

**FINAL REPORT
THE GREAT SODUS EMBAYMENT RESOURCE
PRESERVATION AND
WATERSHED ENHANCEMENT PLAN**

EPA CONTRACT: X-98299000-1

Prepared for:

**Wayne County Soil & Water Conservation District
10 Leach Road
Lyons, New York 14489
(315) 946-4136**



**Prepared by:
Princeton Hydro, LLC
Suite 1, 1108 Old York Rd.
P.O. Box 720
Ringoos, NJ 08551
p – 908-237-5660 – f-908-237-5666**

March 2007

Acknowledgements

Support and Funding For This Project Was Provided By

United States Congressman

James T. Walsh

25th District, New York

A Special Thanks To

Nora Keane Yancey, Staff Member. Office of Congressman James T. Walsh

Additional Acknowledgements

Barbara Belasco, Project Officer, U.S. Environmental Protection Agency. Region II. NY
Contract No. X-98299000-1

Joseph Makarewicz, Department of Biological Sciences. SUNY Brockport

Robert K. Williams, Project Manager. Wayne County Soil & Water Conservation District.
Lyons, NY.

Stephen J. Souza, PhD., Principal Investigator. Princeton Hydro, LLC.

**Wayne County Soil & Water Conservation District
Board Of Directors**

Steve Brownell
Carlyle Darron
Bill Hammond
Jody Bender
Bob VanLare

Wayne County Water Quality Coordinating Committee

David Scudder
Clay Bishop
Rob Williams
Sharon Lilla

Joe Molino
Mark Pearson
Ann Hayslip
Marty Aman

Corinna Herman
Bill Jones
Rob Goosen
Donna Chittenden

Larry Bristol
Sharon Mayer
Bob VanLare
Elizabeth Claypoole

Table of Contents

EXECUTIVE SUMMARY.....	4
AN INTRODUCTION TO SODUS BAY.....	5
MANAGEMENT OPTIONS FOR SODUS BAY’S WEED PROBLEMS.....	11
BEYOND WEEDS AND WEED CONTROL, FACTORS BEHIND THE EUTROPHICATION OF SODUS BAY.....	54
BATHYMETRIC SURVEY – PLOTING THE BAY’S WATER DEPTHS AND BOTTOM CONTOURS...	70
THE HYDROLOGY OF SODUS BAY.....	78
POLLUTANT LOADING – COMPUTING THE INFLUX OF POLLUTANTS TO THE BAY.....	90
RECOMMENDED MANAGEMENT PRACTICES FOR SODUS BAY AND ITS WATERSHED.....	108
References.....	128
Glossary.....	132

Appendices

- Appendix 1 Water Quality Data and Quality Assurance Protection Plan
- Appendix 2 Bathymetric Survey Results and Maps
- Appendix 3 Hydrological Data
- Appendix 4 Pollutant Load Modeling Data
- Appendix 5 Macrophyte Survey Data

1.0 EXECUTIVE SUMMARY

Numerous studies, conducted mostly by SUNY Brockport and the Wayne County Soil and Water Conservation District (SWCD), have documented the water quality and water quality problems of Sodus Bay. These studies clearly document that Sodus Bay is an exceptional aquatic resource that provides a variety of water-based recreational opportunities. However, many of these same reports and studies conclude that the water quality of the Bay and the recreational opportunities that the Bay supports is threatened and showing definitive signs of decline. These threats extend to the Bay's aquatic biota and affect all types of organisms from zooplankton to fish.

Most of the threats to the Bay's water quality are the result of eutrophication. Although a natural process, human factors can greatly accelerate the rate of eutrophication and lead to impairments that unless addressed will impact the ecology of the ecosystem and marginalize its recreational use and aesthetics. Many of the more obvious symptoms of eutrophication are the very same things that cause use impairments and endanger the Bay's ecology. Algae blooms and the dense growth of invasive aquatic macrophytes (more commonly referred to as weeds) are two of the most obvious and deleterious symptoms of eutrophication. Although algae and aquatic plants are part of a healthy, balanced Sodus Bay, when either reach epidemic proportions they become detrimental and in need of control.

Unfortunately, algae and weed control are often implemented in a subjective, reactive manner. Although this may temporarily help lessen the intensity of the impacts created by either intensive weed or algae growth, these efforts often times do little to slow down the eutrophication process or address or control the true cause of these problems. This in itself is a quandary. While there is a need to react to ever increasing weed and algae problems, these cannot be the sole management actions implemented in Sodus Bay. Conversely, if one fails to address these problems, the water quality, aesthetics, ecology and recreational potential of the Bay will decline. The successful long-term management of Sodus Bay must therefore be cognizant of the problems created by the proliferation of invasive weeds and the development of algae blooms, while at the same time correcting the actual factors that are responsible for the Bay's accelerated eutrophication. Thus, in creating a "master plan" for Sodus Bay, the two primary goals of this project were:

1. Obtain the scientific information required to correctly assess the causes for water quality impairments and to properly control the ever increasing intensity of algae blooms and the pervasive nature of aquatic weeds growth,
2. Identify feasible corrective management measures that bridge the in-Bay and watershed causes of accelerated eutrophication, and
3. Present these in the context of a Resource Preservation and Watershed Enhancement Plan for Sodus Bay.

2.0 AN INTRODUCTION TO SODUS BAY

2.1 AN OVERVIEW OF THE STUDY SETTING AND OBJECTIVES

Sodus Bay, a 3,150-acre embayment of Lake Ontario, is located in Wayne County, New York approximately 35 miles east of Rochester. Parts of the Towns of Huron, Sodus, Rose, Galen, Lyons and the Village of Sodus Point are located within the approximately 46-square mile watershed that drains to the Sodus Bay. The Bay is listed by the New York State Department of Environmental Conservation (NYSDEC) as a Class B, stressed, priority waterbody.

An embayment is a shoreline indentation or feature of a larger body of water that creates a unique, defined body of water. In this case, Sodus Bay is an embayment of Lake Ontario.

Numerous studies, conducted mostly by SUNY Brockport and the Wayne County Soil and Water Conservation District (SWCD), have documented the Bay's water quality and water quantity problems. In general, it is recognized that excessive nutrient and sediment loadings from throughout the watershed negatively impact the Bay's quality, recreational potential and aesthetics. The most obvious impact to the Bay's quality from the nutrient and sediment loading is the occurrence of algae blooms and the excessive growth of aquatic macrophytes (weeds). The algae blooms and dense weed growth are symptoms of eutrophication. Although eutrophication is a natural process, the process has been accelerated in Sodus Bay, largely by land development, including agriculture, residential development, and other forms of land clearing. Over recent years, there has been an increasing proliferation of invasive, exotic aquatic macrophytes (weeds) that has impacted the ecology of the Bay. In short, weed growth has increased 33% since the last survey conducted by Dr. Gilman in 1988 (Princeton Hydro, 2006). The weed abundance is impairing recreational uses, clogging water intakes, and decreasing aesthetic values of the lake. The continuing excessive nutrient loading to the Bay from both internal sources of phosphorus (sediments, decaying plants and algae, etc.) and external sources (stormwater runoff, lawn fertilizers and septic systems) are the primary cause affecting the aesthetic and recreational attributes of Sodus Bay. To control phytoplankton, algae or weed growth, it will be necessary to decrease phosphorus loading and reduce the availability of phosphorus for assimilation by plants and algae. As such, the control of phosphorus loading and the limitation of phosphorus availability need to be the cornerstones of the Bay's overall management plan.

*What is eutrophication?
This is a term used by lake scientists to define the aging process of lakes. More appropriately it can be considered a scale used to define the productivity of a water body. A eutrophic waterbody is one which receives an ample enough amount of nutrients to support a diverse array of aquatic plants, algae, fish and other aquatic life. The problem is that if too eutrophic, the amount of plant and algae growth can actually impede in the recreational use of the waterbody and impact its ecology.*

Over the past twenty years numerous in-depth studies have been conducted of the Bay's

water quality. Over that same time, investigations examining the patterns and impacts of the development of its watershed have also been conducted. Although these studies and investigations provide a wealth of information about the dynamics of the Bay and its watershed, questions and unknowns still exist concerning the cause/effect relationships and the key driving factors defining the Bay's water quality and ecology. Simply put, although there is a lot of information on the Bay, to date it has neither been fully integrated nor used to create a long-term, comprehensive, restoration and management plan for the Bay. The primary goal of this project was to create a "master plan" for Sodus Bay. To be successful, the master plan would need to recognize the recreational and economic importance of Sodus Bay and present watershed management and restoration recommendations aimed at slowing the Bay's rate of eutrophication, while enhancing its ecology, water quality, aesthetics and recreational potential.

As such, this project examined in closer detail, the inter-relationships, causal effects, and impacts of such driving factors as internal versus external nutrient loading, hydrologic loading, land use and the impacts of invasive, exotic aquatic weed growth on the quality, aesthetics, ecology and recreational use of the Bay. In conducting this study, the extensive historical water quality and ecological data developed by the SWCD, NYSDEC and SUNY Brockport was fully utilized. Efforts were also taken to integrate the findings and recommendations of recently completed or on-going Sodus Bay investigations, specifically the Great Sodus Bay Harbor Management Plan (FES Associates, 2005). In this manner, it was possible to reflect on the natural resource attributes of the Bay from the perspective of enhancing the Bay's water quality and ecology, while at the same time improving upon the recreational and aesthetic enjoyment of the Bay.

The Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan (Plan) is thus intended to provide for Sodus Bay's proper long-term management. The information contained herein consolidates, contemporizes, and supplements the Bay's water quality and watershed database and provides objectively developed, technically sound management recommendations, that can be used by local government, the County, the State and the local stakeholders and the Bay's users to evaluate, select, prioritize and implement watershed and Bay management options.

2.2 THE EVER INCREASING PROBLEMS CAUSED BY WEEDS AND ALGAE

As noted above, understanding the causes and symptoms of Sodus Bay's water quality problems is the fundamental purpose of this project. Over recent years, there has been an increasing proliferation of invasive, exotic aquatic macrophytes (weeds) that has impacted the ecology of the Bay. In short, weed growth has increased in abundance and intensity throughout the Bay. Although this is often a symptom of eutrophication, in the case of Sodus Bay, the "symptom" has far reaching economic, ecological and water use implications and impacts.

Aquatic macrophytes are the plants, which grow in freshwater ecosystems. They are commonly referred to as weeds, especially when their densities impact recreational use. Most weed problems are due to the establishment of aggressively growing non-native plants.

While we all recognize that aquatic plants are essential for the maintenance of a healthy aquatic ecosystem, when their abundance reaches levels that impair recreational uses, clog water intakes, decrease aesthetic values and other social desires, society then demands a level of management that is acceptable to balance ecosystem needs and social expectations (Williams, 1998). Thus, special attention was given to investigating and developing better management options for nuisance aquatic weed growth since this is the driving force behind Bay-wide social interests and concerns.

2.3 FINDING A BALANCE

As difficult as it may seem, a balance between social needs and expectations, and maintenance of the ecological balance of the Sodus Bay ecosystem must be established. In the long-term, the successful management of the causes and impacts of the accelerated eutrophication of any freshwater ecosystem requires a balanced between what is good for the ecosystem and what is good for the users. It requires a clear understating of the ecological,



assimilative capacity of the ecosystem in questions and the level of cultural influences and uses that degraded water quality. This is far more than simply establishing “how much can Sodus Bay take”. In reality, it is entails establishing a balance between the often contradictory effects of natural and anthropomorphic factors.

It is a natural occurrence that people are drawn to water, and it is the “good things” about Sodus Bay that have resulted in a steady increase in its usage. But, the Bay’s ecosystem is a fragile balance, and the attributes of Sodus Bay that have drawn those who recreate in the Bay and have redeveloped its watershed can be easily and quickly altered and impaired. With this increase in human activity comes a change in the Bay’s ecology and an alteration of the natural ecosystem. Some of these changes are not for the good, and are not always completely compatible with human desires and expectations. Such is the case with aquatic plants. Although an important element of any freshwater ecosystem, the density, composition and distribution of macrophytes (weeds) can change quickly and dramatically, as result of even nominal human influence. Although this may be a “natural” response, the increased density of weeds requires increased management effort, with that effort aimed at striking a balance between ecosystem needs and user needs. Often times this is a very fine balance, as management actions that are good for the ecology of Sodus Bay may not be the same management actions that maximize recreational use or aesthetics. However, it is possible to achieve a proper balance and manage weeds or any other problem, in a manner beneficial for both the Bay and the

Bay's users. As such, emphasis is given in this report's recommendations to management measures, whether dealing with aquatic weed control or other impairments of the Bay, that strike the proper balance between what is good for Sodus Bay and what is really feasible for Sodus Bay, with the latter assessed in terms of practicality, cost, environmental regulations and user satisfaction.

2.4 AN OVERVIEW OF THE SODUS BAY ECOSYSTEM

In the sections that follow, details are provided concerning the Bay's ecology, water quality, physical attribute and hydrology. That information is summarized herein thereby providing a concise synopsis of those aspects of the Bay and its watershed that have been responsible for the proliferation of weeds, the increase in algae blooms, the decline in water quality and the in-filling of coves and shallows.

The water quality of Sodus Bay and its tributaries is presented and discussed in detail in Section 4 of this report. The recent water quality data, much of which was collected by SUNY Brockport provides an up-to-date assessment of what is good and what is impacted with respect to the Bay's water quality. Sodus Bay continues to be characterized by exceptional water clarity, although certain coves and given areas tend to be subject to algae blooms in late summer. The Bay is relatively well mixed, showing little evidence of thermal stratification. However, even though well mixed, at times the deepest waters of the Bay become devoid of dissolved oxygen. This is observed in the latter parts of the summer and has significance with respect to the quality of available fish habitat and the internal release and recycling of nutrients and metals. Similarly, the recent water quality data obtained of the streams draining to the Bay were analyzed to better assess the current major sources of nutrient influxes and sediment transport to Sodus Bay.

To better define the physical properties of Sodus Bay, a comprehensive mapping of the Bay's underwater contours was conducted as part of this project. The process and result are covered in detail in Section 5 of this report. Focus was placed in this effort in mapping those areas close to shore, as these are the areas most likely to support and have been most impacted by the proliferation over the past 20 years of weed growth. The

The littoral zone can be thought of as the interface between the land and the water. This shallow area that extends from the shoreline out into the Bay to depths of 8-12 feet is a highly productive, very important element of Sodus Bay. It provides spawning, nursery and foraging habitat for the Bay's fishery and is supports a wide array of aquatic organisms. It is also where most of the Bay's weeds grow.

bathymetry survey demonstrated that the Bay has a large littoral zone of approximately 1,575 acres (50% of 3,150 acres = 1,575 acres), and slightly more than 25% of the Bay has water depths of only 0-8 feet. Although a large portion of these shallow areas occur near the mouth of Sodus East Creek to Nicholas Point, there are also fairly expansive littoral shelves along the eastern and western shorelines, around Leroy Island, between the eastern shore of Eagle Island and the eastern shoreline of Sodus Bay, and pronounced shallows also occur around Sand Point. The expansiveness

of the Bay's littoral zone, combined with the Bay's typically excellent water clarity (> 3 meters) facilitates the widespread distribution and growth of the weeds.

Section 6 of the report provides the full details of the hydrology of Sodus Bay. The hydrology of the bay is dependent on precipitation; that is the annual amount of rainfall and snow fall. In general, when it rains or snows, the resulting precipitation affects the Bay's hydrology. Some precipitation falls directly on the surface of the Bay and some enters the Bay by means of stormwater runoff. Some of the precipitation will also infiltrate into the ground. It is this recharged precipitation that in turn makes up the

baseflow of the streams, which are tributary to Sodus Bay. Offsetting these hydrologic contributions is the water loss, as a result of evapotranspiration (PET), which describes both evaporation and transpiration (or the cycling of water through plants back to the atmosphere) and evaporation, the water loss directly from the surface of the Bay. Watershed characteristics, namely slope, soils, and the amount and types of land development, play a large role in determining how much precipitation runs off the surface of the land and how much infiltrates back down into the soil.

What is internal loading and why is it important? As the term implies internal loading is a function of factors occurring within the Bay itself, independent of external influences. The death and subsequent decay of weeds, algae, fish and other organic material release phosphorus into the Bay. Some phosphorus can also be recycled from the sediments and inorganic material. If great enough, or if the timing is right, this internal load can drive eutrophication processes, thus necessitating special management attention.

The total hydrologic load (amount of inflow from all sources) totals over 17 billion gallons of water each year, with almost all of that entering as tributary inflow or stormwater runoff. The greatest amount of inflow to the Bay occurs via Sodus Creek East and Second Creek. The hydrology of Sodus Bay, however is complicated by its connection to Lake Ontario. For most lakes, the hydrologic force defining the amount of outflow and flushing rate is the amount of inflow, whether it originates as runoff, tributary inflow or groundwater seepage. Although this is largely the same for Sodus Bay, its association with Lake Ontario complicates matters. The water elevation of Lake Ontario, which is controlled, exerts a measurable effect on the Bay's hydrology, in particular its flushing rate and retention time. Based on the mixing effect with Lake Ontario the modeling indicates that the "effective" flushing rate for Sodus Bay is around 11.7 times per year or approximately 32 days of retention.

In general, the fairly high flushing rate of the Bay helps to mitigate water quality impairments and impacts that arise from the influx of nutrients. While nutrients constitute the basic building block needed for photosynthesis, the primary cause for the accelerated eutrophication of any freshwater system, including Sodus Bay is too great a nutrient load. For most freshwater ecosystems, the nutrient of most significance is phosphorus. Typically, the more phosphorus that enters the system, the more algae and weeds can be expected to grow. The total phosphorus load calculated for Sodus Bay is approximately 28,000 lbs/yr. This total load is split with about 55% coming from external sources and about 45% coming from internal sources. Shoreline septic systems account for only 1.3% of the total TP loading to Sodus Bay. Even so, the maintenance and upkeep of septic

systems should be emphasized not only as a matter of public health, but also as a matter of controlling a potential pollutant source. While 50% of the Bay's external phosphorus load is contributed from stormwater loadings, much of this enters the Bay in the early spring as part of the spring thaw. Much of the nutrients entering with this stormwater runoff are attached to sediment particles, which settle to the Bay bottom and eventually become available for subsequent uptake by weeds and certain forms of benthic algae. The Bay's internal phosphorus load is significant, accounting for at least 22.73% of the annual total load and during the summer, when tributary inflow slows down, this is the primary source of phosphorus loading to the Bay. However, in Sodus Bay, most of this internal loading is attributable to phosphorus liberated from the sediments under oxic (in the presence of dissolved oxygen) conditions as opposed to anoxic (devoid of dissolved oxygen) conditions. This is significant from the perspective of source management and plays a big role in the prioritization of management efforts and funds.

The quantification of the sources of nutrient and pollutant loading to Sodus Bay is addressed in Section 6. Details are provided in that section of the report of how much phosphorus, nitrogen and suspended solids can be expected from different sub-areas of the Bay's watershed and how much is attributable to different land use activities. On a per acre basis, the modeled data show that the Sodus Bay Direct watershed had the greatest per unit area nutrient load followed by Sodus Creek (East) and then Third Creek. Because little of the Sodus Bay Direct sub-watershed relies on storm sewers to collect and direct stormwater runoff into the Bay, management of this source of phosphorus loading cannot be accomplished through the installation of conventional stormwater management devices. Sodus Creek (East) and Third Creek are dominated by orchards and pasture/hay fields, and the influx of phosphorus from these sub-watersheds appears to be largely due to erosion and sediment transport. Services offered by WCSWCD such as stream bank stabilization/erosion control, the agricultural group drainage program, and installation of animal crossings on streams that flow through farmland are crucial to the reduction of sediments and associated phosphorus. These measures at the same time preserve the precious, nutrient rich topsoil needed to sustain the area's agricultural operations.

As most of the Bay's problems are weed related, a considerable amount of effort went into the development of weed control strategies intended to supplement the current weed harvesting program. These are covered in detail in the next section of this report.

3.0 MANAGEMENT OPTIONS FOR SODUS BAY'S WEED PROBLEMS

3.1 INTRODUCTION

As was noted above, the proliferation of weeds (aquatic macrophytes) throughout Sodus Bay has become a focal point of any discussion regarding its long-term management. Although weeds have always been present in Sodus Bay over the past two decades the composition, density and distribution of weeds has reached proportions that impact recreational usage, detracts from the Bay's aesthetics, and has even altered the Bay's ecology. Increasing amounts of time, money and effort are spent responding to and addressing what to do about the Bay's weed growth.

3.2 A PRIMER ON THE WEEDS OF SODUS BAY

Before addressing what to do about the Bay's weed problems, it is of value to understand some about the plants that are creating these problems. Some of the weeds are native, but most of the problem weeds are invasive exotic plants. The following is intended to provide an overview of the most commonly encountered weed species in Sodus Bay. The ranking provided herein is based on the history of these plants with respect to use impairment as well as the frequency of occurrence as determined by the recently completed field survey of Sodus Bay.

1. Eurasian Water Milfoil, Scientific Name: *Myriophyllum spicatum*



Source: Robert Johnson, Cornell University. Ruthanna Hawkins
Cayuga Lake Watershed Network

Origin: Eurasia (Exotic)

Identification: Eurasian Water Milfoil is a submerged, rooted, perennial aquatic plant characterized by slender reddish-green stems often 6-20 feet in length. The leaves are feather like, olive green in color and deeply divided. Each leaf consists of a central axis with 14-24 very slender leaflets on either side.

Distribution: Milfoil is extremely tolerant of varying light, temperature, and salinity conditions and has invaded waterbodies throughout North America. In Sodus Bay, the Milfoil is the *most abundant invasive species* occurring throughout the Bay. Current research is evaluating bio controls using the Milfoil weevil (*Euhrychiopsis lecontei*) and moth (*Acentria ephemerella*).

2. Water Chestnut, Scientific Name: *Trapa natans*



Source: University of Florida

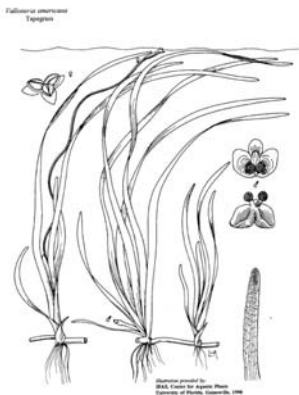
Origin: Asia (Exotic)

Identification: Water Chestnut is an annual aquatic plant with a submerged flexuous stem and a floating rosette of leaves. The stems possess long petioles with certain portions capable of inflation, which can suspend the leaves on the waters surface. Reproductive nuts have 4 sharp spines that are hazardous to swimmers. These seeds may remain viable in the sediments for up to twelve (12) years.

Distribution: Invasive plant found in waters from Virginia to upstate New York. In Sodus Bay the plant occurs primarily in cove areas in close proximity to tributaries. The plant increases sedimentation in the Bay by trapping suspended sediment transported by the tributaries. The plant forms dense, monotypic stands that preclude passage of canoes. The water chestnut reproduces exponentially and 1 acre may produce enough offspring to cover 100 acres the following year.

3. Eel Grass / Tape Grass, Scientific Name: *Vallisneria spiralis*

Source: University of Florida at Gainesville

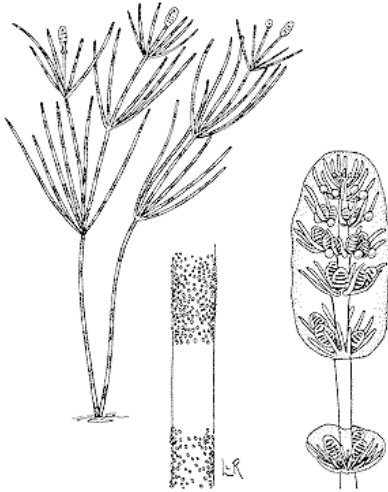


Origin: Eastern North America

Identification: Tapegrass is a submerged perennial aquatic monocot. The most prominent feature of tapegrass are its long, slender, green, ribbon like leaves that often grow to the waters surface. This plant holds to the substrate through extensive fibrous roots, which extend from horizontal rhizomes. A distinct feature of tapegrass is the long cylindrical stalks that coil following pollination.

Distribution: Found throughout the entire United States. Tapegrass is prominent throughout the bay, and grows in water depths up to 12 ft, in dense monotypic stands. It is a native plant but its abundance and density in Sodus Bay has become a nuisance to recreational uses.

4. Nitella / Brittlewort, Scientific Name: *Nitella* spp.



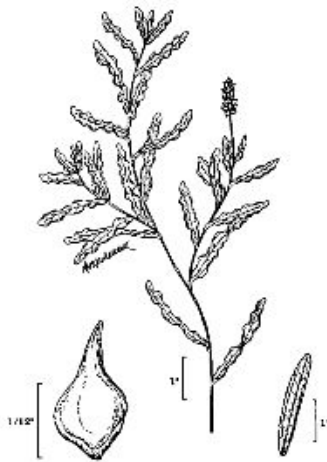
Origin: Unknown

Identification: Nitella, resembles a submerged aquatic macrophyte, but is actually a macro-algae, lacking true leaves. Nitella possesses six to eight evenly forked branchlets, which grow in whorls in regularly space intervals around the stem like structure. Being an algae, Nitella does not possess any roots but adheres to benthic areas through root-like structures termed holdfasts. Nitella is often confused for stonewort, which lacks a “stem” branching and has a rougher texture.

Distribution: Found throughout the entire United States. Extremely dense growth in areas protected from wind in Sodus Bay such as docks, notably on the eastern shore of Leroy Island. It is difficult to harvest

due to its very dense weight, which requires frequent trips to unload. It is common throughout Sodus Bay. *Source: University of Florida*

5. Curly Leaf Pondweed, Scientific Name: *Potamogeton crispus*



Origin: Eurasia

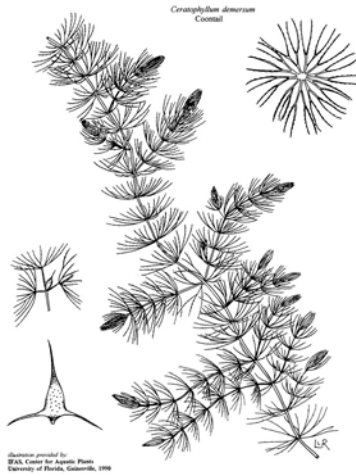
Identification: Oblong, stiff, translucent leaves have distinctly wavy edges with fine teeth and 3 main veins. Sheaths (stipules) are free of the leaf base and disintegrate as they age. Stems are branched and flattened. Flowers are produced in spikes on stalks up to 7 cm long. Curly leaf pondweed produces many sharp angled turions, which fall to the lake bed by mid-summer.

Notable Characteristics: Curly leaf pondweed is able to tolerate cool water. Due to its over-wintering it is often the first plant species to grow in the early spring and often dies back by the fourth of July. It reproduces via spiraled turions deposited onto the sediment.

Distribution: Found throughout the entire United States. It is common in Sodus Bay but less of a nuisance.

Source: plants.usda.gov

6. Coontail, Scientific Name: *Ceratophyllum demersum*



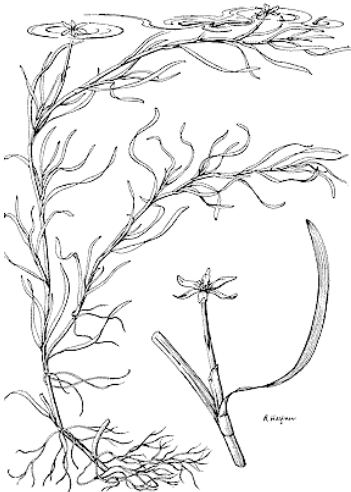
Source: University of Florida at Gainesville

Origin: Unknown

Identification: The serrated, forked leaves of coontail are arranged on the stems in whorls, with usually 5-12 leaves in each whorl. It is generally a dark, olive green color, and rough to the feel. Lacking true roots, coontail acquires most of its nutrients through the water column. When growing close to the sediment coontail may develop modified leaves or “holdfasts” which are used to anchor to the sediment.

