

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