Distribution: Found throughout the entire United States. It is common in Sodus Bay but less of a nuisance.

7. Water Stargrass, Scientific Name: *Zosterella dubia*

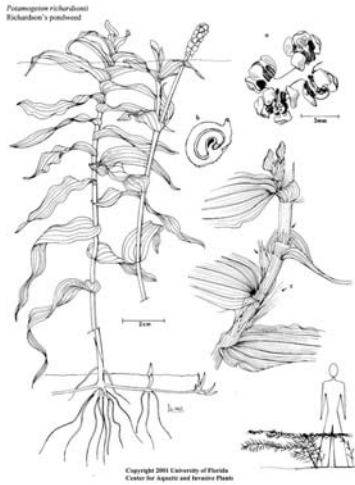


Origin: Unknown

Identification: The long, grass like leaves of water stargrass are similar to those of eel grass. Water stargrass may be recognized by its narrow, parallel-sided leaves with many fine veins, but lacking a central mid-vein. Leaves are alternate, stipitate, linear, obtuse to rounded, or apiculate at the tip. The base of the leaves is jointed to a tubular sheath, which is wrapped around the stem. Stems of water stargrass are slender, elongate, and freely branched.

Distribution: Found throughout the United States. It is common in Sodus Bay but less of a nuisance.

8. Richardson's Pondweed, Scientific Name: *Potamogeton Richardsonii*



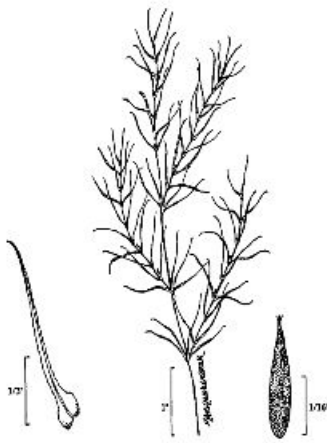
Origin: North America

Identification: Richardson's Pondweed has densely spaced, lance shaped leaves with wavy or crinkled margins that are often curved backwards. Leaves often have two white veins, which run parallel to the whitish mid-vein. Membranous sheaths arise from leaf bases and wrap $\frac{1}{2}$ to $\frac{3}{4}$ the way around the stem. Stems are whitish and often branched. Female plants produce flowers on whorls of emergent spikes.

Distribution: Found throughout the north and west United States, but not in the south. It is common in Sodus Bay but less of a nuisance.

Source: University of Florida

9. Slender Naiad, Scientific Name: *Najas flexilis*



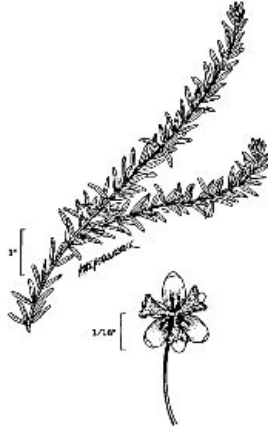
Origin: North America

Identification: Leafs are glossy, green, and finely toothed and are oppositely arranged. Stems are very thin, green, and easily broken and fragmented.

Notable Characteristics: Slender Naiad is an extremely valuable food for duck's.

Distribution: Found throughout the north and western United States. It is common in Sodus Bay but not a nuisance plant.

10. Elodea, Scientific Name: *Elodea canadensis*



Origin: North America

Identification: Leaves are small, green and lance shaped. Leaves attach directly to the stem in a whorl of three leaves. Whorls density becomes greatest the closer to the apex of the stem. Stems are long and slender. Female plants produce tiny, white flowers with three petals that float on the waters surface.

Distribution: Found throughout the United States except for Texas, Louisiana, and Georgia. It is common in Sodus Bay but not a nuisance plant.

3.3 WHY IS THERE A WEED PROBLEM IN THE FIRST PLACE?

Aquatic plants, as previously mentioned, are an essential element of a healthy, well-balanced ecosystem. These plants provide a variety of essential functions that define and shape the ecology and the environment of Sodus Bay. Among other things:

- Weeds provide habitat for young and adult fish, including some of the much sought after game species,
- Weeds help dissipate energy, combat wave erosion and maintain the stability of the shoreline, and
- Weeds channel nutrients that otherwise would be used by algae.

Weed related use problems and the impacts that weeds have on the recreational use of Sodus Bay are no recent issues. Weed control efforts date back to the 1950s. However, with the establishment first of Eurasian water milfoil (*Myriophyllum spicatum*) and more recently the colonization of the Bay by water chestnut (*Trapa natans*) weed problems have intensified to the point where access to areas are impeded, circulation patterns have become altered, sedimentation is being accelerated and the Bay's fishery is being threatened. The magnitude of Sodus Bay's weed problem has necessitated the expenditure of considerable effort and cost to properly manage the native plants and control to the fullest extent practical the spread and success of the invasive weeds. A variety of weed management strategies have been implemented including mechanical harvesting, hand pulling and the application of aquatic herbicides. Of the various strategies put into affect, the most significant has been mechanical weed harvesting. Conducted under the direction of the WCSWCD, the mechanical weed harvesting program has been very successful. However, the density, distribution, species composition and expanse of the Bay's weed problem taxes the capabilities of the County's harvesting program. As of late, is not in itself enough to fully address the impacts created by weed growth, especially the weeds that grow in the shallower areas

inaccessible to the harvester and between the residents' docks and piers, which presents a challenge to effective harvesting. Thus, although much has been done in the past to manage the Bay's weed problem, it is apparent that more needs to be done. Although the Bay's weed problem is a symptom of accelerated eutrophication, it has reached proportions that merit focused attention and prioritization.

The bathymetry of Sodus Bay (Section 5) is characterized by an expansive littoral shelf that extends out from most of the Bay's shoreline. The littoral zone is the shallow water interface between uplands and open water. The Bay's littoral zone provides a variety of suitable habitats for colonization by aquatic plants. This includes shallow protected embayments and shallow shelves that extend far out from the shoreline into the Bay. In some areas the sediments consist of firm, gravelly deposit while in other areas the sediments are dominated by soft, nutrient-rich muds. The combination of available suitable habitat, organic and nutrient rich sediments and clear water not only



makes this perfect for use by beneficial, native aquatic plants. But it has also increased the success of the Bay-wide colonization of invasive aquatic macrophytes (weed). The success of these plants has impacted the recreational use of the Bay and has even impacted the Bay's ecology.

Recognizing this, a significant amount of effort was devoted as part of this project in the investigation of the Bay's current weed problems, and more importantly in the examination of the pros and cons of various weed control techniques. The objective here is not to eradicate aquatic plants, but rather to remove the invasive, non-native species, create conditions that favor the re-establishment of beneficial native species, and manage weed growth overall at densities that enhance the ecology of Sodus Bay but minimize

recreational impacts. The remainder of this section of the report provides not only an up date on the Bay-wide distribution of aquatic plants, but insight concerning the weed control options that should be considered for implementation.

3.4 THE DISTRIBUTION OF AQUATIC WEEDS IN SODUS BAY

3.4.1 STUDY METHODOLOGY

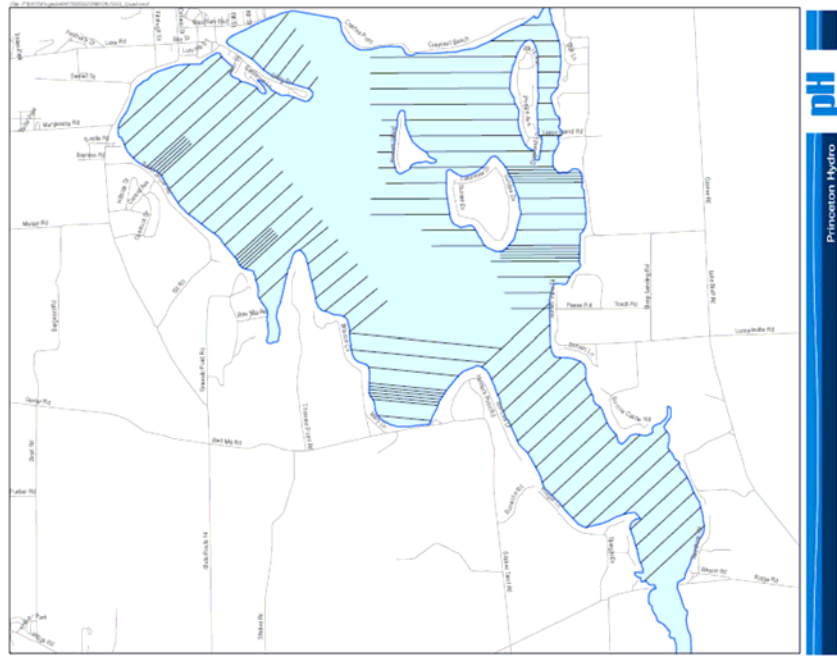
Differences in water quality, water clarity, aqueous chemistry, sediment composition, and water depth are all variables that influence and control the colonization of various areas of Sodus Bay by aquatic macrophytes. These chemical and physical attributes also affect the distribution, density and diversity of different plants throughout the Bay.

A number of investigations and studies have been conducted of the weed community of Sodus Bay. These include data maintained by the WCSWCD, as part of the annual mechanical weed harvesting program, observations made by WCWQCC and Save Our Sodus (SOS), and detailed studies conducted by the Finger Lake Community College and SUNY Brockport. These studies clearly show that the distribution of weeds throughout the Bay is not homogeneous and that the density and distribution of weeds have changed over the past two decades.

An early, but very comprehensive, analysis of the community composition and distribution of the Bay's weeds was conducted by Dr. Bruce Gilman of FLCC, "[An Inventory Of Macrophyte Communities In The Wayne County Bays Of Lake Ontario, New York](#)". That study was used as a bench mark for the weed survey conducted as part of this project. Essentially, the historical data provided a means of objectively examining and analyzing current weed distribution patterns and weed composition.

In order to properly evaluate the Bay's weed community and have the current data comparable to the historical data, transects were selected that overlapped with those surveyed by Dr. Gilman. Actual locations were modified somewhat to allow the study to encompass the natural variability of habitats areas in the Bay, but at the same time including sampling areas currently impacted by weed growth. Twenty one (21) sample transect locations throughout Sodus Bay were randomly selected by Princeton Hydro taking into account the following criteria: habitat currently supporting aquatic plants including, but not limited to, invasive aquatic plants such as water chestnut and Eurasian watermilfoil, and water depths ranging from 2 to 8 feet. Transect locations were mapped at the 0 foot and 100 foot mark using a Magellan© handheld Global Positioning System (GPS) unit and plotted using Geographic Information System (GIS) Arcview 9.0; the transect locations are hereby represented in Figure 3.1.

Figure 3.1 Weed Survey Transects



Monitoring of the survey transects was conducted by Princeton Hydro staff trained in aquatic plant identification and survey methods. A line intercept sampling methodology (Madsen 1999) was used to sample all transects. The sampling was conducted in strict adherence to a Quality Assurance Protection Plan prepared specifically for this task and approved by the USEPA. A copy of the QAPP is provided as an appendix to this report.

Along each transect, transect plots were sampled at the 20, 40, 60, 80, and 100 foot mark from the shoreline. Each plot was delineated by using a floating 3x3 foot quadrant. The area inside the quadrant, defined on the bed of the bay by drop chains, was observed and sampled using an Aquascope or mask and snorkel. Each plot was sampled for aquatic plants, sediment type, and water depth. Water clarity was measured at the 100-foot mark using a Secchi disk. The plant community was identified to species level and each species ranked according to abundance using the following formula: (A) **Abundant**, greater than or equal to 50% of total plant community, (C) **Common** 10% to 50% of total plant community, (P) **Present** less than or equal to 10% of total plant community. Species identifications were made utilizing previous identification knowledge and various aquatic plant field guides including (Borman, 1997, Hellquist, 1980). After all plots were sampled on a single transect, a single, representative plot was harvested using a weed rake. The plant material was then taken back to Princeton Hydro to dry on pervious landscape fabric in an open air environment. Dried plant biomass was then weighed to the nearest 0.01 oz, using a top loading OHAUS balance.

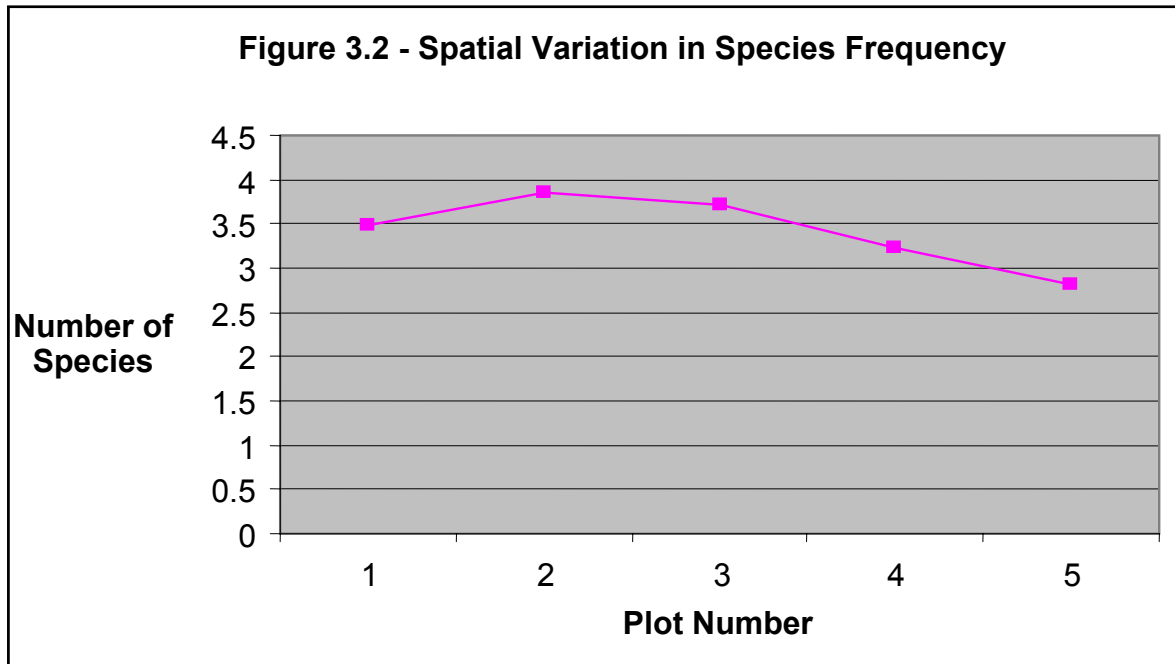
3.3.2 RESULTS

The methods employed in the survey conducted were designed to address the abundance, composition, and distribution of submerged aquatic plant species throughout Sodus Bay and allow a comparison from data gathered from years past.

Sodus Bay possesses vital characteristics essential for macrophyte growth, specifically relatively clear water, abundant nutrients, conducive substrates, and an expansive littoral zone provide favorable conditions for macrophyte growth to reach excessive levels. Sodus Bay's littoral zone, defined here as water depth less than or equal to 12 feet comprises approximately 37.0% of the Bay's total bottom area (Section 5). The survey of the Bay's weeds conducted as part of this study showed no statistically

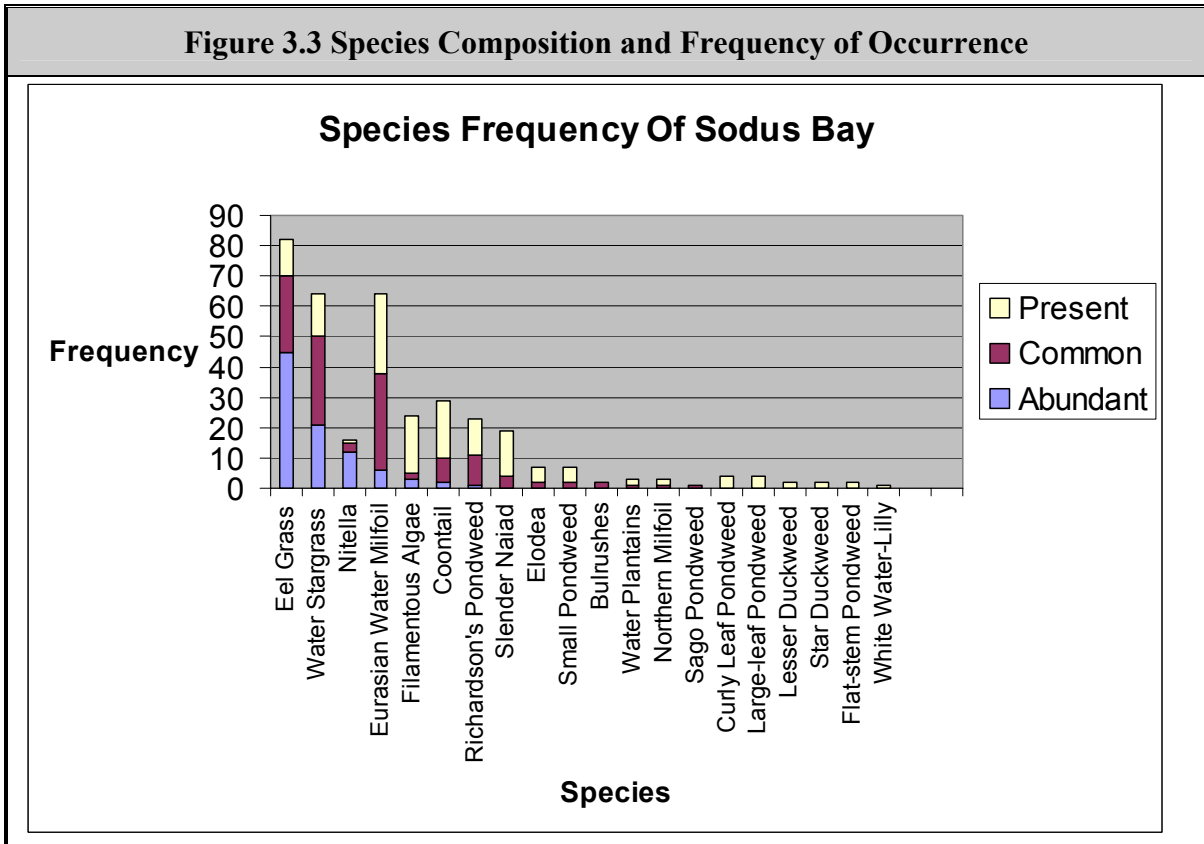


significant variation in the number of species occurring along the length of each surveyed transect to depths of 8 feet ($F(4,100) = 1.60, p = 0.18$). Although plants growth occurs to depths of 12 feet, species numbers and diversity begin to display some differences (Figure 3.2) with fewer species growing in the deeper waters as compared to the shallower waters.

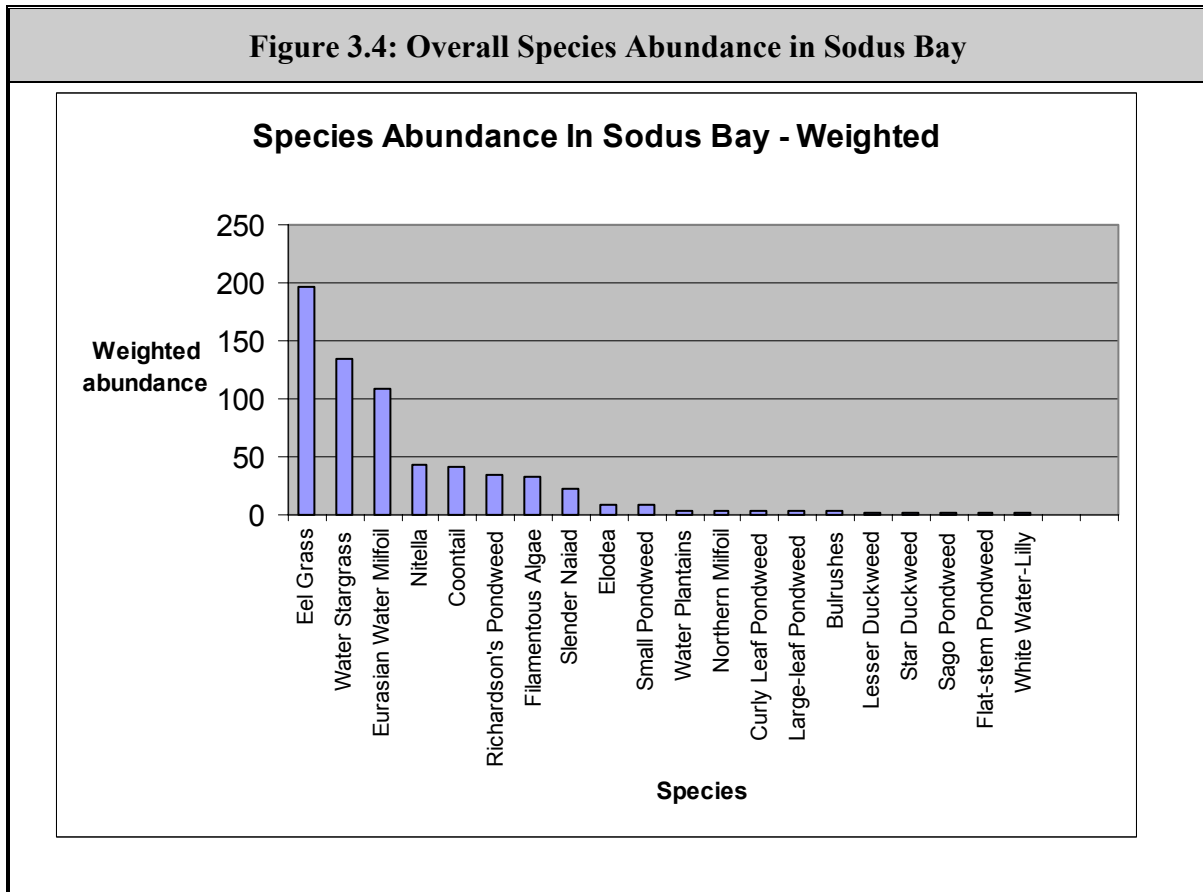


A total of twenty (20) weed species were observed within the sampled plots located along each transect. Two (2) additional species were observed outside of the transect line, bringing the total number of species identified as part of this study to 22. Using the line intercept sampling method each plant species in the observed community was recorded and ranked according to abundance. Each of the three rankings, were then weighted with category coefficients to give species composition a semi-quantitative value. Category coefficients were assigned as follows: Abundant = 3, Common = 2, Present = 1. Species count within abundance categories was multiplied by the correct coefficient and then summed to determine overall species rank. Figure 3.3 illustrates the species composition broken down in the three abundance categories observed in the bay.

Figure 3.3 Species Composition and Frequency of Occurrence



As indicated in Figure 3.3 *Vallisineria americana*, *Zosterella dubia*, and *Nitella sp.* were the most abundant species identified in the sampled transects. The overall species frequency (Figure 3.4) shows a similar pattern with the top three observed species as *Vallisineria americana*, *Zosterella dubia*, and *Myriophyllum spicatum*. It should be noted that the lack of water chestnut in any of the sampled transects is more a function of sampling design as opposed to the lack of this species in the Bay. As the sampled transect locations were conducted to overlap as best as possible with the 1989 study, it appears that areas heavily infested by this plant were not included. Obviously, as supported by data developed independently by the WCSWCD and the WCWQCC, water chestnut is not only present in Sodus Bay, but is becoming increasingly common and pervasive. In the far southern end of the Bay as well as in the mouths of Second Creek and Third Creek, the water chestnut is so dense as to prevent the passage of canoes. Thus, although not identified as part of the field effort, it is present in Sodus Bay, at densities in given areas that can be considered epidemic in magnitude.



As indicated by Figure 3.4 just three species, or 15% of the species observed, make up 67% of the weighted species abundance in the sites sampled in Sodus Bay. In comparison to Gilman’s survey conducted 18 years previously, there was a significant variation in species diversity between replicable plots (replicable plots defined as inventory station #2, Gilman 1989) as indicated in Table 3.1.

<i>Survey</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Princeton Hydro ¹ - 2006	13	55	4.23	3.53
Gilman ² - 1988	13	84	6.46	2.10
$F(1,24) = 11.49, p = 0.002.$				
1. As per survey conducted summer of 2006				
2. As per results reported in Gilman, 1989				

This drop in species diversity, combined with a 33% increase in plant biomass (Table 3.2) compared to Gilman’s 1988 macrophyte survey indicates a strong shift in the macrophyte community.

Table 3.2: Macrophyte Dry Weights 1988 vs. 2006		
	Gilman 1988	Princeton Hydro 2006
Min	19g	13g
Max	619g	1923g
Mean	211g	303g
Median	169g	239g
% Difference - Mean	33.40%	

The community structure indicates a high level of interspecific competition with a few species out competing all others for available light, nutrients and habitat. *Vallisneria americana*, *Zosterella dubia*, and *Nitella* spp. and occasionally *Myriophyllum spicatum* were observed in dense monotypic stands extending to the deepest depths of the transect lines (Table 3.4). These dense monocultures often grow to the surface of the bay, thereby impeding boating, fishing and swimming.

Sodus Bay’s submerged aquatic plant community composition is highly dependent on bay morphology and human structure influences. Wind protected areas such as homeowner docks, coves, and protected island shorelines have characteristically high densities of macrophytes that often impede boating access and dock use. Wind protected areas of the Bay such as the eastern shore of Leroy Island were observed to have immensely dense stands of *Nitella* spp. that make boat access to homeowner docks virtually impossible. The immense amount of biomass associated with *Nitella* spp. presents a challenge to mechanical harvesting. The growth characteristics of *Nitella* spp., namely growing in confined areas such as between docks, and the huge amount of biomass associated with this species combines to preclude efficient mechanical harvesting.

Temporal and spatial changes in Sodus Bay’s macrophyte community may have evolved from numerous factors. Reductions in species richness of submerged aquatic plants have been documented along with a change of watershed land use from forested to agriculture (Crosbie and Chow-Fraser, 1999). Anthropogenic influences into the Bay’s nutrient loading include nutrient runoff from agriculture and inputs from human waste via septic systems. Historic eutrophication has likely altered Sodus Bay’s nutrient dynamics by

contributing a large amount of phosphorus to the nutrient system that is readily available to aquatic plants both directly from the sediments and through sediment release during periods of hypolimnetic anoxia. After plant senescence, this phosphorus is again cycled into the water column and deposited once again into the sediments for uptake by submerged plants the following growing season.

There have also been important changes in the biota of the Bay that have likely contributed to the increasing plant biomass of Sodus Bay. The introduction of the zebra mussel in 1997 has likely increased light penetration and therefore suitable growing habitats for aquatic plants via filter feeding of phytoplankton. Increased light penetration along with decreased nutrient competition from phytoplankton has likely changed the aquatic plant community in terms of composition and biomass.

The role invasive species play in the changing plant community of Sodus Bay should not be overlooked. The introduction of water chestnut (*Trapa natans*) in the late 1980's has left an indelible mark on the plant community of the bay with impacts far reaching. Water Chestnut is a fast growing, exotic species introduced to the United States in 1859 from Asia. In a single year, 1 acre of water chestnut possesses enough reproductive capability to cover 100 acres the following year¹. It is this type of exponential growth that makes water chestnut a target species for eradication. Negative effects from water chestnut are vast and far reaching. Once established, water chestnut has the ability to spread rapidly and exclude native species from the plant community. This has already taken place in the cove areas of Sodus Bay where Second Creek enters the Bay. Associated with large expanses of water chestnut is enhanced sedimentation caused by the plants trapping large amounts of silt entering the Bay. As this occurs, there is a decrease in light penetration with a resulting drop in oxygen content. These factors combine to degrade suitable habitat for native biota such as fish, birds, and insects. Water chestnut also causes severe impacts on recreational uses of Sodus Bay. The large expanses of growth impede boat traffic, fishing, and swimming. The sharp spines on the reproductive seed of water chestnut pose a hazard to anyone who may step on them.

The plant community in Sodus Bay has likely responded to a number of variables to become the impacted community it is today. Anthropogenic impacts on the bay ranging from excessive nutrient inputs, introduction of invasive species, and shoreline construction has altered the bay. As the submerged plant community shifts to one, with less plant diversity and greater abundance, there will not only be changes in the overall plant community but also to nutrient dynamics, sediment retention, fishery habitat, and aqueous chemical composition which will ultimately alter Sodus Bay's overall ecology.

1 (http://www.dnr.state.md.us/bay/sav/water_chestnut.asp).

Table 3.4: Ranked Species – Sorted by Occurrence and Abundance Within Surveyed Quadrants

Weed Species	Ranked Species-Weighted				
	Code	Abundant	Common	Present	Sum
Eel Grass	VA	135	50	12	197
Water Stargrass	ZD	63	58	14	135
Eurasian Water Milfoil	MS	18	64	26	108
Nitella	NL	36	6	1	43
Coontail	CD	6	16	19	41
Richardson's Pondweed	PR	3	20	12	35
Filamentous Algae	AL	9	4	19	32
Slender Naiad	NF	0	8	15	23
Elodea	EC	0	4	5	9
Small Pondweed	PP	0	4	5	9
Water Plantain	AG	0	2	2	4
Northern Milfoil	M2	0	2	2	4
Curly Leaf Pondweed	PC	0	0	4	4
Large-leaf Pondweed	PA	0	0	4	4
Bulrushes	SC	0	4	0	4
Minor Duckweed	LM	0	0	2	2
Star Duckweed	LT	0	0	2	2
Sago Pondweed	PS	0	2	0	2
Flat-stem Pondweed	PZ	0	0	2	2
White Water-Lilly	NY	0	0	1	1

3.5 Management of Nuisance Aquatic Weeds

Since 1988, the WCSWCD has administered and implemented a Bay-wide weed harvesting program. Although this program has been very successful and cost-effective, due to the scale of Sodus Bay's weed problem, it has not been able to keep up with the spread of weeds throughout Sodus Bay. Other techniques have been used in the past in concert with weed harvesting. These have been limited to the actual hand pulling of weeds and the treatment of select areas of the Bay with various herbicides.

Due to the increasing problems created by excessive weed growth, the WCSWCD began investigating, within the framework of a comprehensive management plan for the Bay and its watershed, additional macrophyte control options. These range from doing nothing (A No Action option) to making use of various biological, chemical, manual and mechanical treatment techniques that could be used either with or as a substitute for the ongoing weed harvesting operations.

This section of the report provides a comprehensive assessment of the feasibility of

various weed management alternatives. In assessing the feasibility of each option a number of factors were evaluated including:

- The compatibility of the management option with the WCSWCD's and the community's weed management needs and objectives.
- The cost of the management option.
- The ability of the management option to improve recreational uses or water quality of Sodus Bay.
- The consistency of the management option with regulatory permit limitations and the likelihood of the required permits being issued.
- The potential ecological impact(s) associated with the option.
- The success of the management option in other New York waterbodies.

It should be emphasized, as is the case with any well designed weed control program, that the objective of the WCSWCD is not to eradicate macrophyte growth, but rather to manage macrophytes with the focus placed on the intense control of nuisance, invasive weed species. The program should improve and enhance recreational use and opportunities, while at the same time protecting the quality and functionality of the Bay's aquatic habitats.

The options that were evaluated fall into three basic categories: mechanical/physical, chemical and biological. The specific options falling into each of these categories included for the most part weed control options that have been approved for implementation in other waterbodies State-wide under the auspices of the NYSDEC and/or the USACOE. The exception to this is the treatment of lake sediments with alum or lime.

The options that were evaluated and are discussed below are:

Biological

- Grass carp
- Milfoil weevils and other herbivorous insects

Chemical

- Aquatic herbicides (systemic and contact forms)
- Treatment of the sediments with lime or alum

Physical

- Benthic barriers
- Weed rollers
- Suction assisted, hand harvesting
- Hydroraking / Rotovating
- Dredging

3.5.1 Biological Controls –

Biological controls have been used in various lakes throughout New York. Encompassed by this group of weed management options are the various organisms that are used to control weed growth. For the most part, control is achieved in one of two ways; either through consumption of target plants or through damage to the host plants. Research is also being conducted of certain viruses and fungi that could be used to control invasive plant species, most notably Eurasian water milfoil. All of the biological controls previously permitted for use by NYSDEC were intended primarily to reduce densities of Eurasian water milfoil. The three considered for application in Sodus Bay were the milfoil weevil, the milfoil moth and grass carp.

The success and the level of control obtained through these efforts can be highly variable, and as such the results achieved in one waterbody may not transfer easily to another. The main factors affecting success include the types and distribution of the problem plants, the habitat qualities provided by the host waterbody for the introduced control species and the effect or extent of predation on the introduced biological controls. In addition, because of the nature of this form of control, impact to the target plants may take a considerable time to be realized, especially in the case of large waterbodies such as Sodus Bay. Care must be also be taken with the introduction of any of these species to fully evaluate and prevent secondary impacts to the Bay's biota. This is most likely to occur with the stocking of grass carp as a result of alterations in native fish habitat or decreases in lake clarity. Princeton Hydro documented the latter in two Putnam County lakes that were stocked with grass carp. Although the fish were able to alleviate weed problems that plagued both lakes (Lake Carmel and Peekskill Lake), algal levels in both waterbodies increased and the lakes' clarity decreased.

Milfoil weevils (*Euhrychiopsis lecontei*) are small, herbivorous aquatic beetles that attack only plants of the genus *Myriophyllum spp.* This includes the pervasive and very invasive Eurasian water milfoil, *Myriophyllum spicatum*. The weevils are native to New York, but typically are found in very low numbers and may not be present in every lake or waterbody. The control of the milfoil is achieved by the early life stages of the weevil that essentially bore into the plant and "mine" the plant's stems (Solarz and Newman 1996). There are a variety of factors that determine the success of this form of control including the density of milfoil, over wintering habitat, and predation by fish on the adult weevils. Although these insects are native to New York, a permit is required from the NYSDEC for their introduction for the purpose of weed control. The two biggest concerns with this option though, are first cost (the weevils cost approximately \$1.00 each) and the fact, as evidenced by the Sodus Bay plant data, that milfoil is not the predominant problem weed.

The aquatic moth (*Acentria ephemerella*) is another insect species that has been introduced in New York lakes for the control of Eurasian water milfoil. Unlike the weevil, *Acentria* is not a native New York species, though it is considered to be "naturalized" and as such a non-exotic species. Again, as with the weevil, the

distribution of this insect in New York lakes is variable and its introduction for the purpose of weed control is regulated by the NYSDEC and would require a permit. An extensive amount of research has been conducted on this species by Cornell University and the Lake Champlain Basin Program. The success of the insects is greatly impacted by fish predation. For the same reasons that the milfoil weevils (cost, too plant specific, too slow, difficult to permit), the moths, though promising, do not appear at this time to be a feasible weed management alternative for Sodus Bay.

The Chinese grass carp or white amur (*Ctenopharyngodon idella*) is a fish that has been used very successfully throughout the country to control weed growth. This fish is not native to the United States and should not be associated with the common carp, *Cyprinus carpio*, with which it shares little common traits. In New York, the introduction of grass carp is highly regulated by the NYSDEC. One of the main requirements set forth by NYSDEC, is that stocked grass carp must be sterile (triploid). As such, proof must be supplied in advance of the introduction of the fish that they have been purchased from a NYSDEC approved hatchery.

Unlike the weevils and the moths, grass carp feed on a wide variety of plants. Although these fish tend to prefer the more succulent species such as milfoil and various pond weeds (*Potamogeton spp.*) they will feed on anything from duck weed to water lilies. Research conducted by Pauley and Bonar documented the fish's preferred feeding under controlled pond experiments. Many of the problem weeds in Sodus Bay are among the fish's more highly preferred foods, such as curly leaf pond weed, eel grass (*Vallisneria*) and the milfoil. However, there are a number of problems and issues that greatly limit the use of this species in Sodus Bay. Besides being cost prohibitive (cost per fish approximately \$10.00, stocking rate 5-10/acre) and very unlikely to be allowed by the NYSDEC, the success of these fish is limited as follows:

- Slow to achieve, to control, especially for a large waterbody
- May not result in the control of the most problematic species due to feeding preferences and the heterogeneous distribution of the plants.
- Could disrupt important spawning, nursery or foraging habitats for the Bay's native fish, and disrupt important habitat or food for waterfowl.
- As noted above, could impact the clarity of the Bay by triggering algae blooms.
- Could actually increase the spread of water chestnut by eliminating competition for habitat created by other plant species.

In addition, the NYSDEC requires that the outlet of any grass carp stocked waterbody be screened or equipped with some structure or device to prevent the stocked fish from existing. This is obviously totally impractical for Sodus Bay.

Thus overall, all of the biological control techniques that have been permitted elsewhere in the State by the NYSDEC were considered non-applicable and infeasible for Sodus Bay. Due to a variety of factors including cost, permitting, and proven success rate, biological controls are not considered appropriate either as a primary or a supplemental

weed management technique for Sodus Bay.

3.5.2 Chemical Controls –

Although used in the past, herbicides (chemical designed to kill unwanted plant growth) have been sparingly used in Sodus Bay. Chemical control, if done correctly, is a potentially feasible supplement to the ongoing weed harvesting program. However, chemical control techniques have both their limitations and their own potential environmental impacts, which must be considered in advance of their utilization. It should be noted there are no pre-emptive, or pre-emergent products for use in a lake environment. Therefore, some amount of weed growth must occur in advance of the application of the herbicide. Also, unlike terrestrial weed control products, there are very few products licensed by the USEPA or the NYSDEC for use in aquatic environments.

There are basically two different classes of weed control chemicals; contact herbicides and systemic herbicides. Contact herbicides impact aquatic weeds by literally destroying the portions of the plant with which they come in contact. As such, to be both cost-effective and result in the desired level of control, these chemicals are applied only once a substantial amount of weed growth has occurred. These chemicals are relatively fast acting, having the ability to decimate weed stands in as little as 10 days following their application. Contact herbicides tend to be somewhat selective, meaning that certain chemicals will impact only given weeds. Therefore, considerable amount of thought needs to be given in the selection of contact products; with this starting with proper identification of the problem weed species. As noted above, the success of a contact herbicide control program is largely predicated on the chemical coming in contact with an adequate amount of weed biomass. Factors that can impact success include, flushing and circulation, the amount of suspended sediment in the water column, water temperature and access to the targeted weeds.

Conversely, systemic herbicides are absorbed and subsequently assimilated by the treated weeds. The herbicide elicits an alteration of some biological process, usually involving plant photosynthesis that result in the plant's mortality. For example, some of these chemicals cause the plants to grow rapidly, thereby exceeding internal food reserves, while others alter the chlorophyll content preventing the plants from successfully photosynthesizing. The mortality of weeds treated with systemic herbicides tend to be much slower, than the "die off" caused by contact herbicides. Although this may reduce some of the potential secondary impacts caused by the rapid decomposition of large amounts of decaying weed biomass (e.g., nutrient pulsing, dissolved oxygen depletion, pH shifts and algae blooms), this also means that weed control may not be achieved for an extended period of time (30-45 days) following treatment. Even more so than the contact herbicides, the success of a systemic herbicide application, is impacted by water circulation and flushing, owing to the fact that the chemical must remain in the treatment area in high enough concentrations, for a long enough period of time to be adsorbed by the plants. Systemic herbicides are both somewhat more selective, but at the same time ubiquitous as compared to contact herbicides. The ubiquitous aspect of the chemicals is a

function of their ability to readily dissipate throughout a waterbody. Plus, at the proper concentration, they can impact a broad array of plants. However, at the same time, by using the correct formulation (granular as opposed to liquid), and by properly setting the application concentration and timing the application, these chemicals can target invasive species (e.g., *Myriophyllum*, *Ceratophyllum*, *P. crispus*) while at the same time allowing beneficial native plants to grow in the same treated areas.

Plant selectivity is an important criteria when selecting a contact or systemic herbicide. As noted above, although some of these chemicals can impact a broad array of plants, certain chemicals are more effective in the control of specific groups of macrophytes (emergent species versus floating plants versus submerged weeds). As such, care must be taken in the selection of the herbicide so as to ensure that the target plant species will be impacted. Similarly, chemical control, regardless of the product or dose may not always result in weed control. For example, *Vallisneria americana* (eel grass) is not impacted by herbicides and other plants, notably the native *Potamogetons*, may require very high herbicide concentrations to be effectively controlled.

Any aquatic herbicide application, whether it is a contact or systemic product, is regulated by the NYSDEC. Therefore, in advance of the application of any weed control chemical, a permit must be obtained from the NYSDEC Pesticide Management Program (PMP). NYSDEC Fish, Wildlife and Marine Resources may provide comment to the PMP, particularly when a chemical treatment is proposed in a waterbody supporting a high quality fishery or threatened and endangered species. It should be noted that Sodus Bay is on the NYSDEC list of waterbodies subject to enhanced review. For such waterbodies, an Aquatic Vegetation Management Plan must be submitted as part of the herbicide permit application package. NYSDEC has established guidelines of the preparation of such plans (Appendix A of a Primer on Aquatic Plant Management in New York State (April 2005)) and the implementation of a three-tier, Aquatic Vegetation Monitoring Plan. As per the NYSDEC, Sodus Bay, is a waterbody of enhanced review due to one or more of the following:

- The proposed treatment has the potential to impact endangered, threatened, rare or special concern species; or
- The water body is classified for potable water use (as identified in 6 NYCRR Parts 800-941); or
- The water body is identified by the Department as a priority for water resource protection and restoration, through inclusion on the State Priority Waterbody List; or
- The water body has a department managed public access; or
- The water body has a department managed fisheries; or
- The water body is of special department regional concern.

If a permit is issued by the PMP, the permit will likely include water use restrictions. These restrictions limit the use of the herbicide treated water for a designated amount of for irrigation, drinking, contact recreation, and even fishing. These use limitations can be

significant, especially if the waters are used for potable purposes. For example, Reward (diquat dibromide), the most commonly used aquatic contact herbicide has a 14-day irrigation use limitation. Sonar (fluridone), a popular systemic herbicide is severely regulated in terms of application distance to wells, flushing rate of the treated waterbody and use of the treated water for irrigation.

As such, the design of a chemical treatment program must be based on good scientific data, in particular a clear understanding of the distribution and life history of the targeted weed species. Furthermore, due to potential side effects ranging from algae blooms to the negative impacts on desired native macrophytes, care must be taken in the selection of the treatment product, quantification of the appropriate dose and application of the herbicide so as to maximize the treatment plan's objective while minimizing or avoiding undesired effects.

Herbicide applications have been conducted in Sodus Bay, originally in the 1950s through the efforts of the Sodus Bay Improvement Association and most recently primarily under the direction of the WCWQCC. Starting in the 1950s, in response to already critical levels of weed growth in the north-east corner, a number of herbicides were used reportedly, including sodium arsenate, copper sulfate and 2-4-D. From the 1960s into the 1980s, chemical control was achieved mostly through the application of Reward (diquat). The use of Reward, (under this brand name and other brand names) was terminated at the direction of NYSDEC in the 1990s. In place of the Reward, the NYSDEC directed treatments be conducted using Aquathol (a dipotassium salt of endothal). This switch, from Reward to Aquathol was a result of NYSDEC regulations that require the containment of Reward treated waters; something that is not possible on Sodus Bay. Presently, chemical control involves the airboat application of Aquathol K. Reportedly, the level of control gained through the application of the Aquathol products is far less than that once obtained through the application of the Reward.

Most recently, as per limitations set forth in the PCH issued permit, treatments are limited to the control of weed growth in select waterfront areas. In total approximately 35,000 linear feet of shoreline on Sodus Bay is authorized for treatment by the NYSDEC. This equates to approximately 160 acres of total Bay area. Additionally, the treatments cannot be conducted in waters any shallower than three (3) feet, but no greater than six (6) feet and to a distance no greater than 200' from the shoreline. As per the NYSDEC permit limitations, the applications are limited to the control of Eurasian water milfoil. The areas that have most recently been the subject of these treatments include Crescent Beach (Town of Huron), the entire shoreline of Leroy Island and Eagle Island, the north-east shore from Lake Bluff south to the southern terminus of Owen Shore Road, the entirety of Spiegel Parkway, the northern half of Bayshore Drive (in the south-east corner of the Bay), the southern facing portion of Bonnie Castle Road (that portion facing Oak Park Marina), the eastern facing portion of Ann Lee Drive, and although not recently treated, the western portion of Ann Lee Drive in the past was part of the targeted treatment areas.

Due to the water depth and shoreline distance restrictions invoked in the permit, in 2005

only 100 acres were actually treated. In 2006, although a permit was issued by the NYSDEC, by the time the permit was received, the window of opportunity for the chemical treatment of the target weeds had passed. As such, no chemical control activity was conducted this past year.

As part of this project, a variety of herbicides were evaluated for use in Sodus Bay. In general, chemical treatments of select areas of the Bay are considered a viable and ecologically suitable accompaniment to the current weed harvesting program. The discussion, which follows, is theoretical. The treatment recommendations that are presented, may not either be allowed or could be severely altered as a result of restrictions imposed by the NYSDEC. It should also be emphasized that all those engaged in the management of the Bay are cognizant that care must be taken with any expansive herbicide treatment of Sodus Bay, especially any program involving contact herbicides. This is due to the fast acting nature of these chemicals and the potential negative side effects including dissolved oxygen depression and the release of reactive (organic and inorganic) phosphorus. The significance of the phosphorus release is that the timing of the herbicide treatments, and the subsequent introduction of phosphorus from the dying plants, could trigger large-scale, algae blooms; a condition that is counterproductive to the overall management of Sodus Bay. Systemic herbicide treatments are considered a more favorable approach, particularly in specific areas that have become overwhelmed with water chestnut growth. However, NYSDEC restrictions on the use of these products may continue to severely limit or fully negate their use in Sodus Bay. Furthermore, at the mouth of the major inlets water flushing and circulation may be too great to allow for adequate contact time between the systemic product Sonar and the targeted invasive weeds. However, in general, it is practical to consider the use of herbicides as part of the Bay's overall weed management strategy.

With respect to contact herbicides, the application of these products should continue to be limited in scale, with focus placed on areas supporting milfoil and water chestnut. Consideration must be given to the use of Reward in some of these areas. Although the waters cannot be fully contained, the treatment areas are relatively small and the Bay's volume is so great that the potential for impact to non-targeted areas is minimal. In general, either Aquathol K or Reward, if applied correctly and under that direction of the WCSWCD, could prove effective in limiting weed growth in the difficult to harvest shoreline areas where accessibility of the harvester, due to docks, piers and shallow water depth, have become increasingly infested.

Target areas must also be expanded to the creek mouths in the southern portions of the Bay, where water chestnut (*Trapa natans*) is growing rampant. Of the various contact herbicides neither Reward nor Aquathol are especially effective in the control of *Trapa*. As such applications of 2-4D, a systemic herbicide licensed for use by NYSDEC need to be considered. NYSDEC restricts the use of 2-4D with respect to the timing of the treatment, allowable treatment area, and dose. There are two chemical formulation of this chemical approved by the EPA for use in the treatment of aquatic weeds. The granular form of this herbicide is a low-volatile butoxy-ethyl-ester formulation. The

liquid form, is a dimethylamine salt. Common brand names of 2-4D include AquaKleen, Weedar 64 and Navigate. In addition to water chestnut, 2-4D is very effective in the control of milfoil and other broad leaf, submerged aquatic plants. NYSDEC does restrict the use of 2-4D, whether pellet or liquid seasonally (treatments must be conducted between late spring and mid-summer, and in terms of water depth, no treatments can be conducted in waters shallower than 2 feet). In addition, there is at least a 24-hour use restriction for the drinking of treated waters and irrigation may be prohibited for a much longer period of time (as stated by NYSDEC until an adequate amount of product decay has occurred). Spot treatments with this chemical would likely only be feasible using the pellet version of the herbicide. However, its efficacy could be greatly diminished in areas having very soft sediments, due to the settlement of the pellets into the mud. Studies have been initiated in the combined use of 2-4D (specifically, Weedar 64) and Rodeo (a broad leaf, contact herbicide) applied as a spray using a sticking agent to adhere the product to the very waxy leaves of the plant. This appears to be a very viable approach and needs to be advanced with NYSDEC for implementation in Sodus Bay.

Alternately, fluridone (Sonar) could be used to control many of the submerged aquatic plants. Recently, improvements have been made in the formulation of the pellet version of this chemical, including a “time release” feature. Unlike 2-4D, which is a somewhat faster acting systemic herbicide, Sonar is slow acting. This has a number of benefits in terms of avoiding or minimizing the aforementioned secondary water quality impacts associated with contact herbicides. However, the slow acting nature of this chemical necessitates that it remain in contact with the target plant(s) for a long period of time (usually 30 days). Water currents and wave action can result in the drift or dilution of the chemical and diminish its effectiveness. The slow release formulation minimizes some of these problems, but as with the 2-4D, there may be product loss and reduced efficacy in areas where the lake bottom is muddy and soft. FASTest is a means of measuring the amount of fluridone in targeted areas following a treatment. This test enables an applicator to ensure that a proper dose rate is being maintained over the course of the treatment period. When used in concert with “split” treatments (the introduction of the chemical in stages as opposed to all at once), improved weed control can be achieved, sometimes using less than the theoretically correct dose rate. The biggest problem with Sonar is its water use restrictions. Treated waters cannot be used for irrigation for 30 days following treatment. Even more important is that areas within 100’ of a potable water intake cannot be treated. The NYSDEC has not been receptive to the use of Sonar in Sodus Bay due to the presence of wetlands, non-target, beneficial weeds and concerns of the impact of the product on fish habitat. However, there is ample evidence showing Sonar can be applied in a manner that targets invasive species such as milfoil, while at the same time avoiding any impact to fish habitat or the fish themselves.

Even with all the regulatory limitations facing the use of herbicides in Sodus Bay, we concluded, based on our observations of the lake, review of the historical weed distribution and speciation data and discussions with lake users that some consideration should be given to the use of 2-4D as a supplementary means of controlling nuisance weeds, especially water chestnut. Furthermore, NYSDEC needs to re-evaluate present

restrictions on the use of Reward in the Bay. It should be emphasized that weed control with chemicals is seen as a much needed supplement to the ongoing weed harvesting operations, as opposed to a replacement. It is clear that there are too many sensitive habitats within the Bay where chemical control will never be permitted or is not warranted. As such, chemical weed control should be conducted in a supplementary manner with the on-going weed control activities.

An additional note, with respect to chemical controls of macrophytes concerns the use of dyes. Dyes are used to darken the water thereby reducing the amount of incident radiation (light). This reduction in clarity theoretically should reduce the degree to which plants can grow in the lake. In New York, because of the way these products are labeled and their claims of “controlling plant growth”. The introduction of a dye into Sodus Bay would be considered a regulated activity and require a permit. This is the case even though the dye itself has no true herbicidal properties. In reality, for a waterbody as large as and as diverse as Sodus Bay, the cost-effectiveness of this control option is low. As such, dye applications are not recommended.

Finally, under this heading of chemical control option are the control techniques involving the treatment of the lake’s sediments with either alum or lime. Based on our recent experience with NYSDEC, in investigating the merits of these nutrient control measures, it does not appear that the State will at any time soon be in a position to issue the SPDES permits needed to authorize such treatments. However, these techniques do appear to have some merit and should be permitted by the NYSDEC in a controlled, experimental basis. The mode of action, with the application of either a lime or alum slurry is not the direct die-off or destruction of the plant, but rather the binding of interstitial nutrients.

Phosphorus is typically the limiting nutrient in northern aquatic ecosystems. Thus, increases in water column phosphorus concentrations can dramatically influence the growth of plants and algae. The application of aluminum sulfate (alum) has proven to be an effective method for reducing phosphorus concentrations in lakes by binding available phosphate ions, thereby rendering it unavailable for plant or algal uptake.

Some interest has arisen concerning the use of an alum slurry to fix phosphorus present in interstitial sediment pore water. As this is a nutrient source for macrophyte growth, theoretically fixing this source of phosphorus could potentially limit macrophyte growth and result in a decrease in the density of weeds in the treated areas. The value of this approach is that macrophyte control is achieved through nutrient management as opposed to having to resort to killing or harvesting the weeds. The objective of this alternative control technique would thus be to fix enough interstitial phosphorus to inhibit excessive invasive macrophyte growth. As noted above, early experimentation with sediment fixing additives proved reasonably successful. This technique could also enable control of benthic algae, which derive the majority of their phosphorus supplies initially at the mud-water interface.

The application of a lime slurry has been the subject of extensive testing and actual whole lake projects in the Canadian shield lakes of western Canada. The theory behind this macrophyte control technique is essentially similar to that of the alum slurry technique; that is to fix interstitial sediment pore water phosphorus supplies. A potential advantage of lime relative to alum is that there are no potential toxic effects. A negative impact can arise with alum if the pH of the treated water body declines below a pH of 5.5. However, the binding of phosphate ions by lime is not as strong, nor as effective as that accomplished with alum. The objective of this alternative control technique is again to manage weed growth through nutrient control.

As such, with both the lime and the alum injections, by reducing the availability of nutrients for uptake and use by the plants, a reduction in plant biomass should be achieved. This can be accomplished without the impacts created by herbicides, and since both alum and lime are routinely used in the treatment of potable water, concerns related to the impact to human consumption of treated water should be minimal. So although these techniques remain promising, they are likely not to be allowed, even in a very controlled experimental setting, at this point in time.

3.5.3 Physical Controls –

For the purpose of this discussion physical control techniques have been divided into two distinct sub-groups; mechanical control and manual controls. The former pertains to any physical control technique that is conducted on a large scale and Bay-wide projects involving the use of weed harvesting, dredging or similar equipment. The latter pertains to smaller scale projects, some of which are mechanically assisted, that are typically implemented by the individual homeowner on a lakefront lot-specific basis.

3.5.3.1 Mechanical Control Techniques –

As the heading implies, mechanical control techniques are those involving the use of specialized machinery to cut, harvest, dislodge or uproot aquatic weeds. We have grouped together the discussion of mechanical and manual controls as both involve some type of physical disturbance to the weeds or the sediments in which the weeds are growing. In any case, the use of dredging for the control of aquatic plants is no way recommended. Rarely can enough depth be achieved to preclude weed growth, and the cost, even on a small scale, is prohibitive. As such, dredging is not a solution for the weed problems of Sodus Bay.

As far as the various manual control measures, most are best suited, due to cost, application or labor intensiveness, for small areas. Private beaches, docking areas, and areas around bulkheads and piers are the ideal locations for the more commonly employed manual measures (hand pulling, diver assisted hand pulling, benthic mats, etc.). It should also be noted, that some of these measures although not regulated by the NYSDEC must be conducted in accordance with their protocols (e.g., the use of benthic matting). Also, again in the case of the benthic mats, the introduction of any “structure or

material” in Sodus Bay is considered by the USACOE as the placement of “fill” in a navigable water. Technically, a permit is therefore required for the USACOE of the use of benthic mats, even though the NYSDEC requires the matting be removed annually. The following summarizes various manual control options for use in Sodus Bay. The majority of the information presented below is from Appendix A of the NYSDEC Primer on Aquatic Plant Management in New York State (NYSDEC, 2005).

3.5.3.2 Hand Harvesting –

Hand harvesting involves grasping the plant material as close to the sediment layer as possible, even digging into the sediment to grab the root crown, and pulling the intact plant out of the bottom sediment. Plants are pulled slowly to minimize fragmentation, and the entire root system should be removed from the sediment if possible. This technique is largely restricted to small areas, and its effectiveness is directly a function of the effort taken by the harvesters to reach and remove the rooted plants. Hand removal methods can be a preferred technique for sensitive environments that harbor threatened native plants, have intermixed community of desirable and nuisance plants or are important fish spawning areas (Cook, 1993, Sutherland, 1990). Most of the reported hand harvesting projects are limited to small, shallow lakes and ponds, though as highlighted this has been used as a primary weed control measure in some of the larger New York lakes including Lake George and Upper Saranac Lake. It has been used extensively in Sodus Bay in the control of water chestnut. The hand harvesting program, conducted under the direction of the WCSWCD has had tremendous public support and involvement. The program has also had a measurable impact on the removal of water chestnut from areas that are either too shallow to harvest, too difficult for the harvester to navigate or in areas that are not allowed for chemical weed control by the NYSDEC. As such, although it should be continued, it in no way is capable of addressing the increasing severity of weed infestation in the Bay, especially with regard to water chestnut.

This technique however, is more often associated with the control of weed growth in shallow lakes, ponds, water courses, ditches and canals, as opposed to large, deep lakes and reservoirs. Hand harvesting was tested in a luxuriant watermilfoil-dominated area that is located at the south of Chautauqua Institution (Nicholson, 1981). Plants were removed by manual uprooting. The results of this experiment showed that shoots and total biomass of both watermilfoil and all macrophytes combined were lower in most instances in treatment plots than in control plots.

Although limited by scope and the degree of effort, hand pulling can be an effective means of controlling unwanted weed growth. However, hand-harvesting removes plants a single plant at a time. The effort can be very targeted with only those plants that are identified as exotic, invasive, or otherwise contributing to nuisance conditions removed. In some cases, the removal of the weeds is conducted by divers who use suction equipment to carry the pulled weed to the lake surface. The one significant positive attribute of hand pulling of weeds, especially when it is done without the use of suction equipment or divers, is that it is relatively cheap. However, it is very labor intensive. In

Sodus Bay the success of the program has been associated with the engagement of the public and the use of volunteers (e.g., SOS, scouts) to conduct the harvesting as part of Bay and watershed public outreach programs. Furthermore, the effectiveness of hand harvesting and hand pulling techniques are often dependent on sediment types. Loose sediments should pose fewer problems for the removal of plants, but can become quickly turbid as a result of the disturbance of fine silts and organic materials. This decreases water visibility, slows down the overall process and impacts the effectiveness of weed removal.

In general, the majority of reports dealing with hand harvesting and hand pulling of invasive plants conclude that it is most appropriate for small-scale weed control project (generally < 10 acres) or in highly sensitive areas, or areas where the invasive plants are growing intermixed with desirable native plants. As such, we envision this process as applicable in small, high-use areas, especially where water depths are shallow, around private docks and piers, within and adjacent to beaches and, as noted above in areas that are too difficult for the weed harvesting equipment to access or in areas deemed too sensitive by the NYSDEC for chemical weed control. However, as noted above, one of the larger projects conducted in New York involving diver assisted hand harvesting was implemented at Upper Saranac Lake. As detailed in the project's summary report²:

“Divers hand-pulled Eurasian watermilfoil plants in a systematic path around the lake, using an extensive support system with other dive team members tracking locations with GPS units, recording detailed survey information about the location and presence of milfoil and native plants, and transporting bagged milfoil to a remote location...It was determined that a reasonable strategy for the control (not just removal) of Eurasian watermilfoil by hand harvesting would require 2 divers for approximately every 500 acres of infestation, corresponding to 20 divers.”

The Upper Saranac Lake project also required a considerable amount of logistics (planning, mapping, diver support) and was expensive due to the “extensive overhead” associated with the operation of such a large dive team. The report establishes the cost of the project \$200 per acre, or a total of \$534,000. The effectiveness of the operation was concluded, on the basis of in-lake observations, had the majority of the sites exhibiting anywhere from 60% to >90% removal.

Besides the areas of the State under the jurisdiction of the Adirondack Park agency, hand harvesting is not a regulated activity, although some NYSDEC Regional Offices may require permits or approval to perform larger-scale operations due to concerns related to sediment disturbance or the destruction of fish habitat, or in areas partially or wholly encompassed within wetlands, the disturbance of wetlands.

2 Martin, M. and C. Stager. 2005. The use of hand-harvesting to control Eurasian milfoil in Upper Saranac Lake, Franklin County, NY. Presentation at the Northeast Aquatic Plant Management Society, Annual Conference, Saratoga Springs, NY.

3.5.3.3 Diver Assisted Hand Harvesting (Suction Harvesting) –

A variation of hand-pulling is “diver-assisted plant removal”, which in some cases is also referred to as “suction dredging, suction harvesting or diver dredging”. This type of plant removal can be conducted both in deep and shallow waters. The basic process involves a single diver or a team of divers that swim over the lake bottom removing, once again one plant at a time. As noted above, the big benefit with this technique is that the pulled weeds are conveyed to the surface by a suction device. This increases productivity and increases the amount of lake area that can be managed per day. Essentially the pulled weeds are fed into a flexible hose that is connected to a vacuum pump or industrial trash pump situated on the shore or, more commonly, on a shallow draft barge positioned above the diver(s). As the extracted plants reach the surface they go into a mesh bag, a hopper or some other type of containment device that segregates the weeds and any other material vacuumed up from the bottom. Fine sediments and water are discharged back into the lake.

The positive attributes of this technique are very much similar to the positive attributes associated with simple hand harvesting. Specifically, the technique can be used in tight, shallow areas, areas populated by mixed stands of native and invasive weeds and in areas where there is a significant fishery or threatened endangered plants and animals are known to occur. Suction harvesting should also result in less fragmentation of the removed plants than hand pulling, which is a positive when dealing with plants that can grow from fragments, namely Eurasian water milfoil. However, the spread of plant material is still possible and could actually exacerbate depending on a number of factors. The skill and acuity of the operator thus plays a big role in the effectiveness of the operation and the minimization of any secondary impacts. If suction harvesting is not properly conducted the sediments will become disturbed leading to increased turbidity, a reduction in clarity, the release and recycling of nutrients and perhaps even the creation of localized sediment oxygen demand condition. Granted, most of these problems are short-lived and occur on a small scale. Care may also have to be taken with the discharge water. Not only could it contain plant fragments and fine sediments, but the turions and seeds of the plants that are trying to be controlled. As such, the design of the containment system is important; too gross and the opportunity for plant fragment, seed and turion release is increased, too fine and the operation will need to be stopped and the bag or capture device frequently emptied.

Although hand harvesting is typically cheap, suction harvesting can be very costly. Reportedly, the per acre cost of suction harvesting is approximately two to ten times greater than the cost of mechanical harvesting. While part of the overall cost is incurred at the beginning in capital expenditures, the most significant cost is in operations, due to the slow rate at which diver dredges can be operated. The operational cost for this mode of weed removal is also much greater than simple hand pulling in that it entails the use of skilled labor. Unlike the hand pulling option, where nominally trained personnel can be used, the dredge operation requires some skills and the personnel engaged in the removal of the plants need to be trained and certified SCUBA divers. Time constraints are also a

factor, in that the operation will need to be periodically stopped to empty the containment device or barge and because of diver fatigue. There may also be the need to stop the operation to reposition silt curtains and turbidity barriers. In addition, in dense populations, the removal of the target species probably will be too slow for practical application of diver assistance (Cooke, 1993). Underwater obstacles, such as rock or debris can also hamper the speed of a diver assisted operation and create safety issues or entanglements of air lines, safety ropes, and the suction tube. Generalized estimates of costs, as derived from projects conducted in New York, are in the range of \$500-\$1,000 per person per day, or from \$1,000 to \$25,000 per acre. A recent report published for Cedar Lake in Connecticut, concluded that the use of diver assisted harvesting would be feasible in some of the more congested, highly used areas, but the cost was projected to be on the order of \$1,000/day with only 0.25 to 1.0 acres cleared per day. Similar data is available for suction harvesting conducted at Upper Saranac Lake.

In conclusion, as with the hand pulling technique, diver assisted suction harvesting should prove very effective in small high-use areas such as swimming areas, navigational channels, boat launches, piers, marinas and mooring areas. Since the diver, and not the barge, controls the operation in suction harvesting, plants can be removed between docks, in very shallow water, or other areas with physical constraints to weed harvester access. The current NYSDEC regulations covering suction harvesting are similar to those imposed for a lake dredging project. A permit will have to be obtained from the NYSDEC and possibly from the Army Corps of Engineers. Projects may require a public notification period. Overall, as is the case with the hand harvesting, there is a place for this technique in the management of the weeds in Sodus Bay. However, suction or diver assisted harvesting must be viewed as an ancillary management technique perhaps most suitable for very select areas or portions of the Bay, for example the southern most portion of Sodus Bay, south of Grassy point and near the mouth of East/West Sodus Creek.

3.5.3.4 Benthic Barriers -

Benthic barriers, sometimes called benthic mats, benthic screens or bottom barriers, prevent plant growth by blocking out the light required for growth. Many materials have been used, including sheets or screens of organic, inorganic and synthetic materials, sediments such as dredge sediment, sand, silt or clay, fly ash, and combinations of the above (Cooke 1980b; Nichols 1974; Perkins 1984; Truelson 1984). The problem with using the non-screen or sheet techniques (aside from potential impact associated with the sediment material) is that new plants establish on top of the added layer (Engel and Nichols 1984). The problem with synthetic sheeting is that the gases released from decomposing plants and normal bacterial activities collect under the barrier, lifting it (Gunnison and Barko 1992).

The common element associated with the bulk of the more commonly used textile type products is that they are made of a negatively buoyant, gas permeable material. Such benthic barriers, in order to be fully effective should have the following characteristics:

sufficiently opaque to block photosynthetically active radiation, durable enough to withstand physical abuse (foot traffic, scrapping by boat hulls, boat trailer traffic), be negatively buoyant, and allow for the escape of gases. It is also desirable for the material to possess a smooth upper surface to inhibit fragment rooting (Cooke, 1993). The material, which can run in sizes of 100' x 25-50' or even greater sizes, are typically laid down on the lake bottom early during the growing season in advance of the establishment of extensive plant growth. There is the need to anchor the material in place. The anchoring system can be readily available materials such as re-bar or concrete blocks, or product specific anchoring equipment that is slipped through the material into the underlying sediments, much similar to a tent stake.



As well as limiting growth through the reduction in sunlight penetration, the barriers also provide a physical barrier to growth. The tightly weaved, open cell material will control plant growth by reducing the space available for expansion and physically limiting the development of the plant stem and leaves.

In some cases the mat can be placed over active growing plants. Most aquatic plants present under

the screen will be controlled within 30 days (Perkins et al, 1980). Unless the material is gas permeable, the resulting gas generated through the biological decomposition of the plant material can buoy the mat off of the bottom.

Since all aquatic plants require sunlight, by inhibiting light penetration the mats or barriers reduce photosynthesis ultimately leading to the die-off or control of all plants present underneath the barrier. Obviously this is a non-selective control strategy. However, while benthic barriers do not selectively control the underlying plants, the placement of the mats can be limited to areas dominated by a combination of invasive plants or areas where a monoculture of a particular invasive or nuisance plant occurs. In Sodus Bay, the use of the mats would be particularly well suited for the heavily developed shorelines of Eagle, Newark and Leroy Islands. The matting most suitable for use in Sodus Bay appears to be Aquascreen[®]. The material is light, easy to put into place and meets all the other requirements of benthic matting including gas permeability and its ability to be easily removed from the lake at the end of the growing season (a requirement of the NYSDEC).

For small applications, such as along docks and private beaches, the average cost appears to be in the range of approximately \$1.10 per square foot installed. A typical installation

(15' X 100') should be in the range of \$1,500 to \$2,000. The ability to reuse the material over multiple years will help to decrease the overall costs. This technique has a significant level of practicality for implementation in Sodus Bay. Again, as with the hand harvesting, it is not feasible for use on a large scale or in exceptionally weedy, high use areas. However, it would be especially useful and practical for use in the aforementioned areas of the Bay between docks and along beaches. This could free up a considerable amount of weed harvesting time and address weed control in areas, which due to the shallow water depths, have been precluded to date by NYSDEC for chemical control. For the most part, the Aquascreen can be set in place and anchored by volunteers or private lake users after only minimal training. Applications in difficult sites, for example where water depths drop off quickly or where there are a lot of underwater obstructions or areas where heavy plant growth already exists, professional installation may be required. This obviously increases the cost. Most of the larger installations will require the use of scuba divers not only to set the material in place but also to anchor it to the sediments.

Aside from the basics entailed with the placement of the material, the ACOE, Vicksburg Experimental Laboratory offers the following recommendations and cautions:

“...Covering sediments that normally exchange gases with the water column will trap gases. Covering clay or sand substrates where this type of gas generation is not extensive will limit that type of problem. Covering highly organic sediments will require that the operator consider this and develops a maintenance program to deal with it. In addition, if the barrier is placed over actively growing weeds, those plants will die and decompose under the mat. This will also create gas problems in the short term. Gas buildup can be dealt with fairly easily. The operator should have divers periodically inspect the mats and push gas bubbles to the edge of the mat, where they are released. Divers can also cut small slits in the material to vent this gas. Pinning the material to the bottom will also help.”

Interestingly, benthic mats were used in an experimental nature in Saratoga Lake to control zebra mussel growth. This experimental use of the matting resulted in +90% decline in the treated areas as opposed to the control area where only 5% mortality was measured. In summary, the pros and cons of the benthic mats are as follows:

Advantages

- Installation creates an immediate open area of water.
- The majority of the materials are usually easy to install, especially when used to control growth in relatively small (< 1/8 acre) applications.
- Possible to achieve 90-to100% control.
- No chemicals added to system and sediment disturbance nominal.

Disadvantages

- Non-selective control achieved, will kill both beneficial and invasive plants
- Best suited for small areas where localized control desired.
- The material subject to damage by boats, boat trailers, fishing hooks, and even heavy foot traffic.
- Must be regularly maintained and kept free of accumulated sediment.
- Improperly anchored bottom screens may create safety hazards for boaters and swimmers, and the anchoring materials (e.g., rocks, concrete block, re-bar etc.) could injure those swimming on the controlled area.
- Anchoring of the material can be difficult in areas with steep slope, underwater (man-made and natural) obstacles or especially soft sediments.
- The material will occlude fish habitat used for spawning or nursery grounds. DEC may require the material be seasonally removed to facilitate use of the area by littoral zone fish. Bottom screens interfere with fish spawning and bottom-dwelling animals

In most regions of the State, the use of benthic barriers is not a regulated activity, although some NYSDEC regions may require approval or permits to prevent disruption of fisheries habitat, particularly for large-scale operations covering a large portion of the lake bottom. However, because Sodus Bay is designated a navigable water by the USACOE, a USACOE permit is required in advance of the installation/placement of the material in Sodus Bay. The material, as previously noted, is considered “fill”. This appears to be an over zealous interpretation of the rules in that the NYSDEC requires the material be removed each fall and prohibits the use of loose concrete blocks or rebar as anchoring devices. For further information concerning NYSDEC requirements for the installation of benthic mats, please consult the Owasco Lake website (www.co.cayuga.ny.us/wqma/weedswatchout/documents/benthicmatvacuuming.pdf).

3.5.3.5 Lake Sweepers -

A lake sweeper or WeedRoller[®] is a relatively new device used mostly to control weed growth in small areas such as private bathing beaches, lake front areas and around docks. The basic concept is through the repetitive, gentle agitation of the sediment surface, plant growth is impeded either because of mechanical damage to the plants or the creation of a sediment habitat unsuitable for plant colonization. Several brands of this type of automated plant control product are commercially available. As noted above, they all work in a similar manner mechanically disturbing the lake bottom. The devices can be free standing and anchored to a post centered within the control area, although most are designed for attachment to a permanent fixture such as a dock or pier piling. Obviously, to operate these devices must be provided with an electrical power source. Depending on the product, up to a 42-foot radius around the anchoring device can be subject to control.

For Sodus Bay, we again see the lake sweeper devices as a very practical solution for the

control of inter-pier weed growth and the management of weeds in small private breach areas. It is best to install and start operating these devices in the spring before plants begin actively growing. If they are operated after plants have grown, plants could be uprooted or detached from the sediment. In such cases, the detached plants should be removed from the water with a rake or gathered by hand. Once the plants are cleared from the area, the lake sweeper may only need to be used as little as one day per week or less to keep plants from re-colonizing the area. Little maintenance is required, but these units must be removed from the water in winter in areas where lakes are expected to freeze, as they will be subject to damage by ice flows. It is highly likely, that one unit could be shared by three to four lake shore users. This is important, as these devices are somewhat expensive. Purchase cost varies between products, with some of the cheaper, more basic units starting at approximately \$1,000.00, but the majority being in the \$4,000.00 to \$5,000.00 price range. The WeedRollers used on a limited experimental scale this past summer in Sodus Bay cost approximately \$5,000 each. The electrical costs associated with the operation of these units must be added to the overall costs, but this should be far less than \$100 per year. Although only anecdotal information is available, based on user responses the units in operation within Sodus Bay appear to work very effectively and are capable of maintaining a neat, weed free bottom without creating any turbidity problems. The units have been successful not only in controlling the establishment of aquatic weeds, but also in controlling the colonization of the stalked algae, *Nitella* (Stone wort) in shallow areas in the eastern portion of Sodus Bay.

Factors that may limit the practicality and utility of these units include the presence of large rocks, stumps and similar underwater obstacles, steep slopes and uneven bottom terrain. Obviously, their application is also limited to areas where electrical service can be provided (typically 110 volt, 8 amps). As with all mechanical devices, unless routinely maintained the longevity of these units will be limited. The units should be removed in the winter to prevent damage from ice.

There does not appear to be any clear regulations governing the installation or use of these devices. Currently, as per information provided by the NYSDEC Region 8 office, a permit is not required for this technique, provided the sweeping action does not create water turbidity or encroach deeply into the lake's sediments. Since most of the lake sweeper devices currently available on the market function by abrasion, a permit should not be required.

3.5.4 Mechanical Controls –

3.5.4.1 Mechanical Harvesting -

Mechanical harvesting is the physical removal of rooted aquatic plants (macrophytes) using a machine designed to cut, remove and transport the removed vegetation to shore for proper disposal. This is one of the most common methods of aquatic vegetation control used in New York, especially in management of weed growth in large lakes. Weed harvesting is generally considered a non-selective weed management technique

since the mechanical harvesters cut most of the plants that come into contact with the cutting bar. However, through proper planning and operator training it is possible to limit cutting in prime fish spawning or nursery areas, or in areas where non-invasive plants are dominant. It is also possible through altering the depth of the cutter head to maintain a bottom “carpet” of plants. This can be advantageous in decreasing the propensity for benthic algal mat formation. It can also increase the efficiency of the operation, but may require multiple or repeat harvesting of the same areas over the course of the growing season. As such, selectivity can be increased through pre-harvesting surveys and directing the harvesting effort to areas where monoculture plant beds exist. In recent years, most mechanical harvesting operations in New York State have targeted Eurasian water milfoil. This is also true of the operations conducted in Sodus Bay, although more recently the machines are used to control nuisance densities of other species including eel grass (*Vallisneria*), water chestnut and *Nitella* (stone wort). Details of the Sodus Bay harvesting program are proved below.

The regulations governing mechanical harvesting vary within the State. Presently, weed harvesting does not require a permit from NYSDEC. However, harvesting may be regulated in cases where the harvesting occurs within or adjacent to classified wetlands. In these circumstances, a permit from the NYSDEC regional office may be necessary. It should be noted that harvesting in some other States (e.g., Wisconsin) is a regulated activity requiring a permit. NYSDEC is considering moving in this direction. When and if this occurs it will become increasingly important to develop a technically sound macrophyte management plan and maintain good records on the distribution, composition and density of both non-native, invasive plants and native, beneficial plants.

Obviously, largely due to the capital investment and ongoing labor costs, weed harvesting is an expensive proposition. In addition to the cost of the harvesters, there are operational and maintenance costs and additional labor associated simply with the transport and disposal of the cut weeds. For example, each harvester (assuming an 8 foot, 6,000 - 8,000 pound capacity) costs in the range of \$100,000 and \$200,000 depending on options and construction material (e.g., stainless steel vs. powder coated steel). There are additional costs associated with the shore conveyers needed to move the cut plants from the harvesters to the disposal area or into dump trucks for off-site disposal. There is also the cost, as noted above, of the dump truck to transport the



weeds from the lake to a disposal area. Again, details specific to Sodus Bay are presented below.

Under typical operating conditions, assuming moderate to high weed densities, a large harvester can cut approximately one acre of aquatic plants every 2-4 hours. However, the actual amount cut and harvested per day will be influenced by a number of factors ranging from the experience of the operator to the weather conditions. As mentioned above, one of the biggest factors controlling productivity is the distance from the harvesting area to the disposal site. Essentially the harvesting operation becomes less efficient as the time involved in transporting cut weeds to shore increases. Docks, piers, stump, hanging trees, irregular shorelines and rocks and obstacles will all impact operations and decrease the overall effectiveness of the harvester. Also certain plants, such as *Vallisneria* and the stalked algae (*Nitella*) may be more difficult to harvest. Areas where dense plant growth has occurred, although easier to harvest may require more time simply due to the frequency of off-loading.

As noted at the beginning of this section of the report, weed harvesting has been the primary means of large scale weed control implemented for Sodus Bay. The operation is conducted by the WCSWCD. Started in 1988 with the purchase of two harvesters and treated offloading equipment (two shoreline conveyors and three dump trucks), the WCSWCD weed harvesting program has staved off many of the impacts created by the density of weeds in Sodus Bay. The harvesters, when fully loaded, have a two-ton capacity. They cut a swath approximately 7-10 feet in width and can operate in water as shallow as 18" and to depths approaching 8'. The two original machines were over time replaced and recently the harvesting fleet was expanded to three harvesters with the addition of another machine in 2004. The average cost of each harvester is \$91,000. It should be noted, that due to County obligations, the harvesters are also used in the management of weeds in Port Bay, Blind Sodus Bay and East Bay.

Based on actual harvesting data reported for 2006, the operation resulted in the removal of 1,732,000 pounds of weeds from the Bay. The nutrient removal achieved through this effort is on the order of 200 pounds per year of phosphorus and 1,200 pounds per year of nitrogen; a significant removal of nutrient loading. This amount to the removal Bay-wide of approximately 10% of the annual P load associated with plant senescence (Section 6).

Operational costs of the program have been increasing over the years due to the increased fuel costs and increased maintenance as the machinery ages. As per the WCSWCD, the cost of operating the harvesters is approximately \$300.00 per day per harvester for a daily expense of \$900 to \$1,000 per day. These estimates include wages, insurance, unemployment, workman's compensation parts, maintenance, fuel, etc. Over the course of typical harvesting season, the time spent by staff on various weed harvesting related activities breaks down as follows:

- Actual harvesting of weeds 78%,
- Down time resulting from inclement weather 6%,

- Time lost to repairs and maintenance 16%.

As with any weed harvesting program, the process is relatively slow and the operation is limited to areas that are easily accessible and unencumbered by obstructions, piers and docks. As a result, even though the operation is successful and cost-effective, it has been criticized. The most significant challenge arising with this program, and all other weed harvesting programs, is the inability to fully meet the demands of the public. Machine, labor and fiscal limitations impact the ability to harvest every area. Furthermore, site limitations impact accessibility and impede the ability of the machines to operate in given areas of Sodus Bay. Thus although the operation has had a positive impact on the Bay, it has not, nor can it alone, meet the weed control needs of the Sodus Bay community. Unfortunately, this has resulted in a non-favorable public perception of the program and complaints to the WCSWCD. In 2004, Wayne County representative actually discussed the logistics of discontinuing this service and donating the equipment to the various private Sodus Bay community associations and/or the surrounding municipalities. This did not occur as no entity desired to take on the operation and the overwhelming difficulties associated with the successful implementation of the program. This is further evidence that although a very worthwhile operation, the current weed harvesting program alone cannot meet the weed control needs of the community.

The harvesting data compiled by the WCSWCD shows that the ongoing weed harvesting operations have been very successful. Not only does it result in the removal a large amount of biomass and associated phosphorus from the lake (approximately 200 lbs/yr), it addresses the majority of the public's concerns regarding accessibility and recreational utilization of the lake. It has also been successful from the standpoint of inhibiting the further spread or increased dominance of Eurasian water milfoil. As previously noted, the data clearly show that since reaching its peak densities and distribution in 1994, milfoil standing crops in the lake have actually been reduced. As illustrated in Table 3.4, *Myriophyllum spicatum* is only the third most commonly occurring plant species in Sodus Bay. So although it continues to be a problem, it has not over run the Bay as has been seen in other lakes throughout New York.

As with many of the above techniques, mechanical harvesting is often viewed as a cosmetic or short-term measure for aquatic plant control. Although it provides immediate benefits in the area subject to harvesting, the effect may be temporary as plant growth is expected to continue. The technique does however, have the ability to relatively quickly open up the water column and achieve relief from surface canopies and dense underwater growth of nuisance plants. The tops of the aquatic plants are cut, removing the growing leaves, seed heads and nutlets and flowering parts of strongly rooted plants. Weakly rooted plants may be uprooted. For aquatic plants that propagate primarily from seed banks or nutlets, such as water chestnut, removing the top of the plant (which usually carries the seeds) prior to the maturation of the seeds can eliminate the following year of growth. Multiple years of harvesting may gradually deplete the bank of seeds in the sediments. We have also observed in Lake Hopatcong a decisive switch in plant dominance with milfoil becoming increasingly replaced in areas by

Vallisneria, tape grass. This pattern is also reflected in the aforementioned Sodus Bay data. In general, an operation such as the Sodus Bay weed harvesting that focuses on the removal of weed biomass in the upper reaches of the water column helps maximize recreational use and accessibility, while at the same time preserving fish habitat and maintaining competition between weeds and algae for nutrients.

It is recognized that fragments and “floaters” constitute a big problem with any harvesting operation. The WCSWCD’s harvester operators recognize this and are especially careful to minimize floaters for a number of reasons. First, the resulting fragments can regenerate and create the new plant growth in other areas of the lake. Second, the floaters will tend to pile up in windward areas creating a major aesthetic problem. Third, the retrieval of the wind concentrated floaters can result in a waste in operational time, money and resources.

Our observations made of the ongoing Sodus Bay harvesting program indicate that a far greater number of off-loading sites are needed. First, a greater number of sites would decrease the “down time” associated with the simple transport of weeds from the harvesting areas to the offloading area. Second, it would preclude the need for high speed transport barges, thereby possibly enabling the purchase of additional weed harvesters as opposed to simple weed transport equipment. Finally, additional drop off areas decrease the overall wear and tear on the existing weed harvesters.

3.5.4.2 Hydroraking and Rotovating -

Although rotovating and hydroraking are similar they are very different with the former creating a greater amount of bottom disturbance than the latter. However, rotovating usually achieves a longer period of weed control because of the extent to which the lake bottom is disturbed and the amount of seed stock and biomat removed as part of the process.

Rotovating and hydroraking can equally be used to control either weakly rooted plants (such as Eurasian water milfoil and stone wort) or densely rooted plants (such as water lilies or *Phragmites*). Each of these techniques can be used as an alternative to, or a compliment to standard mechanical harvesting. The machines used for either consist of a barge mounted cutter head, rototiller or deep tine rake that cuts and/or dislocates aquatic plants and their roots from the sediment. As with harvesting, the cut or dislocated plant material is removed from the lake. As noted above, rotovators work in a manner somewhat similar to a rototiller operating on dry land. The blades of the cutter head, which may extend seven to nine inches below the sediment-water interface, disrupt the sediments and in the process dislodge and remove the plants including their roots. The dislodged plant and root material wraps around the cutter device. The material is then freed from the cutter head by reversing the rotation and dumped in a “helper barge” or a standard weed harvesting barge. In those cases where the dislodged plants are freed to float in the water column they will need to be removed with a conventional harvester.

The hydrorake essentially drags the rake's long tines through the sediment in the process raking up rooted weeds, benthic algae and non-rooted weed masses. The material that collects on the rake is, as with the case of the rotovator, dumped into a helper barge or conventional weed harvesters. As with the rotovator, floaters and other freed material will need to be collected at the end of each day's operation with a weed harvester. .

As hydroraking and rotovating removes the roots as well as the plant, the process is typically considered more effective than mechanical harvesting as they have the potential of providing a longer period of weed control. It has been demonstrated, because of its mode of action and the disturbance of the sediments, to be capable of maintaining low levels of weed growth for several seasons. For example, there are a number of studies showing this technique controlling Eurasian water milfoil growth (a plant with a weak root system) for as long as two years. As such, these techniques provide immediate relief. Depending on the size of the rotovator, the types of targeted plant material and site logistics they may work either faster or slower on per unit area than large scale harvesting operations. This method of plant removal also tends to most efficient when the plants are shorter since longer plants tend to wrap around the spinning blades and may damage the equipment. However, it must be recognized that because most aquatic plants are annuals, new plant growth can easily occur if seeds have already dispersed.

Although in many cases hydroraking and rotovating are conducted in the spring or summer during peak weed growth conditions, it can be conducted year-round, especially when the control efforts are directed towards the removal of water lilies and water chestnut.

A typical rotovator barge is approximately as large as a large (8' cutter head) harvester. They tend to draft little water and thus may be able to operate in water as shallow as 18" – 24". Given the size of the equipment, rotovators are typically limited to use in large water bodies. Hydrorake, by comparison are somewhat smaller, typically the size of a small to medium sized weed harvester. In some cases, due to their size and added maneuverability, hydrorakes are a better choice for working around docks and piers or in tight quarters. As with the rotovators, these units draft very little water. With respect to either unit, there may be the need to use a crane to transfer the unit into the lake. However, most of the more recently designed units can self-deploy much in the same manner as a typical weed harvester.

As noted above, it is usually the case where the hydrorake or rotovator must work in concert with a weed harvester or weed transport barge. In these cases, where the disposal site is a distance from the site of operations, the weed harvester or transport barge is used to collect floaters and, more importantly, transport raked, cut and dislodged weed materials to the disposal area. This aids in the overall effectiveness of the operation by decreasing the amount of "down time" associated with the simple transport of the dislodged and removed weed material. However, it adds to the cost of the total operation. Another problem with the operation of the hydrorake or rotovator is the disturbance of the sediments. This can create turbidity problems, release nutrients into the water

column, create a short-term oxygen demand problems and impact benthic organisms and fish. Much of these impacts can be avoided by erecting sediment curtains or turbidity barriers. Again, this adds to the cost of the operation. Hydroraking and rotovating, due to their disturbance of the sediments and creation of turbidity may also severely impact habitat critical to fish spawning. As a result, NYSDEC may limit when these devices can be used on the lake. Also because they involve the disturbance of the bottom sediments, USACOE approvals are also required. Specifically, because of the disruption of sediments, rotovator or hydrorake operations require a NYSDEC Article 15 permit.

The capital costs for a rotovating and hydroraking machines are generally equivalent to the capital costs for mechanical harvesting, with machines ranging in price from \$100,000 to \$200,000. Operating costs are generally on the order of \$200-300 per acre, with only about 1-3 acres per day being hydroraked or rotovated. If contracted out, the approximate cost of these techniques is on the order of \$1,500 per acre (as based on our actual experience with sub-contracting such work). These costs and time estimates do not consider retrieval and disposal of the removed plants or the need to use a weed harvester in tandem with the rotovator/hydrorake to transport weeds to disposal areas.

Rotovating and hydroraking have been used primarily in New York State to control Eurasian water milfoil. These techniques can be especially effective in controlling this species and other plants growing in monocultures. However, as this is a fairly non-selective technique, it is infeasible to expect to use this equipment in areas with a diverse plant community without the technique impacting non-targeted weeds. Also because rotovators, even more so than hydrorakes, cannot be easily maneuvered, their use in cramped areas or areas with numerous obstructions may be difficult. Finally, neither type of machine should be used in areas having significant underwater obstructions, such as rocks and logs, as large submerged debris can damage the equipment.

Overall, we feel that hydrorakes and rotovating techniques could be used in limited areas of Sodus Bay as a compliment to the current weed harvesting program. Before either type of operation is implemented it will be important to conduct a detailed survey of the targeted area. The survey should be used to establish the homogeneity of the targeted weed stand and the presence of any submerged obstructions that could impact the operation of either type of unit. As noted above, large rocks, stumps, tree limbs, etc. can damage these machines. Also, the location of any water intakes would need to be flagged. If the targeted areas do not support a monoculture of plants, the survey should establish that the targeted area is dominated by problematic plant species, which in this case could include dense stands of the eel grass, coontail and elodea. Because of the lake's fishery resources, we recommend that operations of this nature be conducted either in the late summer or early fall, with the plant removal intended to benefit the upcoming year, more so than the year within which the operation is conducted. That is, although it would make the most sense to implement the project in the spring, doing so would impact fish spawning. Not only is this a negative impact on the lake, but will likely result in NYSDEC rejecting a permit application. Conducting the effort in the later part of the summer will still result in the removal of large amounts of biomass, but will have a more

positive impact on the recreational use of the lake for the following year.

In addition it should be noted that implementation of either of these techniques in the southern end of the Bay will be limited by the adjacent NYSDEC wetlands. Although the weed control activity will not directly impact the wetlands, there will likely be some reluctance from the NYSDEC to permit either hydrotanking or rotovating in this area even with the implementation of special precautions (sediment boom, etc.). This also likely will apply to the Bay's eastern shoreline near Sunset View, and in the mouths of Second and Third Creek. Similarly, the existence of the threatened and endangered fish species, the pugnose shiner (*Notropis anogenus*) very likely precludes the use of these techniques in the northeast corner of the Bay. As previously noted, sediment disturbance, or any other activity that could impact the regulated wetlands, will require an Article 24 permit.

Judging from the current plant distribution patterns in the lake, we see the benefit of either the hydrotanking or rotovating techniques to make the most sense for the lake's western shoreline and around the islands, especially the southern end of Leroy Island near the causeway. The weed beds in these areas are somewhat more expansive due to the prevailing bathymetric contours. However, as noted above, specific areas where such operations could be conducted need to be more closely evaluated, mapped and limiting factors assessed.

3.6 WEED CONTROL CONCLUSIONS AND RECOMMENDATIONS -

The information concerning weed growth in the Bay shows that the greatest biomass occurs in the southern most areas of the Bay, in the mouths of the creeks and around the western side of Leroy Island. In most of these areas, water depths are shallow (1 to 4 meters). The data show that currently the dominant weed, in terms of biomass is eel grass. However, Eurasian water milfoil remains a big problem and increasingly so, the stalked algae, *Nitella*, is creating increasing problems. Overshadowing all of this is the increasing occurrence and spread of water chestnut. Although the transects surveyed in this project did not occur in areas populated by water chestnut, it is apparent from the data compiled by WCSWCD and WCWQCC that this plant, threatens to overrun the shallow coves and embayments of Sodus Bay. As documented in other lakes throughout New York, this weed is especially pervasive and has the potential to significantly alter the ecology of affected areas. Overall, relative to the historic conditions documented by Gilman in 1989, the distribution of weeds, Bay-wide has increased markedly as has the density of weed growth.

Based on Princeton Hydro's review of available data and discussions with the WCSWCD, the following recommendations regarding ongoing and future weed control options and initiatives:

1. Continue to use the harvesting program as the center piece of Sodus Bay's weed control efforts.

2. To increase the efficiency of the harvesting program increase the number of drop off sites. We understand that this is easy to say and more difficult to implement, however, it is evident that the lack of multiple drop off areas is impacting the efficiency of the overall weed harvesting operation.
3. Increase the number of weed harvesters. This will require an infusion of funds not only with respect to capital costs but in terms of providing the WCSWCD a guaranteed source of revenue to operate and maintain the equipment.
4. Hydroraking, more so than rotovating, could be considered as a supplemental management option. We feel that a well designed hydroraking program could be used to decrease weed densities in areas that are difficult for the harvesters to effectively operate within due to dock related obstructions. However, before any such operation can be conducted a concerted study of candidate areas needs to be conducted. Furthermore, as this is a regulated activity it will be necessary to file a permit application (Article 15) with the NYSDEC. The need for the Article 24 permit is largely due to the significant fishery resources of the Bay and freshwater wetlands issues. We advise a pre-application meeting be requested with the NYSDEC before venturing too far with hydroraking. Finally, given the expense of hydroraking, it would be prudent well in advance of even developing the permit application materials to meet with potential qualified contractors and obtain from them general price estimates.
5. Although we remain cautious with the use of any herbicide, we do see that the use of chemical control is not only warranted, but could be safely and effectively conducted in Sodus Bay. Without doubt, a 2-4D treatment of the lake's water chestnut stands is warranted and must be investigated with the NYSDEC. Also, relief needs to be requested with respect to the "flow containment" requirement of the NYSDEC regarding the application of Reward. The Aquathol K applications have not proven as successful.
6. Of particular importance with respect the any chemical control program is cooperation from the NYSDEC PMP. Issuance of permits too late in the growing season negates the benefits of any control that could be achieved with chemicals and results in a significant reduction in the cost-effectiveness of such operations.
7. Although not a macrophyte, the increased occurrence of stone wort in the Bay presents an increasing weed management problem. The harvesting of this "weed" is not only difficult, but because of its weight, imposes operational problems because of the more frequent need to off load the collected material. The control of the stone wort may be best achieved using a chelated form of copper sulfate or copper carbonate (Cutrine + or Captain).
8. We strongly recommend the implementation of homeowner specific weed control techniques that rely on "manual" control measures. In particular, based on our personnel evaluation of such techniques we recommend the use of bottom sweepers (weed rollers) and benthic mats (AquaScreen). Both are easy to implement and are relatively cost effective, particularly when implemented for the purpose of maintaining "weed free" areas adjacent to docks, bulkheads and personnel beach fronts. A permit appears to be required for the USACOE, for the installation of the benthic matting.

9. Although the NYSDEC has been reluctant to date to grant a permit for the experimental use of lime or alum, for the purpose of managing interstitial phosphorus, this effort should continue to be pursued. The practice, if it provides effective, could be used in very specific areas for the control of invasive weed species and potentially event the management of benthic algae.

4.0 BEYOND WEEDS AND WEED CONTROL, FACTORS BEHIND SODUS BAY'S EUTROPHICATION

4.1 THE WATER QUALITY OF THE BAY AND ITS MAIN TRIBUTARIES

The preparation of any master plan for Sodus Bay begins with the examination of key water quality parameters and indicators. These data provide insight not only into the "health" of Sodus Bay, but are fundamental to deciphering the causes and resulting symptoms of its eutrophication. Therefore, a major element of the technical component of the *Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan* involved the collection and analysis of existing water quality data for the Bay proper and its main tributaries. These recent data were both analyzed within their own context as well as compared to historical data for the Bay. Overall, the water quality data, recent and historical, were used to objectively assess the Bay's water quality and overall "health". The data however were also used in concert with some of the detailed modeling of the Bay and its tributaries to help validate the results of various water quality modeling activities.

For this project, SUNY-Brockport Department of Environmental Science and Biology (SUNY-Brockport) was responsible for the collection of water samples, the analysis of those samples and the interpretation of the resulting data. SUNY-Brockport, under the direction of Dr. Joseph Makarewicz, had also been responsible for the bulk of the historic data gathering and water quality surveys of the Bay and its tributaries. For over the past decade, SUNY-Brockport has performed limnological and stream water quality monitoring in the Sodus Bay watershed. Monitoring and analysis over the years was designed to meet the following objectives: document current sediment and nutrient conditions in the bay; document stream loading to the bay; and characterize the bay's community of phytoplankton and zooplankton. Each year, results were summarized and presented through a series of reports generated by Dr. Makarewicz, Ph.D. and Robert K. Williams of the Wayne County Soil and Water Conservation District. Some of the more important historical reports include:



- Nutrient Loading of Streams Entering Sodus Bay and Port Bay, NY: A Summary of Port Bay and Sodus Bay Tributary Monitoring, dates covered include April 1990 through April 1994.
- Interim Data Report: Sodus Bay Limnology, Lake Chemistry, Phytoplankton Abundance and Nutrient and Soil Losses from the Watershed dated December 2004

By routinely collecting physical, chemical and biological data from established sampling stations it is possible to examine water quality trends for the Bay. The trend analysis may

be used to investigate possible changes in water quality caused by specific watershed development activities; evaluate the improvement in water quality attributable to an implemented management practice or restoration project or simply conduct a “check up” of the Bay’s condition. Focus has been characteristically placed on the collection of water quality data from May through September during the “growing season”. For Sodus Bay, it is typically during the “growing season” that observed water quality and aesthetic problems peak, in particular the infestation of given areas by dense stands of invasive, exotic weeds and the onset of intense obnoxious algae blooms. This is due to a number of reasons including: the rate, amount and type of nutrients that enter the Bay from internal and external sources; the prevailing weather conditions; the degree and extent of water column mixing; and the growth patterns of both weeds and algae.

4.2 SAMPLING METHODOLOGY

During the spring, summer and fall of 2004, limnological and sub-watershed data were collected from Sodus Bay. In general, the 2004 monitoring and water quality analyses were designed to meet the following objectives:

- Document current nutrient and sediment concentrations in the Bay,
- Document the concentrations of nutrients and sediments in the Bay’s tributaries,
- Characterize the Bay’s phytoplankton and zooplankton community, and
- Assess seasonal changes in tributary flow into the Bay.

In total this water quality data provided an up-to-date assessment of the Bay’s existing water quality and the water quality of the streams that drain to the Sodus Bay. The utility of these data is that they could in turn be used first in comparison with the historical database and second as a benchmark against which the effectiveness of future management actions could be measured. With respect to the former, by comparing the 2004 data to the historical database an assessment can be made whether the Bay is getting better or worse with respect to overall water quality. This comparison also provides us with better insight into the relative role of the individual tributaries’ impacts on the Bay. The latter use of the data, to establish a benchmark, is important in that it provides us with a tool by which to potentially gauge the effectiveness of ongoing and future in-Bay and watershed based management and restoration efforts. Finally, the resulting data will assist us in developing a watershed enhancement plan by providing the empirical data needed to support various weed, algae and nutrient management techniques.

All water quality sampling and the subsequent laboratory analyses of these samples were conducted in accordance with a Quality Assurance Project Plan (QAPP) prepared specifically for this project (Appendix 2). The sampling effort involved the collection of both *in-situ* data (data collected by means of a field meter) and discrete grab samples that were subject to laboratory analysis. The data collection effort also included the collection of phytoplankton and zooplankton samples. It should be noted that the Water Chemistry Laboratory at SUNY Brockport is certified through the New York State Department of Health's Environmental Laboratory Approval Program (ELAP - # 11439). This program

includes bi-annual proficiency audits, annual inspections and good laboratory practices documentation of all samples, reagents and equipment. Figure 4.1 shows the locations of all the water quality sampling stations, both in-Bay and stream.

In 2004, water quality monitoring and analysis was performed on five dates between May and September. *In-situ* measurements were taken with water quality sampling meters that included temperature, conductivity, dissolved oxygen, Chlorophyll *a*, photosynthetically active radiation, turbidity, light transmission, pH, and Secchi disk transparency. The specific instrumentation utilized in the collection of the *in-situ* data are as follows: temperature (SBE 3F sensor), conductivity (SBE 4C sensor), dissolved oxygen (YSI), chlorophyll *a* (WetLabs – WetStar sensor), photosynthetically active radiation (LiCor Li-193SA), turbidity (OBS-3, D&A Instruments), light transmission (WetLabs C-star, 25 cm path length), and pH (SBE 18) were done with a pre-calibrated Sea-Bird CTD (Model 25 SBE) sonde.

In concert with the collection of the *in-situ* data, on each sampling date, water samples were also collected from the two deepest bay stations (Stations 5 and 9) at three depths (1 m, 5m and 11m at Station 5 and 1 m, 5m and 8m at Station 9) and analyzed in the SUNY lab for total phosphorus (TP), soluble reactive phosphorus (SRP), nitrate (NO₃), total Kjeldahl nitrogen (TKN), total suspended solids (TSS), ammonia (NH₃-NH₄), hardness, and alkalinity. Phytoplankton samples and zooplankton samples were also taken at the two deepest stations. In addition, six streams (First, Second, Third, Sodus West, Sodus East and Clark Creeks) were sampled on five dates from May to September 2004. The stream flow discharge was estimated at all stations for each sampling date. *And* field measurements included temperature, dissolved oxygen, pH and conductivity, and water samples were analyzed in the laboratory for TP, TKN, NO₃, and TSS.

It should be noted that as a supplement to the 2004 database, a limited amount of *in-situ* sampling was conducted in August of 2006. This data collection was conducted by Princeton Hydro and focused solely on the measurement of dissolved oxygen and temperature profiles from the surface to the bottom of Sodus Bay. The purpose of this data collection was to more clearly evaluate whether the Bay was subject to stratification and anoxia, conditions that promote internal phosphorus release and could be a contributing factor to the Bay's eutrophication, the intensification of summer algae blooms or event increased establishment of weeds throughout the Bay. Princeton Hydro's measurement of the *in-situ* temperature and dissolved oxygen data (1 meter increments from surface to bottom) was limited to the collection of said data at Station 5. The full compliment of data collected by both SUNY-Brockport and Princeton Hydro are presented in tabular and graphical form in Appendix 1 of this report.

Figure 4.1 – 2004 Sampling Stations



4.3 WATER QUALITY MONITORING RESULTS

Water quality data collected during the 2004 monitoring effort was analyzed in concert with historic data collected in the 1990's by SUNY-Brockport. Special attention was placed on phosphorus concentrations and sediment loading to the Bay through the major tributaries. This empirical data was used to confirm pollutant modeling and to help refine the nutrient budget for the Bay.

Sodus Bay and its tributaries are listed on the Lake Ontario-Oswego River Basin Priority Waters List by the New York State Department of Environmental Conservation (NYSDEC). This list is an inventory of water quality and use assessments for individual waterbody segments for each of the 14 major drainage basins in the state. The 2005 listing concludes that Sodus Bay and its tributaries are impaired waterbodies due to the repeated exceedances of state water quality standards for Class B waters. The 2005 listing also highlights that within Sodus Bay the uses of public bathing, recreation and aesthetics are being stressed as a result of declining water quality. The NYSDEC reported that a suspected cause for declining water quality is high levels of nutrients from failing onsite wastewater or septic systems. The tributaries of Sodus Bay are also highlighted in the same report as being stressed with regard to their ability to support aquatic life, and are impacted by elevated nutrient loading, most of which is suspected to originate from agricultural sources. Based on this data, the NYSDEC designated the Bay with an impaired status, in regard to compliance with State Water Quality Standards.

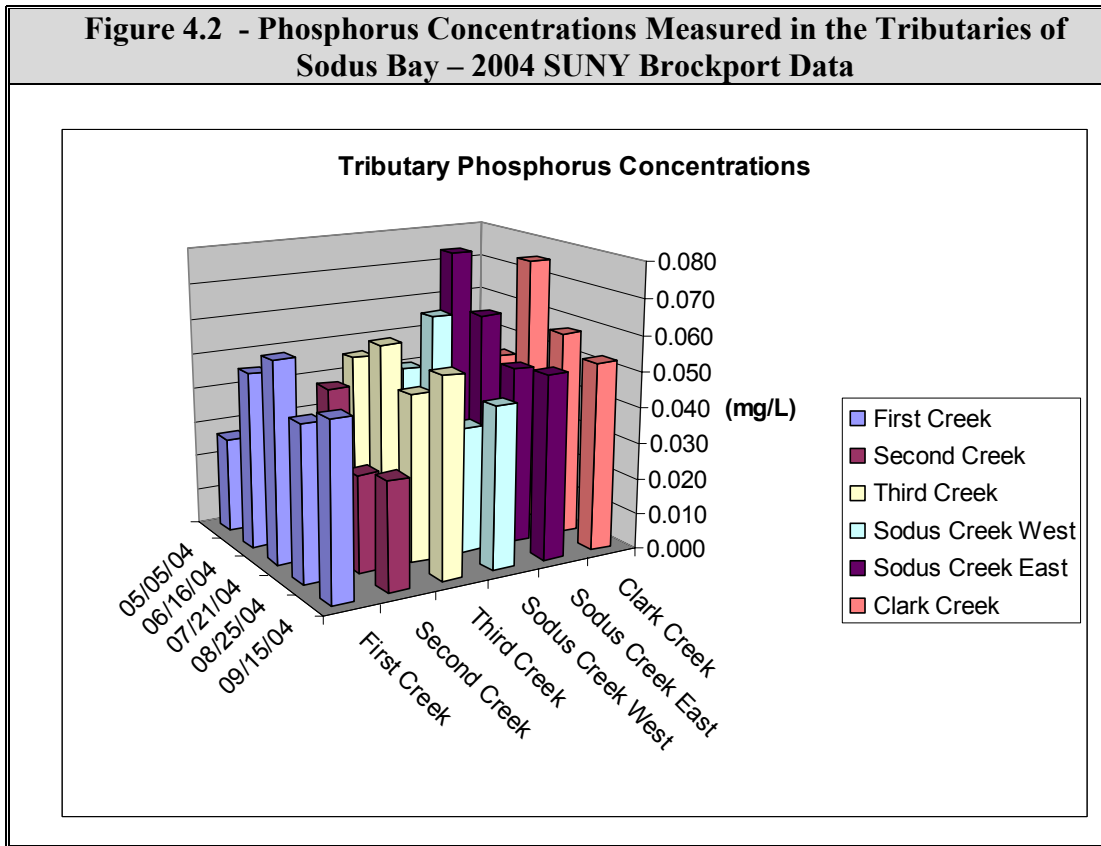
*Class "B"
waters in New
York State are
designated for
primary and
secondary
contact
recreation and
fishing*

Data collected by SUNY-Brockport from the 1990's through 2004 depicted repeated occurrences of phosphorus concentrations that were high enough to support nuisance algal blooms and excessive plant growth in both the Bay and its major tributaries. As has been previously discussed, phosphorus is the limiting nutrient in Sodus Bay. In other words, the biological demand for phosphorus is greater than its concentration. Therefore, any small increases in phosphorus concentration in the Bay will lead to excessive plant and algae growth.

Results from discrete sampling in 2004 by SUNY-Brockport and nutrient loading analysis by Princeton Hydro characterize Sodus Creek East subwatershed as the greatest contributor of sediments and nutrients to Sodus Bay overall and Sodus Bay Direct as the subwatershed with the greatest nutrient loading on a per unit basis. Identification of the areas, which contribute the most nutrients overall and on a per unit basis is crucial to targeting management and improving the efficacy of nutrient loading reduction efforts.

Total phosphorus (TP) concentrations in Sodus Creek East ranged from 0.03 mg/L to 0.08 mg/L with a mean concentration of 0.05 mg/L (Figure 4.2). On a relative scale these concentrations are low; that is they are typically less than 0.05 mg/L. However, concentrations of this magnitude, though low, are still high enough to stimulate algal blooms. Thus, in terms of the Bay's eutrophication the TP concentrations measured in 2004 are of concern.

Figure 4.2 - Phosphorus Concentrations Measured in the Tributaries of Sodus Bay – 2004 SUNY Brockport Data

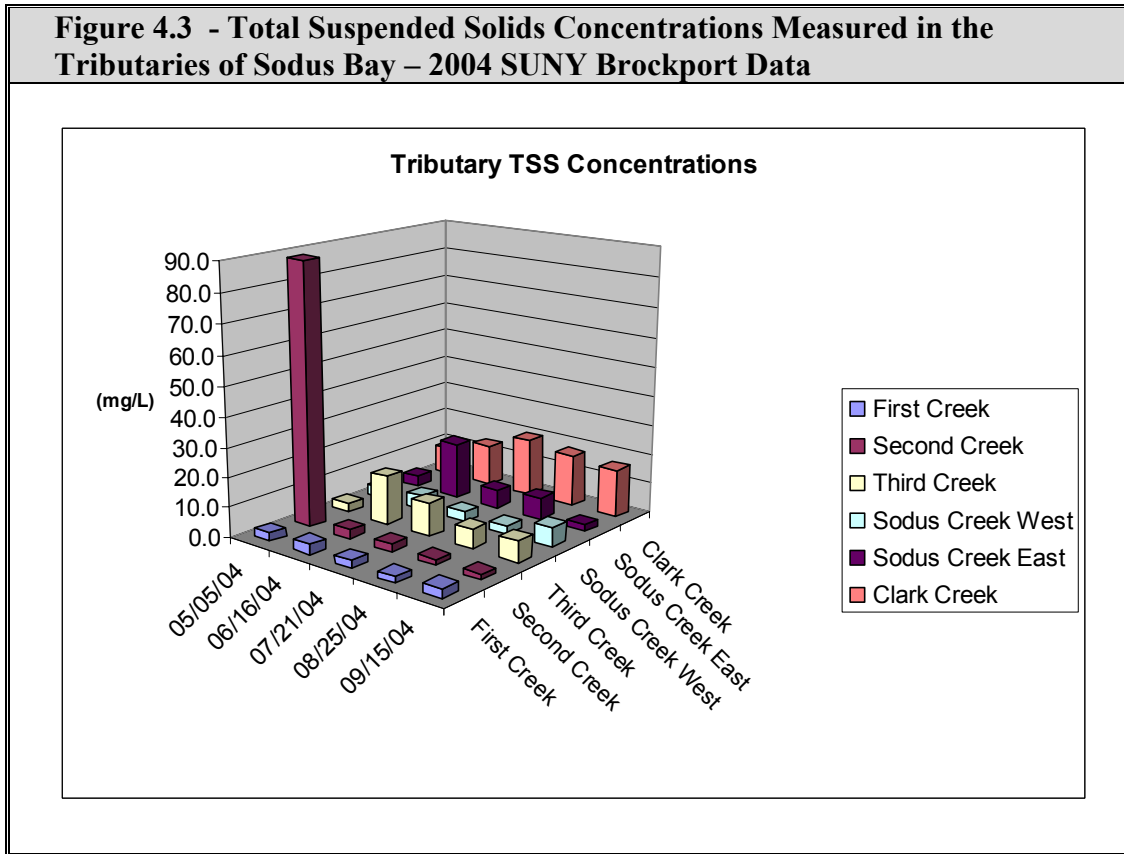


It is interesting to note that no seasonal trends were observed with respect to the baseflow TP data. As shown in Figure 4.2, the concentrations measured in the spring were similar to those measured throughout the summer. Typically, spring concentrations would be expected to be somewhat higher than the summer concentrations due to the spring thaw and the flushing of nutrients from fallow fields, manure stockpiles and urban surfaces.

Overall, the 2004 data also show that with the exception of Second Creek, the measured TP concentrations in all of the Bay's tributaries are relatively similar. The markedly lower concentrations measured in Second Creek may be a function of the prevailing land use and land cover that characterize this watershed.

Historically, elevated total phosphorus concentrations have been repeatedly reported in the reports summarizing past sampling efforts. As observed with the 2004 data, the concentrations are high enough to promote nuisance plant and algal growth. As such, the 2004 data, though not showing any worsening of the streams' TP concentrations, do suggest that conditions have leveled over time. While this is good news, it also suggests that future reductions in TP concentrations may be difficult to achieve unless more aggressive runoff control is implemented and stream corridors are further protected.

Figure 4.3 - Total Suspended Solids Concentrations Measured in the Tributaries of Sodus Bay – 2004 SUNY Brockport Data



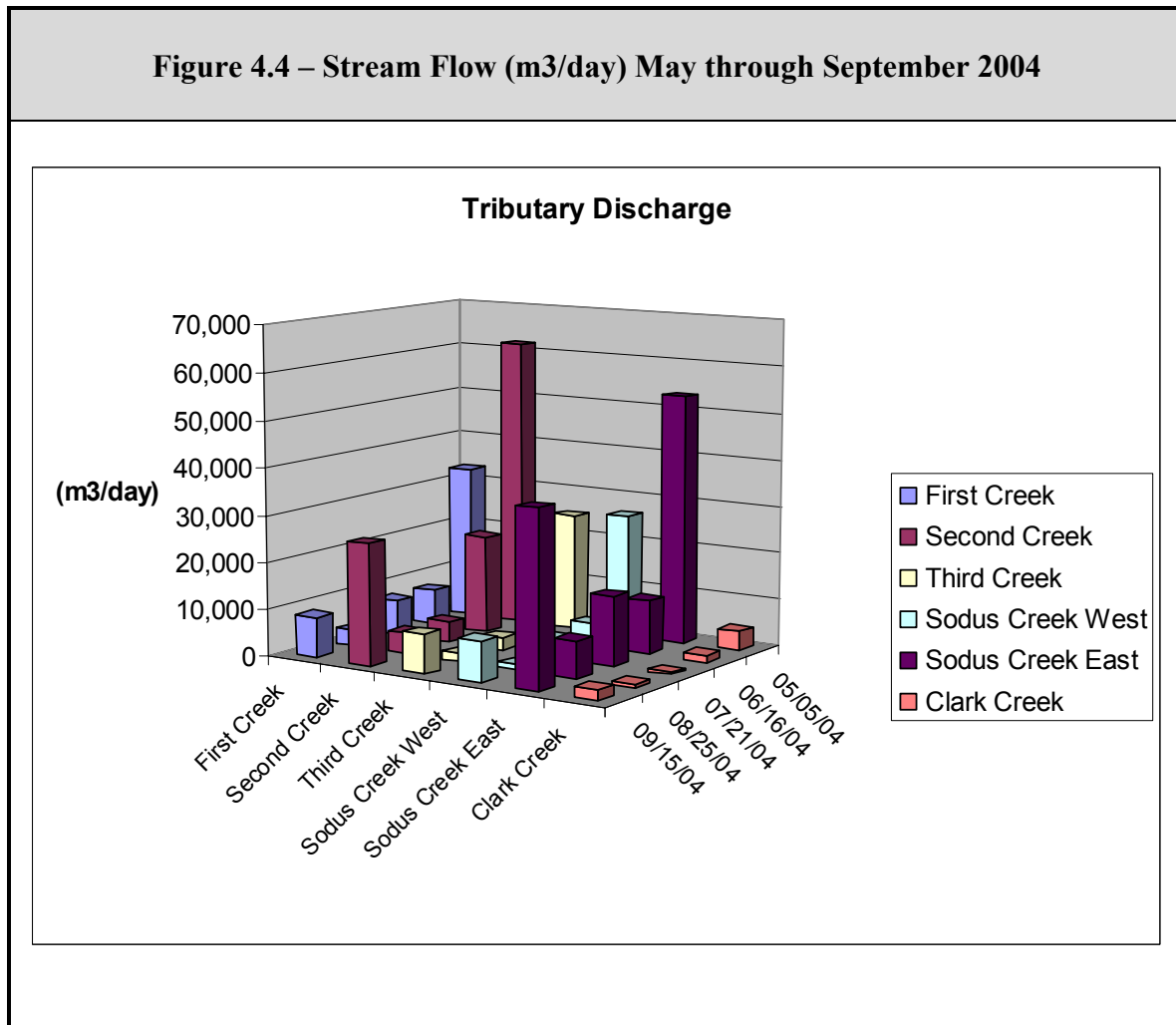
Under baseflow (flow not affected by stormwater runoff), the total suspended solids (TSS) concentrations measured in the streams were fairly low. This is to be expected, as under baseflow conditions there should not be any influx of eroded soil into the streams, flows should be low enough not to disturb and re-suspend any sediment that may have accumulated in the bed of the streams, and there should be no erosion of the streams’ banks. The one outlier in Figure 4.3 is the data collected in May in Second Creek. This abnormally high TSS concentration may have been caused by sampling error, or reflects a very temporary anomaly in this stream’s TSS concentrations.

Sampling from the 1990s attempted to isolate areas of high nutrient loading by utilizing a *stressed streams analysis*. That protocol allowed for the addition of sampling points along stretches of the waterway as the monitoring program progressed in order to pinpoint sources of nutrient loading. The stressed streams analysis involved sampling at over 20 sites in the Sodus Creek East watershed, the Bay’s largest tributary watershed. The findings of the stressed stream analysis conducted in the 1990s found stretches of this creek impacted by phosphorus loading attributed to residential septic system failures and from improperly managed runoff from agricultural areas. Both failing septic systems and agricultural loadings appear to continue to be leading causes of elevated nitrogen and phosphorus levels in the Sodus Creek East watershed.

While the measurement of phosphorus concentrations in the streams is informative, these

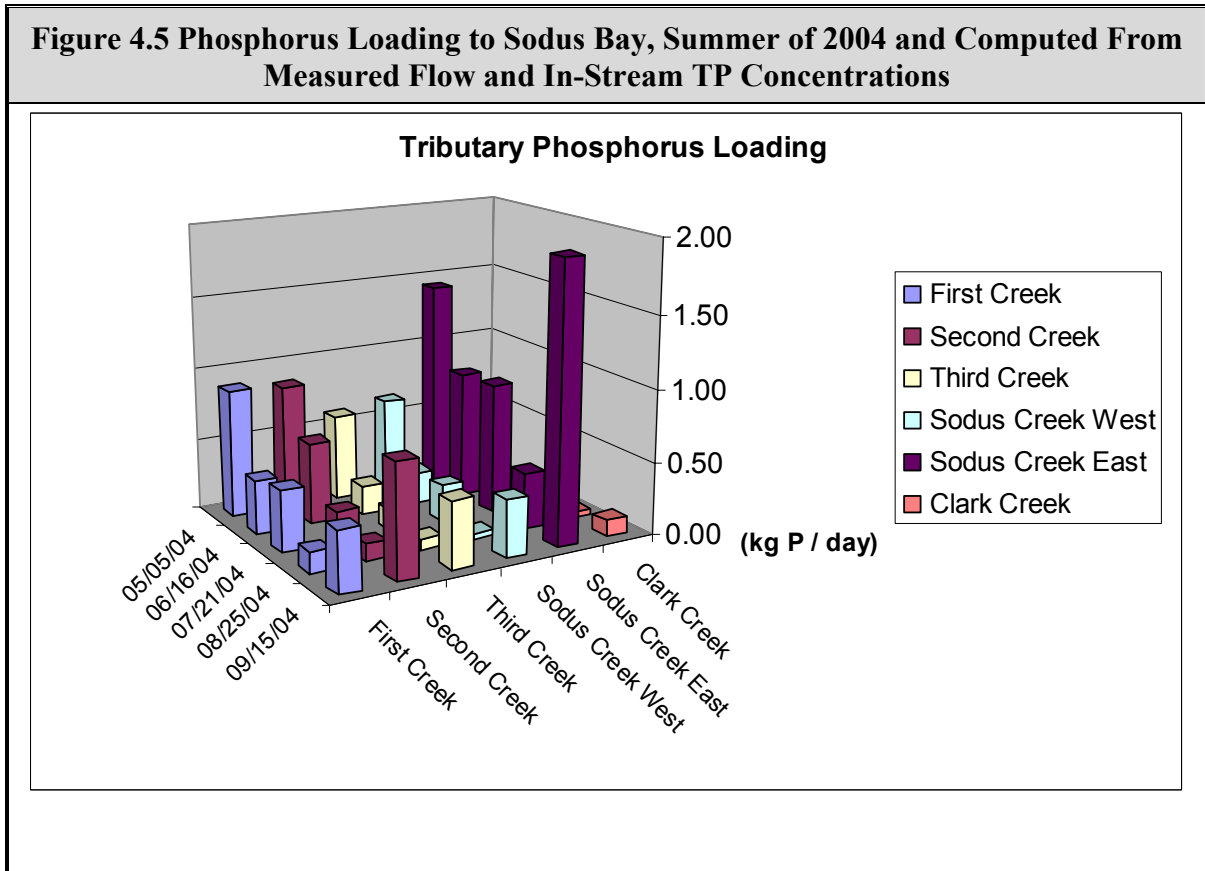
data provide only a “snapshot” of the streams’ effect on the eutrophication of Sodus Bay. To obtain a better understanding of the how much phosphorus is contributed to the Bay from each stream, it is necessary to compute the phosphorus load. This actually yields an assessment how much TP is entering the Bay from each stream. To arrive at this data it is necessary to measure flow. This again was accomplished by SUNY Brockport in 2004 and is summarized graphically in Figure 4.4.

Figure 4.4 – Stream Flow (m3/day) May through September 2004



The above graph shows that over the course of the 2004 growing season there was a considerable amount of inter-station and intra-station variability in flow. The inter-station differences are largely a function of watershed size, although prevailing land use also played somewhat of a role in determining the amount of flow. What the graph shows is that the greatest inflow occurs from Sodus Creek East, followed closely by Second Creek. The intra-stream variability is totally a function of prevailing weather and rainfall conditions. The greatest inflow, as would be expected, occurred in the spring. As the summer progressed, stream flows subsided, until the uncharacteristically wet conditions experienced in September of 2004 caused stream flows to increase markedly.

From the standpoint of pollutant loading, the changes in flow have a direct bearing on the amount of sediment, nutrients and other pollutants transported from the watershed into the Bay. This is reflected in the summarization of the 2004 measured stream phosphorus data presented in Figure 4.5.



Interestingly, the loading data and the flow data do not necessarily fully correlate. Temporally, the same seasonal relationship exhibited in the flow data is observed with the TP loading data. That is, the greatest amount of loading (in this case expressed and Kg/day) occurs in the spring and then again reflects a secondary peak in September. However, the inter-stream comparison of loads reflects a somewhat different pattern than was reflected by the flow data. Although Sodus Creek East is the largest daily TP contributor of the five streams, the loading attributable to Second Creek is basically not too different than that attributable to First Creek, Third Creek or Sodus Creek West. Thus, although the unit flow for Second Creek was significantly greater than that measured in these other streams, the TP load is fairly similar. Returning to Figure 4.2, it is clear that the TP concentrations measured in this stream were generally lower than those measured in the other streams. Thus, although the flow from the Second Creek watershed is substantial, it carries with it a small amount of phosphorus, and for that matter (Figure 4.3) total suspended solids.

The management implications of these data will be discussed in greater detail in subsequent sections of this report. However, it is clear from the review of the historical data base that excessive loading of phosphorus and sediment from the tributaries has not only contributed to higher in-bay nutrient concentrations but has also altered the morphometry of the Bay by expanding prime habitat for nuisance macrophyte growth. As is highly evidenced by bathymetric data and visual observation, all major tributaries entering Sodus Bay have deposited a substantial amount of unconsolidated sediments to the Bay. Associated with the deposited sediment, are high concentrations of phosphorus, which readily binds to soil particles. The process of sedimentation has created a fertile zone for plant growth with ample nutrients and shallow depths that allows for maximum penetration of sunlight.

These sediment deltas are a source of compounding problems for the ecology of Sodus Bay and the management of its ever growing weed problem. Firstly, the nutrient rich, shallow delta areas are prime habitat for nuisance plant growth. This is evidenced by the colonization and expansive growth of these areas by the exotic, invasive water chestnut. As has been previously discussed, this plant is of great concern in Sodus Bay due to its exponential growth potential, ability to out compete native species, hazards to recreational Bay users, and difficulty in control. Secondly, the shallowness of these areas impedes access to mechanical harvesters. Continued loading of excessive nutrients and sediments from the watershed will enlarge the delta areas, provide more suitable habitat for invasive species, and further hinder access to the mechanical harvesters.

Identification of failing septic systems and best management practices in agriculture areas are crucial to preventing excessive watershed based nutrient and sediment loading. Certain practices have already been implemented by the WCSWCD and are available to residents of Wayne County that will ultimately help improve both Sodus Bay's water quality and the water quality of its tributaries. Those practices that help reduce erosion and nutrient loading are implementation of stream animal crossings and shoreline stabilization amongst others. The continued implementation and expansion of these programs is crucial in helping to protect Sodus Bay. Other agricultural best management practices that have been proven to reduce erosion and nutrient loading include planting of cover crops, animal waste storage and runoff management, and riparian buffer corridors. An effective watershed management plan will tailor the best management practices to individual properties and address site specific areas that pose the greatest threat in terms of nutrient and sediment loading. These and other management options for the control of sediment and nutrient loading to Sodus Bay will be addressed in greater detail later in this report.

In addition to the watershed based nutrient load, it is necessary when evaluating the Bay's overall trophic state and the examining causes for its increased productivity to

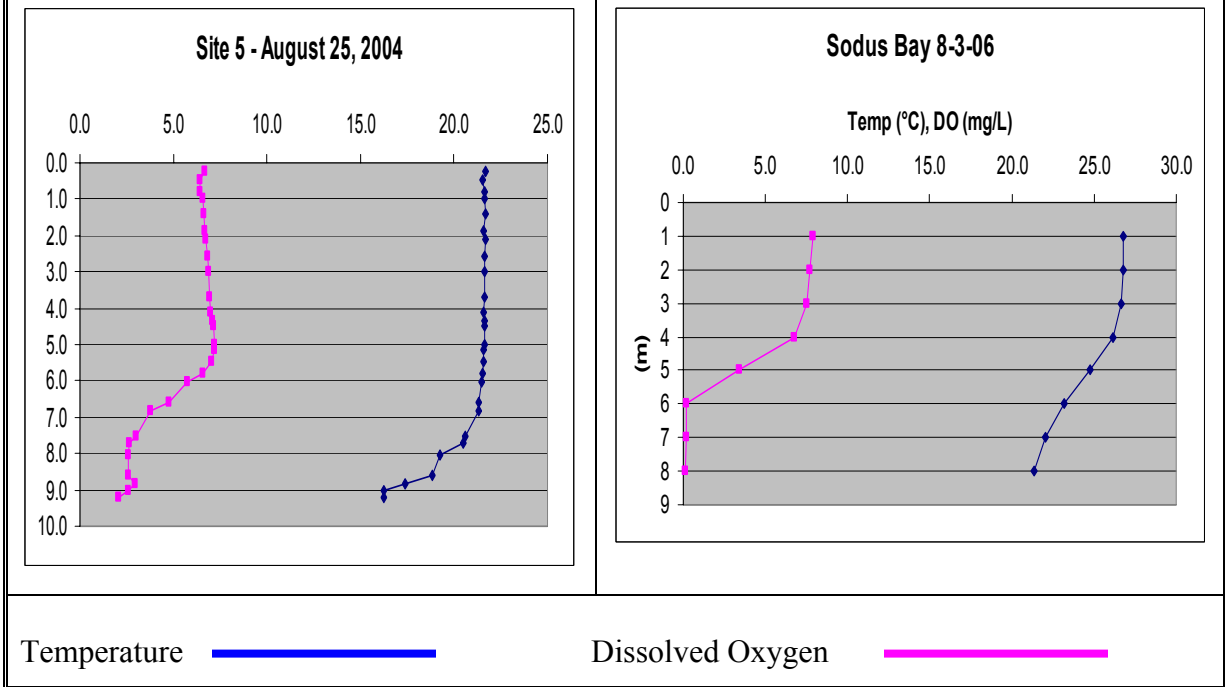
evaluate the role played by internal processes which control and contribute nutrients to the Bay. This component of the Bay's annual nutrient load is referred to as the internal load. The components of the internal load are sediment loading, both in oxic (dissolved oxygen present) and anoxic (devoid of dissolved oxygen) conditions, and loading from the die-off and decay of aquatic plants, most commonly referred to as plant senescence.

Internal loading dynamics are driven largely by thermal and dissolved oxygen conditions. As has been demonstrated in many other freshwater ecosystems, especially large, deep lakes and reservoirs, as a waterbody thermally stratifies, vertical mixing patterns are altered leading to a segregation of the upper and lower portions of the water column. Dissolved oxygen levels in the lower depths of the water column quickly become exhausted, leading to anoxic conditions. Under such conditions, major changes occur in the sediment's chemistry leading to the pulsing of phosphorus from the sediments into the overlying waters. Although some release of phosphorus from the sediments into the water occurs even in the presence of dissolved oxygen, under anoxic conditions the rate of release is much greater, thus leading to the introduction of large amounts of phosphorus within short periods of time. A critical element in the evaluation of the Bay's overall water chemistry involved assessment of the role played by thermal stratification and anoxia in the introduction of phosphorus to Sodus Bay.

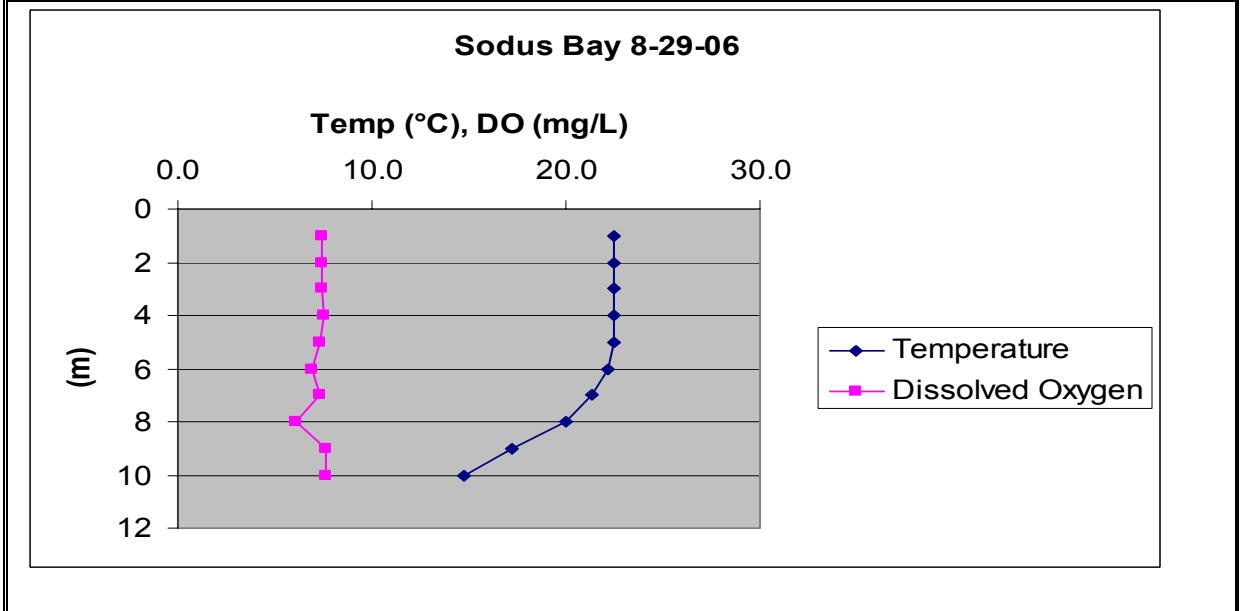
As such, temperature and dissolved oxygen profiles were measured in Sodus Bay by SUNY-Brockport in 2004 and Princeton Hydro in 2006. The resulting data characterize Sodus Bay as a polymictic waterbody. That is, although the water temperatures of the Bay varied seasonally, the Bay's water column (surface to bottom) tended to display relatively uniform temperatures. Between May and September, only at depths of greater than 8 – 9 meters (approximately 26.5 to 30 ft.) was a notable thermal change observed (Figure 4.6). At these same depths, the Bay's dissolved oxygen concentrations decreased markedly and approached or attained anoxic conditions (Figure 4.6). However, as illustrated in Figure 4.7, for Sodus Bay this condition of anoxia and thermal stratification is fleeting. Although on 3 August the Bay was devoid of dissolved oxygen at depths of 6 meters and greater (deeper than 19 feet), by the 29th of August the Bay had mixed and there was significant concentrations of dissolved oxygen in the Bay's deeper waters. However, by mid-September the Bay had once again become anoxic at depths greater than 6 meters. This vacillation between oxic and anoxic conditions is a function of the Bay's weak thermal stratification. As shown in Figures 4.6 and 4.7, the temperature differences from surface to bottom amount to only a 5 to 6 °C. The density differences attributable to these temperature differences are not great enough to create strong thermal layer and cannot withstand wind and current related mixing. As a result, the Bay easily "turns over" in a manner characteristic of a polymictic waterbody.

Polymictic waterbodies may experience brief periods of thermal stratification, but are generally thermally mixed throughout.

**Figure 4.6 Temperature and Dissolved Oxygen Profiles,
 August 2004 and 2006, Station 5, Sodus Bay**



**Figure 4.7 Temperature and Dissolved Oxygen Profiles,
 29 August 2006, Station 5, Sodus Bay**



The relevancy of these data is two-fold. First, they show at times in the summer the deeper, cooler waters of the Bay do not have enough dissolved oxygen to support fish. Second, when the deepest portions of the Bay periodically stratify and become anoxic,

the sediment chemistry is altered, setting the stage for the release (internal recycling) of relatively large amounts of phosphorus. This phosphorus load, if great enough, can become a significant driving factor in the Bay's overall eutrophication, actually stimulating algae blooms independent of phosphorus entering the Bay from external sources. Although the overall role of this internal phosphorus load is discussed in greater detail in Section 6 of this report, the data clearly show that at times during the summer internal phosphorus loading spikes due to the pulsing from anoxic Bay sediments.

Specifically, the water samples collected at the lower depths (11m) of Station 5 during the 2004 sampling season show a marked increase in phosphorus concentrations relative to mid depth and surface water concentrations. Two of the five sampling events in 2004 had deep water total phosphorus concentrations that were an order of magnitude higher than surface water concentrations. The disparity between surface water and deep water total phosphorus concentrations indicate a substantial amount of internal loading due to hypolimnetic anoxia.

Table 4.1 Station 5 and Station 9 Phosphorus Concentrations May - September 2004						
Date Collected	Station 5	TP (µg P/L)	SRP (µg P/L)	Station 9	TP (µg P/L)	SRP (µg P/L)
05/05/04	1 meter	17.6	8.4	1 meter	27.0	4.6
05/05/04	5 meter	12.1	5.8	5 meter	13.3	5.2
05/05/04	11 meter	11.3	3.3	8 meter	14.4	4.3
06/16/04	1 meter	12.3	6.7	1 meter	13.0	3.7
06/16/04	5 meter	14.2	2.7	5 meter	12.3	4.7
06/16/04	11 meter	148.7	3.0	8 meter	9.1	2.0
07/21/04	1 meter	14.1	1.5	1 meter	17.9	3.1
07/21/04	5 meter	25.2	<1.2	5 meter	28.4	2.3
07/21/04	11 meter	30.1	1.9	8 meter	16.3	1.2
08/25/04	1 meter	16.0	3.7	1 meter	22.2	3.3
08/25/04	5 meter	19.9	12.5	5 meter	20.2	1.8
08/25/04	11 meter	242.0	199.7	8 meter	19.4	3.3
09/15/04	1 meter	24.9	1.4	1 meter	24.6	2.2
09/15/04	5 meter	24.1	1.4	5 meter	25.7	1.7
09/15/04	11 meter	39.7	22.4	8 meter	32.7	13.4

TP = total phosphorus, SRP = soluble reactive phosphorus

As illustrated above in Table 4.1, the highest concentrations of both total phosphorus (TP) and soluble reactive phosphorus (SRP) (the form of phosphorus readily taken up by algae and weeds), are attained in the summer months, deep in the water column (11 meters) at Station 5. A similar condition was observed in September at Station 9, again with the highest measured TP and SRP concentrations measured in the deeper portions of the water column. The peak TP and SRP concentrations coincide with periods of time

when the deeper waters of the Bay become anoxic. These data support the fact that during periods of anoxia large amounts of phosphorus are released from the sediments.

However, the overall impact of this source of phosphorus appears to be relatively minor compared to the other phosphorus sources of Sodus Bay. Clearly the *in-situ* data collected in 2004 and 2006 characterize Sodus Bay as a polymictic system. However, when compared to a classically dimictic waterbody, it is apparent that Sodus Bay is only stratified for short periods of time. In addition to being stratified for only brief periods, by referring volume/area (hypsographic) data presented in Section 5, it can be seen that the total Bay bottom area that actually becomes stratified and anoxic amounts to a relatively small portion of the entire sediments of the Bay. As such, due to the periodicity, duration and extent of Bay bottom impacted by anoxic conditions, it appears that although anoxic sediment release of phosphorus does occur in Sodus Bay its role in the overall eutrophication of the Bay is relatively minor. Although this will be addressed in greater detail in Section 7, the greatest source of internally regenerated phosphorus is attributable to sediment loading that occurs under oxic, as opposed to anoxic, conditions. Sodus Bay's unique morphology of expansive shallow water areas in conjunction with its polymictic nature means that the majority of the sediment will be covered by oxic water for a substantial portion of time. The trophic state modeling of the Bay (Section 7) conducted by Princeton Hydro shows that approximately 20% of the Bay's entire nutrient load is a function of oxic sediment release.

Dimictic waterbodies experience strong thermal stratification while only undergoing mixing during spring and fall turnover.

Diffuse sediment loading during oxic conditions in conjunction with macrophyte facilitated sediment phosphorus release will always play a substantial role in the nutrient budget of Sodus Bay. Control of this source of phosphorus loading may be achieved in localized areas through the binding of interstitial phosphorus through the application of alum or lime. However, it will be the reduction in phosphorus loading achieved through the control of watershed sources, as opposed to internal sources, that will ultimately help to slow the Bay's eutrophication process.

The role of internal loading is also reflected to some extent in the observed increases in total phytoplankton abundance as measured in 2004 and presented in Figures 4.8 and 4.9. Although one would expect in the summer months as the water warms and the days get longer that more algae will to be growing in the Bay. However, phytoplankton abundance begins to increase long after the peak influx of the Bay's external phosphorus load occurs. Although some of the growth observed in the early part of the growing season is related to the external load, the increases observed in August and September are attributed to the Bay's internal loading of phosphorus. This will be discussed further in Sections 7 and 8 of this report, both in terms of why this occurs as well as from the perspective of short and long-term management implications.

Figure 4.8 – Sodus Bay Total Phytoplankton Biomass, Stations 5 and 9, May – Sept 2004

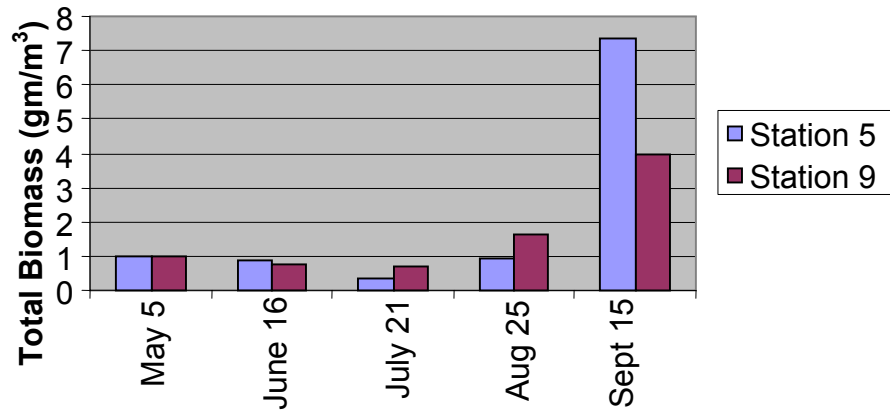
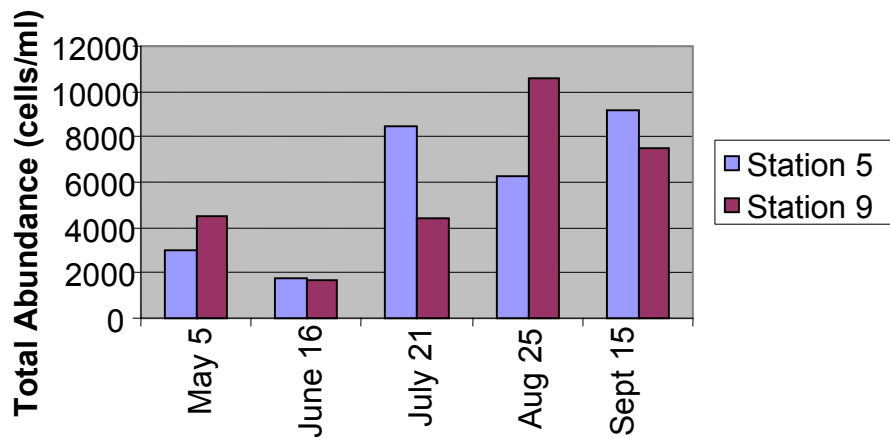


Figure 4.9 - Sodus Bay Total Phytoplankton Abundance, Stations 5 and 9 May – Sept 2004



The late season increases in algal abundance and biomass are even greater in the shallow backwater areas than those observed at the open water (Stations 5 and 9) areas of the Bay. For example in August and September of 2006, the Secchi clarity along the eastern side of Leroy Island was less than 1 meter, whereas at the same time it was still in the 2-meter range in the open water areas of the Bay. This in part speaks to the differences in productivity in the open water areas versus the littoral areas of Sodus Bay and helps to emphasize the need for the special management measures needed to address conditions in the littoral versus the open water areas of Sodus Bay.

**Figure 4.10 Mat Algae Bloom Near Leroy Island
August 2006**



4.4 SUMMARY

The water quality data compiled over the course of this project, together with the data compiled over the past two decades, provides a sound scientific basis for understanding the factors responsible for the Bay's eutrophication. Nutrient loading from both internal (sediments, decaying plants and algae, etc.) and external (stormwater runoff, lawn fertilizers and septic systems) sources provide the phosphorus and nitrogen needed to stimulate the algae and weed growth that impact the aesthetic and recreational attributes of Sodus Bay. To control phytoplankton, mat algae or weed growth, it will be necessary to decrease nutrient loading and, in particular, reduce the availability of phosphorus for assimilation by plants and algae. As such, the control of phosphorus loading and the limitation of phosphorus availability need to be the cornerstones of the Bay's overall management plan. This approach will have a significant positive impact on improving the water quality, recreational utility and overall aesthetics of Sodus Bay.

Although the water quality data discussed above provides relevant insight pertaining to the sources and seasonality of nutrient influxes to Sodus Bay, the data need to be put into a trophic state context. This is accomplished through the quantification of source specific loading. To do this requires accurate information pertaining to the Bay's morphometry (depth and volume relationships), hydrology (water balance) and pollutant loading. The next three sections of this report provide the details of how each of these elements were developed and discusses the significance of the resulting data in the context of the short- and long-term management of Sodus Bay.

5.0 BATHYMETRIC SURVEY - PLOTTING THE BAY'S WATER DEPTHS AND BOTTOM CONTOURS

5.1 INTRODUCTION

Although there are a number of maps that display the Bay's water depths, with the exception of the revised channel profiles prepared by the Army Corp of Engineers, none of these maps are recent. In addition, none of them offer detailed data of accumulated sediments. Information of this nature is needed to evaluate many of the weed control options and also to determine where dredging may be both needed and practical; whether the dredging is aimed at improving circulation, improving fish habitat, reducing internal nutrient sources or enhancing and restoring recreational areas.

The purpose of the Sodus Bay bathymetric survey was therefore to develop up-to-date information pertaining to the depth of water and the amount and distribution of accumulated sediments. Furthermore, because most the emphasis in the past with regard to bathymetric data focused on boat navigation in the open water areas of the Bay, emphasis was placed in this study on the acquisition of water depth and sediment data within the shallow, littoral areas of the Bay. Due to the increasing impacts of excessive weed growth on the ecology and recreational use of Sodus Bay, the collection of water depth and sediment accumulation data within the shallow, near shore areas of the Bay is critical, as these are the areas of the Bay most commonly subject to weed infestation problems, mat algae blooms, and impaired water quality resulting from planktonic algae blooms. The littoral zone is essentially the interface area between the Bay's true open water habitats and communities and the up-land watershed. As is the case for any lake, pond, reservoir or embayment, from a human use standpoint the littoral zone is the most highly developed portion of Sodus Bay. From an ecological perspective, it is the most dynamic and biologically diverse area of Sodus Bay. However, it is also the area where the greatest amount of sedimentation occurs and where weeds and benthic mat algae densities are most likely to attain nuisance densities. Thus, knowing precisely the characteristics of water depth and sediment deposition facilitate the implementation of management and restoration techniques that target those areas of the Bay perhaps the most subject to user and ecological related problems, in particular those associated resulting from dense stands of noxious aquatic weeds and mat algae blooms.

As such, the bathymetric data are important for a number of reasons, most of which are directly related to the Bay's eutrophication. First, the physical attributes of the Bay, in particular its mean depth, maximum depth, area and volume are fundamental pieces of information needed to properly analyze and compute the Bay's pollutant loads, hydrologic properties and trophic state (Sections 6 and 7). Second, as emphasized above, water depths and sediment thickness play a key role in determining the colonization, distribution, density and perhaps even the composition of aquatic weeds or the occurrence and magnitude of algae blooms, especially those caused by mat forming, filamentous algae. Third, examination of sediment deposition patterns illustrates watershed-based erosion problems, and the subsequent use of these data can help

document cause/effect relationships of land clearing and development impacts. This same information can be used to assess the need for or the prioritization of remedial dredging projects that improve circulation, remove nutrient rich sediments or enhance recreational access and use of Sodus Bay.

The following sections of this report review the field techniques used to acquire the up-to-date bathymetric data and discuss the relevancy of the resulting data in terms of the long-term management of Sodus Bay and its watershed.

5.2 METHODOLOGY

To obtain these data a dual-frequency, continuous recording fathometer, equipped with GPS and a GIS interface was used to simultaneously record both water depth and sediment thickness data along a series of pre-established transects (Figure 5.1). Each transect was separated for the most part by 200-400 feet, with limited areas where the separation width between transects was reduced to 50 ft. These areas where the transect separation increments were narrower were selected due to existing or historic prevalence of dense weed growth and weed growth patterns observed over the past 10+ years.

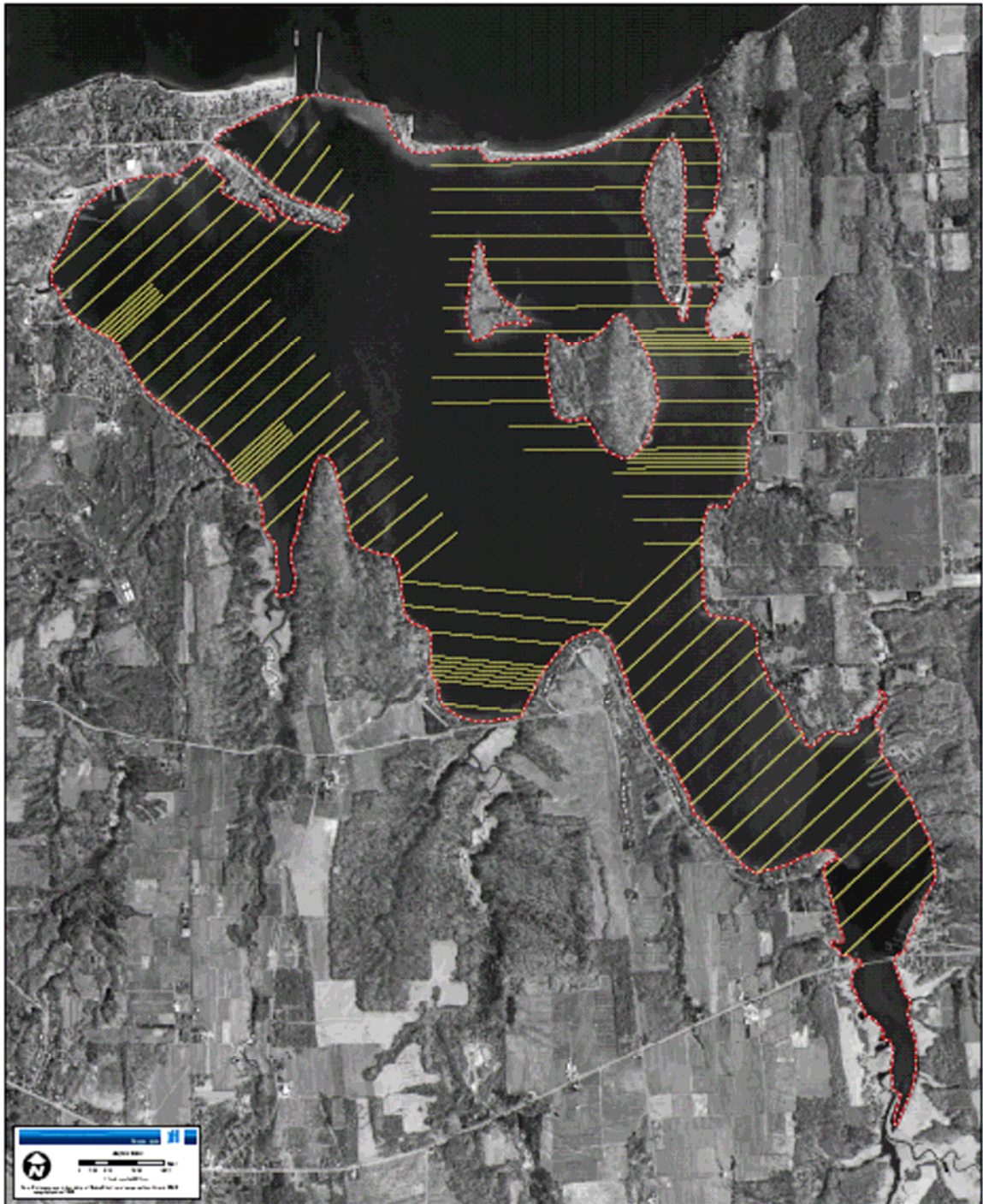
As noted above, special attention was placed on the documentation of water and sediment data within the Bay's littoral zone. The transects varied in length, but typically ran perpendicular to the shoreline from a water depth of near zero to a maximum water depth of between 12 to 15 feet. Typically, it is in water depths of this range (0-15') that most of the Bay's weed problems are observed and a large percentage of recreational activity occurs.

The bathymetric survey was conducted in the spring of 2004. Some supplemental data collection was also conducted in the spring of 2005 and the summer of 2006, to specifically evaluate alternative weed control strategies. The water depth and sediment thickness data collected with the fathometer were cross-checked in the field during the time of the bathymetric survey at random locations using a graduated survey rod. The digital data were subsequently post-processed, in order to integrate and interpolate the areas between the surveyed transects, thereby smoothing the resulting contours. The corrected data were then plotted using ArcView GIS software. A map of the water depths and depths of accumulated sediments within the surveyed littoral zone was prepared along with a series of the cross-sections of each of the surveyed transects. The cross-sectional transect data were interpolated using Spatial Analyst software and used to generate estimates of the sediment volumes that could potentially be dredged, where dredging appears necessary. Full scale maps that depict the Bay's water depths and depths of accumulated sediments are provided in the pockets at the end of this report.

5.3 Results

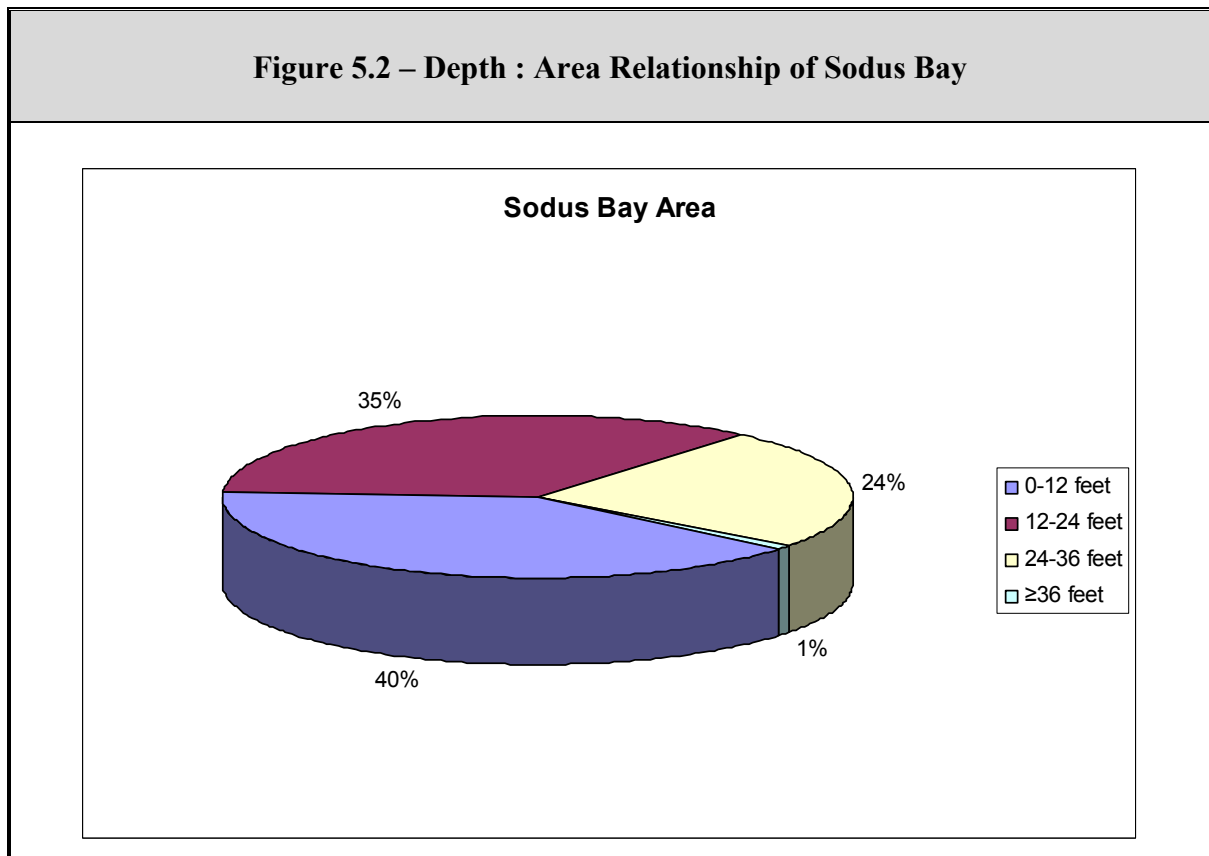
As noted above, the full scale bathymetric maps generated for this project are provided in a map-pocket appendix to this report. From the basic depth data it is possible to develop

Figure 5.1 – Bathymetric Transect Locations Throughout Sodus Bay

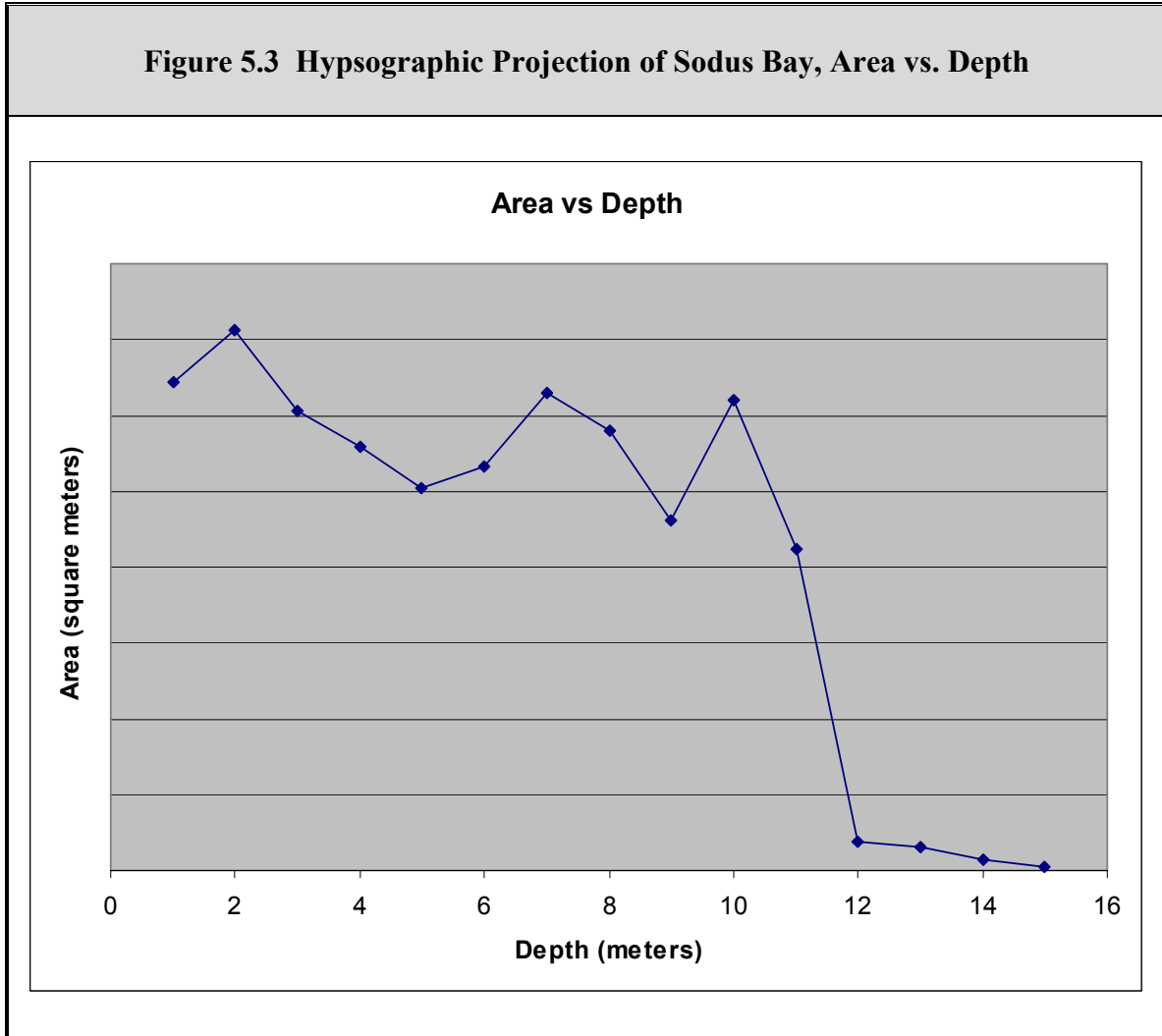


information detailing the changes in volume with each increment of depth. This relationship is most often presented in the context of a hypsographic curve; a simple projection of the depth:area relationship (Figure 5.2). The utility of such data is that it can be used to better understand various biological, ecological and physical aspects of Sodus Bay, such as habitat distributions throughout the Bay. As documented, approximately 40% of Sodus Bay's total surface area is associated with water depths that are less than approximately 12 feet (12' = 3.66 meters). This is significant in that it emphasizes the fact that a large percentage of the Bay is shallow. Examining the data more closely shows that slightly more than 25% of the Bay has water depths of only 0-8 feet. Although a large portion of these shallows are associated with the area extending from the mouth of Sodus Creek to Nicholas Point, there are also fairly expansive littoral shelves along the eastern and western shorelines. Littoral shelves are also present around Leroy Island and along the eastern shore of Eagle Island and along the western shoreline of Sodus Bay. Localized, but pronounced shallows also occur around Sand Point. In part, the importance of these data relate to understanding why the Bay is so susceptible to weed and benthic mat algae related problems and the evaluation of weed and algae control options. The expansiveness of the Bay's littoral zone, combined with the Bay's typically excellent water clarity (> 3 meters) facilitates the widespread distribution and growth of nuisance aquatic weeds. As such, what the hypsographic data shows is that the Bay, by nature, will be a system subject to weed related problems.

Figure 5.2 – Depth : Area Relationship of Sodus Bay

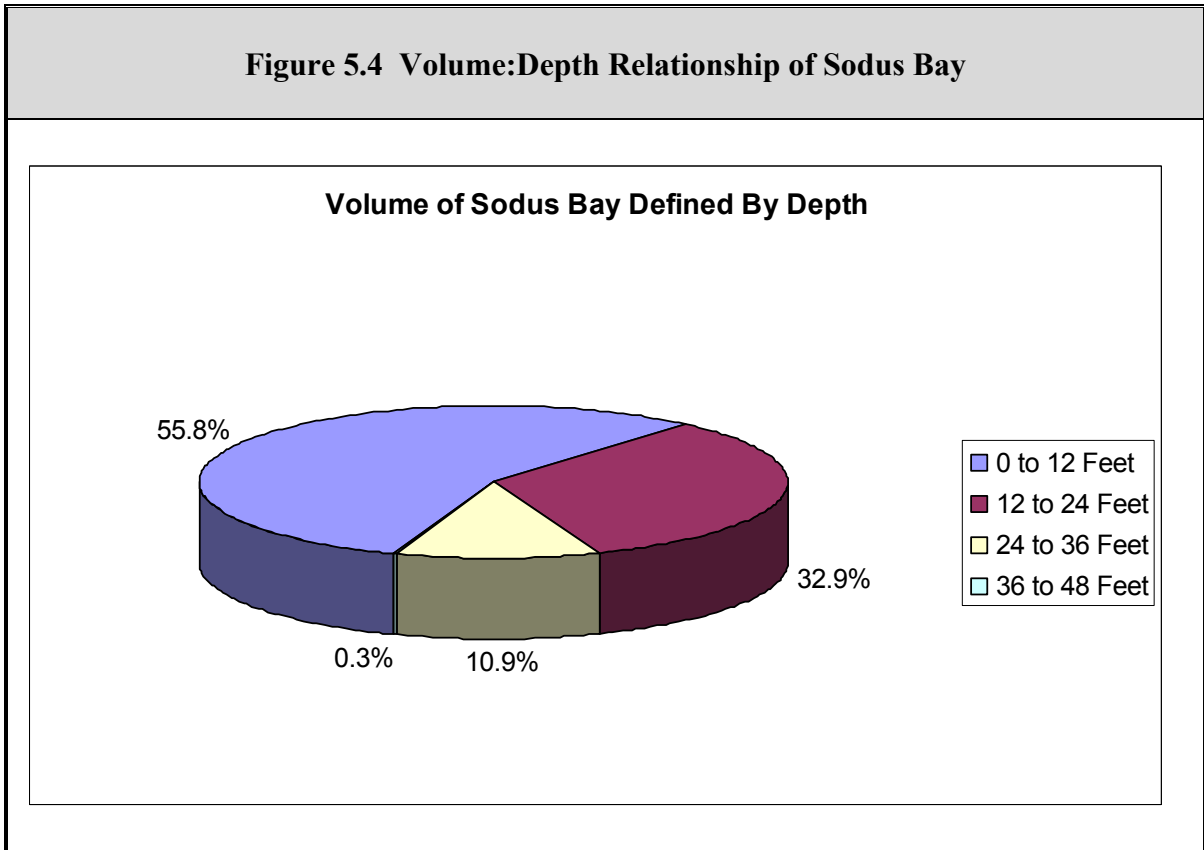


This is can also be illustrated by the hypsographic curve displayed in Figure 5.3 which simply shows that by far the majority of the Bay, by area, ranges in depth between 0 and 8 meters, which equates to less than approximately 26 feet.



Additionally, the data (Figure 5.4) show that by volume, only 25% of the Bay can be classified as deep (> 8 M or approximately 25 feet or greater in depth). From a limnological perspective this is important, in that it suggests that internal processes will not be as important as external processes in defining the trophic state of the Bay. Typically, deep waterbodies, with large percentages of the waterbody's volume comprised of deep areas are more subject to thermal stratification and internal nutrient recycling phenomena than are waterbodies having most of their volume associated with predominantly shallow areas. For Sodus Bay, over half of the Bay's volume is associated with waters less than 3 meters, or 12 feet deep.

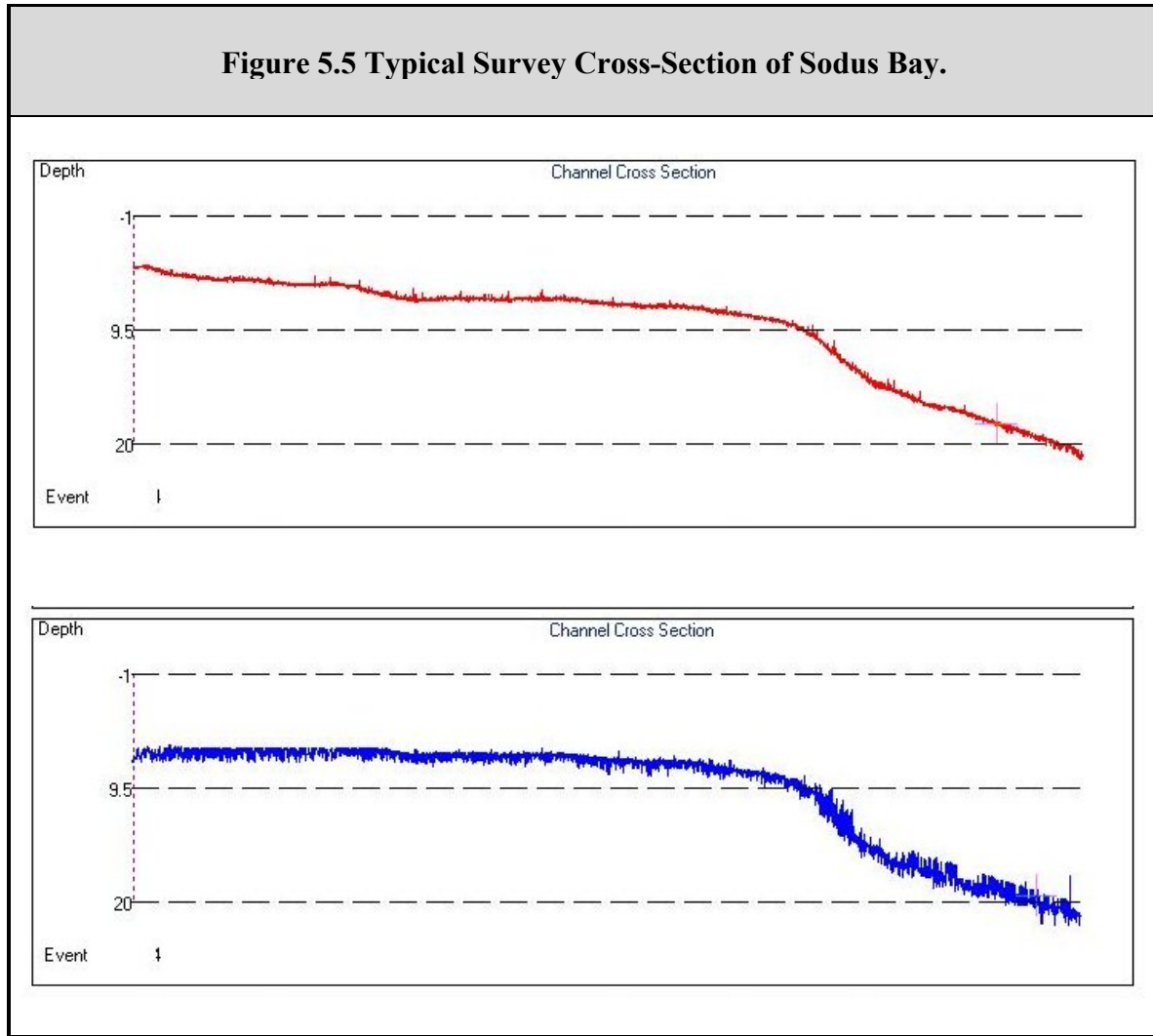
Figure 5.4 Volume:Depth Relationship of Sodus Bay



Examination of the sediment accumulation data shows, as one would expect, that the most significant deposits of unconsolidated (fine, muddy) sediments occurs at the mouth of each of the main tributaries. Soft sediments are also encountered in the northeastern sector of the Bay and along the eastern shoreline of Leroy Island. A typical cross-section of the Bay bottom, prepared from data collected along one of the surveyed transects is presented in Figure 5.5. What is illustrated in this cross-sections are both the existing water depth along the transect (extending from the shoreline into the open water reaches of the Bay) and the thickness of the accumulated sediment. This particular transect was conducted along the Bay's western shoreline. The upper line represents the existing water depth. Along this transect, the Bay's depth at the inception of the transect is approximately 4.5 feet, and at the termination of the transect it has reached a depth of approximately 21 feet. The lower line is a display of the sediment echo encountered over the course of the transect. The difference between the upper line and the bottom line is the thickness of the accumulated sediment. In this case, the thickness of the loose sediments was greatest, closest to the shoreline (approximately 3.5 feet thick), but petered off quickly to less than 1 foot thick. This pattern of sediment deposition is typical for what was observed throughout most of the Bay free of the influence of any of the tributaries. In general, once 100 feet from the shoreline, sediment thickness became minor, meaning that most of the accumulated muck and loose sediments are deposited

close to the water's edge. Most of these loose sediments are comprised of eroded shoreline soils and a matrix of leaf litter and decomposed aquatic plants.

Figure 5.5 Typical Survey Cross-Section of Sodus Bay.



By integrating the numerous transect cross-sections (as represented by Figure 5.5), it was possible to develop the aerial projections of water depth and sediment deposition illustrated in the full-scale maps contained in the appendix map pockets.

For the most part, we found the Bay's sediments to be highly variable in composition. Near the mouths of the tributary streams, the sediments tended to be dominated by silty, somewhat organic sediments, reflective of a combination of upland eroded soils and organic muck most likely the product of the decomposition of aquatic plants. In areas clearly outside of the influence of the stream's discharge, the sediments had only a minor muck component, and tended to be relatively firm. Although there was evidence of organic material, again largely the result of aquatic plant decomposition, the majority of the sediments could be better defined as silty-sands. These sediments lacked any

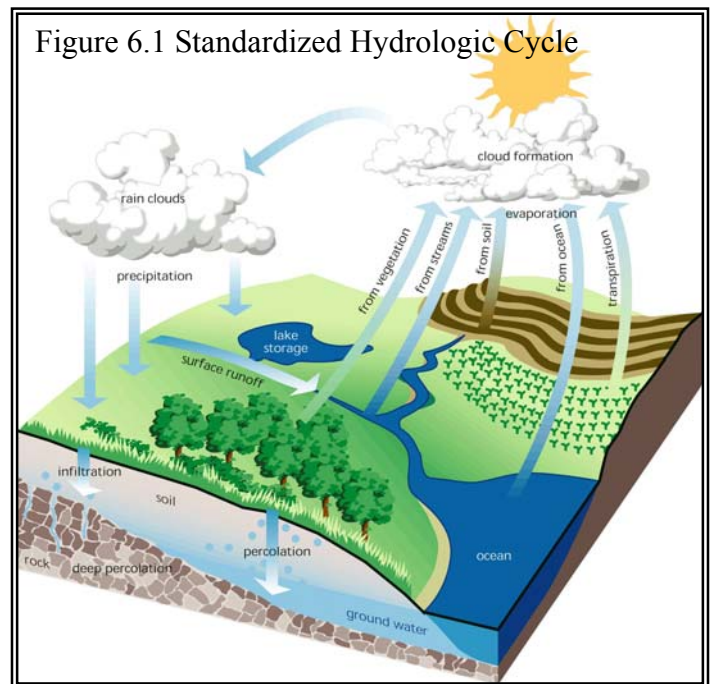
pronounced organic odor.

State designated wetlands are found in many of the more shallow, silty areas of the Bay, in particular at the mouths of Sodus Creek, Clark Creek and First, Second and Third Creeks. It is in many of these same areas where invasive aquatic weeds flourish. These areas have come to be populated by water chestnut and cattails and an increasing amount of purple loosestrife. The sediment deltas that have evolved at the mouth of Second Creek are very pronounced. Sediment depths in this section of the Bay reportedly exceed three feet. These areas are becoming increasingly overrun by water chestnut. As this plant becomes increasingly established, additional sediment is becoming trapped due to the reduction in flow and filtering of the water caused by the density and volume of plant growth. This has exacerbated sedimentation problems in this section of Sodus Bay. The deposition of sediment has in turn altered flow patterns in the back water areas, resulting in new “channels” being formed during periods of higher flow. Overall, the impact of the water chestnut on these intra-Bay microcosms is pronounced. Essentially, as more plants take hold, more sediment is trapped, with this leading to an increased loss of water depth and sedimentation of important littoral habitats, including nursery and spawning habitats used by many of the Bay’s resident fish. The decreased water depths make it increasingly difficult to harvest these areas, thereby decreasing the potential for the mechanical control of the water chestnut. These areas, in particular Second Creek, are thus prime candidate areas for hydrotanking and chemical weed control strategies. A reduction in the density of the water chestnut would reverse the aggravated sedimentation problems being documented in these areas. This will be discussed in further detail in the management sections of this report.

6.0 THE HYDROLOGIC BUDGET OF SODUS BAY

6.1 Introduction

In its simplest definition, the hydrology of Sodus Bay refers to its water budget. In effect, this represents the balance of all water sources to the Bay and all water losses from the Bay. Defined in this manner, the Bay's hydrologic balance is the relationship of "water in" versus "water out" as schematically illustrated in Figure 6.1. When defining the hydrology of any freshwater ecosystem for the purpose of establishing or studying the impacts of eutrophication, the hydrologic budget is quantified on an annual scale. However, because of differences that occur seasonally in terms of the amount of rainfall and runoff, and the losses due to evaporation, it is often more accurate to examine a waterbody's hydrology on a seasonal scale. This is important as the seasonality of water flow into and out of the Bay controls the rate and amount of nutrient and sediment loading, the rate of sediment and particulate matter settling and potentially even the utilization of nutrients by algae and phytoplankton.



The volume and rate of water entering the Bay together with the volume of the Bay itself determines the flushing rate of Sodus Bay. The flushing rate represents the time it takes the water present in the Bay to be fully exchanged; or if emptied the time it would take for the Bay to completely refill.

Unlike a lake or reservoir, the hydrology of Sodus Bay is complicated by its connection to Lake Ontario. Changes in the elevation of Lake Ontario affect water flow out of the Bay, and wave and current action within Lake Ontario may actually force water into Sodus Bay. Understanding these properties of water exchange is important to fully understanding nutrient use by algae and phytoplankton, sediment deposition, the utility and applicability of various weed control and nutrient management techniques, as well as factors that govern the water temperature and dissolved oxygen profiles in the Bay during the summer time. As such, a thorough understanding of the hydrology of Sodus Bay is crucial to understanding its biology and ecology as well as understanding the Bay's flushing rate, settlement of sediments and the retention of pollutants. The hydrologic data is also used extensively in conducting trophic state analyses and is needed to assess the feasibility of many management options, including pesticide application and alum applications.

6.2 Methodology

The scope of this project did not allow for an in-depth analysis of the interactions of Lake Ontario and Sodus Bay or for the plotting/modeling of Sodus Bay's internal circulation patterns. However, it did enable us to examine details of the primary factors affecting the hydrology of Sodus Bay and to assess the influence of Lake Ontario on water exchange and flushing properties of Sodus Bay.

The basic input parameters used to model and analyze the Bay's hydrologic budget consisted of:

- Precipitation,
- Watershed area,
- Watershed area land use and land cover,
- Water elevations of Lake Ontario and
- Volume and bathymetry of Sodus Bay.

Because the watershed of Sodus Bay is so large (46 square miles) one of the key factors influencing the Bay's hydrology is watershed development. The role of land clearing, development and increased amounts of impervious (paved) cover affects the volume and rate of stormwater runoff on inflow to the Bay. As such, a key component of modeling the Bay's hydrology is to accurately map land use / land cover (LU/LC), geology soils and slope, developing such data for each of the sub-watersheds of the Sodus Bay watershed.

For Sodus Bay and its watershed, a number of hydrological models were used to both quantify and describe its hydrology. These models were used to define and investigate such specific hydrologic components as direct precipitation, stormwater runoff, tributary baseflow, groundwater seepage, and the two-way exchange with Lake Ontario. As noted above, the hydrologic budget (an estimate of all of the hydrologic inputs and losses to the Bay) is typically computed on an annual scale. But when dealing with lake systems, such as Sodus Bay, the hydrologic budget should be examined on a seasonal scale due to the significant seasonal differences in rainfall, runoff and evaporation. As previously mentioned, although past studies have examined the hydrologic loading of the major streams that drain to the lake (Makarewicz, et al. 1991, 1992 and 1993) these past studies have not examined, in full, the dynamics of the Bay's hydrology.

Four components of the hydrologic budget were investigated and quantified:

1. Direct precipitation
2. Tributary inputs
3. Overland runoff
4. Groundwater seepage.

The methodology employed in preparing this hydrologic budget was essentially a mass-balance approach. In this case, a variety of mathematical models were used to describe specific components of the loads and then the results added together to form a sum of the hydrologic budget. The models themselves are based on empirical data collection and use generalized loading coefficients documented in scientific literature, then refined with site specific data. As with the pollutant budgets discussed later in this report, Geographic Information System (GIS) software was used extensively in developing the hydrology of the Sodus Bay system. GIS was used to delineate the watershed and a variety of GIS datasets were utilized to accurately describe the geology, soils, LU/LC, and other parameters that are necessary in preparing this budget. The following section outlines the use of the models, the specific mathematics and any assumptions made in the calculations of these models.

Long-term precipitation data were obtained from the National Oceanic and Atmospheric Agency's (NOAA) 30-year historical rainfall records. The gross annual precipitation load, which equated to the rain and snow falling directly onto Sodus Bay, was calculated using this data. An adjustment to the total volume of water entering the Bay computed in this manner was conducted to account to the evaporative loss of water from the Bay's surface. This was accomplished using pan evaporation equations for the water loss from the surface of the Bay itself.

Groundwater related interflow to the Bay and its tributaries were computed using a modification of the United States Geologic Service GSR 32 methodology. This component represents the precipitation that passes through the upper soil horizon and root zone, but then flows laterally into the streams and the Bay's littoral zone. Interflow constitutes a large fraction of a stream's "base flow". These data were compared to stream flow data compiled during this study and past efforts by SUNY-Brockport (Makarewicz, et al., 1991, 1992 and 1993; Makarewicz and Lewis, 1990).

The component of the Bay's hydrologic load that is associated with storm related surface runoff was quantified using a modification of the USDA's modified Rational Method (USEPA, 1990; Maidment, 1993). This is a semi-deterministic model that can be used to compute monthly or annual amounts of runoff. Essentially, this will involve the application of runoff coefficients for each land use within the watershed and the computation of the expected runoff volume generated because of storm events of different magnitude and duration. Evapotranspiration (ET) losses associated with terrestrial vegetation were estimated for each sub-watershed using NRCS/USDA generalized ET rates. The computation of the watershed based component of the Bay's hydrologic load was facilitated by use of the GIS platform, which enabled easy integration of precipitation data with land cover, slope and soils data. As noted above, the analysis was conducted for each of the Bay's main sub-watersheds, with the resulting data subsequently combined to generate monthly, average inflow rates for each of the sub-watersheds.

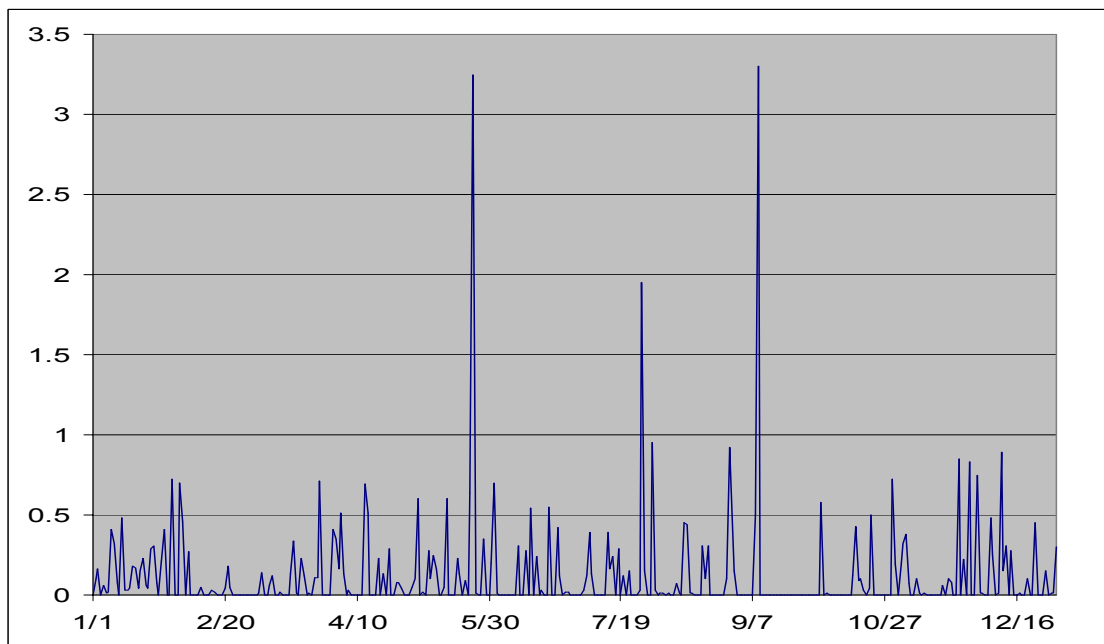
6.3 Results

The following provides a summary of the findings of the hydrologic budget analyses, presented individually for each contributing element.

6.3.1 Precipitation

Precipitation is the most important factor in describing the hydrology of most systems. Sodus Bay is located within a temperate region of United States that receives typically around 40 inches of precipitation a year. Site specific data from CLIMOD and the New York State Climatologists Office indicate that the 30-year mean precipitation at Sodus Center was 0.974 meters or 38.9 inches. Generally, precipitation is fairly well distributed throughout the year, but monthly rainfall totals are greatest from September through November due in part to the lake-effect climate of the region. The 2004 precipitation data shows that February and March were the driest months. There were also three significant storms in 2004, each generating well over 1.5 inches of rain. These occurred in May, July and September (Figure 6.2).

Figure 6.2 – 2004 Precipitation Records for the Sodus Bay Watershed



In total during an average rainfall year, the Sodus Bay watershed, including the Bay itself, receives in excess of 134 million cubic meters of precipitation per year (Table 6.1). Precipitation has four generalized fates within a watershed: direct precipitation to the waterbody itself, Potential Evapotranspiration (PET) which describes both evaporation and transpiration (or the cycling of water through plants back to the atmosphere),

stormwater runoff, or infiltration into the groundwater. Watershed characteristics then dictate the fate of these components. Where there is more impervious cover (pavement, rooftops and roads), a large percentage of this precipitation will runoff into the Bay. Where land cover is dominated by forested lands and native, non-compacted soils, a large percentage of the precipitation will be taken up by the trees and under story or seep back into the soils, resulting in very little runoff. The following sub-sections examine these rainfall/runoff relationships within the context of the Bay’s hydrologic budget. The data summarized in Table 6.1 shows that due to PET, in the late spring and summer, very little runoff should be generated (precipitation surplus), whereas from late fall through early spring, large amounts of runoff can be expected.

**Table 6.1 Summary of Precipitation Data
As Based On Mean 30-Year Precipitation Records For Sodus Bay**

Month	Average Monthly Precipitation			
	(inches)	(meters)	(million M ³)	(% of annual total)
January	2.54	0.065	8.9	6.62
February	2.04	0.052	7.7	5.32
March	2.58	0.066	9.0	6.73
April	3.18	0.081	11.1	8.29
May	3.18	0.081	11.1	8.29
June	3.70	0.094	12.9	9.65
July	3.08	0.078	10.8	8.03
August	3.31	0.084	11.6	8.63
September	4.04	0.103	14.2	10.53
October	3.77	0.096	13.2	9.83
November	3.92	0.100	13.7	10.22
December	3.01	0.076	10.5	7.85
Annual Total	38.35	0.974	134.36	100.00

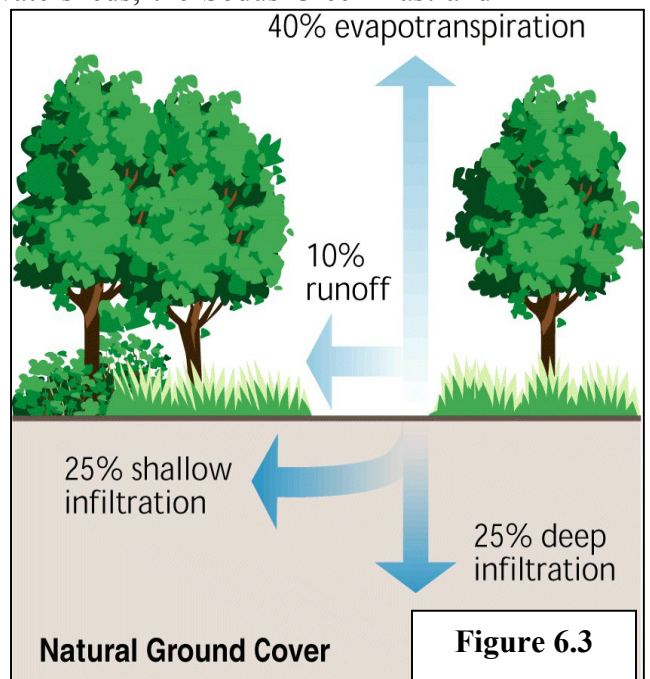
6.3.2 Surface Runoff, the Results of the Modified Rational Analysis

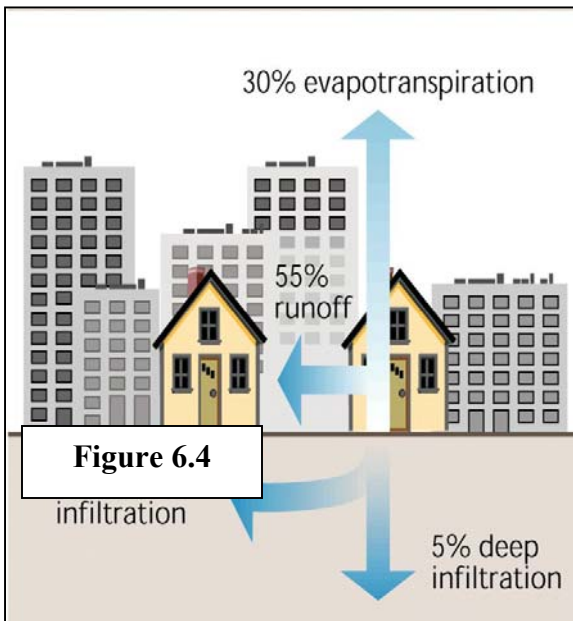
The Modified Rational method or model was developed the by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) to describe the runoff component of the hydrology budget. While originally designed for small sites during a single storm event as a sizing model for designing stormwater infrastructure the model is also useful when applied to a large watershed. The Modified Rational model is based off of the use of curve numbers (CN) applied to delineated parcels based on LU/LC and soil hydrological group. CN are in effect simple percents that describe how much precipitation will runoff a site and factor PET and groundwater infiltration into this estimate. Using the Modified Rational in this manner tends to provide overestimates

when applied to an entire watershed, because over long distances the runoff volumes tend to be more quickly converted towards PET and infiltration components before it can reach the waterbody.

For this reason, Princeton Hydro has adopted a Corrected Modified Rational Model that accounts for these overestimates by accounting for PET when utilized on a watershed wide scale over the course of the year. As such, monthly precipitation values taken from the Northeast Regional Climate Center CLIMOD 30 year average climate dataset were corrected by subtracting PET values calculated using the Thornthwaite methodology to create a net precipitation category. Since PET can exceed precipitation values during the warm summer months, the precipitation minus PET value is used as the precipitation value for the model, or at least 50% of precipitation is assumed to be available as runoff, whichever value is greater. This corrected model gives a more complete accounting of the various components that contribute to the overall water budget of the Bay. In addition, the model used in this fashion also accounts for some of the groundwater inputs to the Bay in the form of interflow; the baseflow of streams attributable to groundwater seepage.

In total, inflow to the Bay, accounting for all sources including precipitation direct on the Bay's surface, is nearly 1.8×10^{10} gallons per year (67 million M^3). Because of the large area associated with each of the Bay's main sub-watersheds, the Sodus Creek East and Second Creek subwatersheds are responsible for the majority of the annual inflow to Sodus Bay. However, the importance of the smaller sub-watersheds in the hydrology and pollutant loading to the Bay cannot be overlooked. For example, although area wise lands directly adjacent to the Bay (Sodus Bay Direct) account for a small percentage of the Bay's total watershed area, the hydrologic loading from this sub-watershed is strongly influenced by the amount of impervious cover as opposed to watershed size alone. Greater amounts of impervious cover decrease the opportunity for precipitation to infiltrate back down in the ground, thus resulting in the generation of greater amounts of runoff as compared to less developed areas having small amounts of impervious cover (Figures 6.3 and 6.4). Essentially with an increase in impervious cover comes an increase in the volume and rate of stormwater runoff. The greater volumes and rates of runoff in turn have the ability to mobilize and transport on a unit area basis a greater amount of pollutants during each and every storm event. As will be discussed in greater detail in Section 7, this has a deleterious effect on the water quality of Sodus Bay.





Another interesting pattern was the seasonal and monthly variation in runoff loading predicted by the model. Since PET was directly factored into this model, it can be seen that the summer months contribute significantly less to the hydrologic budget because of the loss of water attributable to evapotranspiration. Thus, even though these months are characterized by some of the greatest amounts of rainfall, a lot of this rainfall never becomes manifested as runoff due to photosynthetic evapotranspiration,

evaporation from heated ground covers and the assimilation of precipitation by dry soils. It must be noted that much of the precipitation, runoff, and groundwater interflow calculated during the winter months is suspended because of freezing conditions and snow-pack and therefore is not fully manifested as a contributing element of the hydrologic budget until temperatures are high enough to permit the melting of stored ice and snow in the early spring.

Table 6.2 Corrected Modified Rational Method Summary¹

Subwatershed	% of Total Area	Total Runoff Million M ³	% of Total Runoff
Clark Creek	1.76	1.15	1.73
First Creek	8.12	5.29	7.92
Second Creek	22.70	13.76	20.59
Sodus Bay Drainage	9.29	6.23	9.33
Sodus Creek, East	26.24	17.45	26.13
Sodus Creek, West	9.18	6.06	9.07
Third Creek	13.57	9.00	13.48
Sub-Total Land Mass	90.86	58.95	88.25
Sodus Bay, proper	9.14	7.85	11.75
Total Inflow	100.00	66.80	100.00

¹ Utilizes surplus/deficit of P - PET as the basis of precipitation inputs, but also assumes at least 50% of precipitation always available to become runoff. Runoff in winter months suspended in snowmelt, and occurs in March and April.

6.3.2 Measured Tributary Inflow

While the corrected modified rational method used for this study is the primary means by which the hydrology of Sodus Bay was investigated and defined, it is useful, given the availability of actual stream flow data collected over the course of this project to use that

data in concert with the modeled results. The measured data, which was collected and compiled by SUNY-Brockport, can be used to quantify tributary contributions. This data was previously presented and discussed in Section 4 of this report. Also as previously discussed, used in this way these data have limitations because they only reflect the conditions that existed in 2004. Within the context of this section of the report the SUNY flow data was used to evaluate the accuracy of the computed inflow. While 2004 was in general a wet year, the due to PET and other mitigating factors the resulting SUNY data (Table 6.4), when extrapolated over the entire growing season likely represents an underestimate of total stream flow. This is reflected in the results.

**Table 6.3 Tributary Discharge Data
As Based on 2004 SUNY Discharge Monitoring Data**

Subwatershed	Area (% area of land mass)	Mean Annual Hydraulic Loading Rate (cubic meters/ha/yr)	Annual Discharge (cubic meters/yr)	% Annual Discharge (% tributary discharge)
Clark Creek	1.93	4,623.79	1,120,034.63	2.88
First Creek	8.93	4,412.96	4,940,692.46	12.70
Second Creek	24.98	2,839.09	8,888,773.47	22.86
Sodus Bay Drainage ²	10.23	3,501.61	4,488,506.71	11.54
Sodus Creek, East	28.89	2,739.39	9,917,000.56	25.50
Sodus Creek, West	10.10	4,019.88	5,090,344.57	13.09
Third Creek	14.93	2,374.52	4,443,906.81	11.43
Total Land Mass	100.00	3,501.61	38,889,259.21	100.00

Derived from 2004 dataset of Makarewicz and Lewis discharge values. While 2004 had more precipitation than the long-term average, the discharge measurements were taken during the growing season, and thus underestimate annual discharge.

Specifically, the inflow to the Bay computed using the modified rational model yielded an annual tributary loading to Sodus Bay was calculated by both measured discharge data and by regional loading analysis. The two techniques yielded the following results respectively 39,000,000 cubic meters, as based on the SUNY-Brockport data and 55,000,000 cubic meters as based on the regional, USGS computed data. As discussed above the tributary load based on discharge measurements most likely represents an underestimate of total hydrologic load, but this deviation also helps to highlight the seasonality of the water budget in which hydrologic inputs in the summer months are reduced relative to other periods in the year. However, the regional stream hydrologic loading model matched closely with the corrected modified rational number. This agreement between these two independent models supports a conclusion that that the data generated through these models are robust and that the annual water budget from within

the watershed likely lies in between these two points. It again needs to be emphasized that the results generated via the corrected modified rational also accounts for the groundwater component of the water budget.

**Table 6.4 Tributary Discharge Data
As Based on Regional Discharge Sampling**

Subwatershed	Area (%of land mass)	Annual Hydraulic Loading Rate (cubic meters/ha/yr)	Annual Discharge (cubic meters/yr)	% Annual Discharge (% tributary discharge)
Clark Creek	1.93	4,373.90	1,059,502.96	1.93
First Creek	8.93	4,373.90	4,896,962.98	8.93
Second Creek	24.98	4,373.90	13,694,024.83	24.98
Sodus Bay Drainage ²	10.23	4,373.90	5,606,651.65	10.23
Sodus Creek, East	28.89	4,373.90	15,834,186.27	28.89
Sodus Creek, West	10.10	4,373.90	5,538,630.94	10.10
Third Creek	14.93	4,373.90	8,185,752.63	14.93
Total Land Mass	100.00	4,373.90	54,815,712.27	100.00

Regional discharge calculated from mean annual discharge of 9 regional streams draining to Lake Ontario with records beginning in 1941. Mean annual hydraulic loading rate - 4373.9 m³/ha/yr, maximum 6616.09 m³/ha/yr, and minimum 2792.69 m³/ha/yr.

6.3.5 The Role of Flow Exchange with Lake Ontario

A very important factor that impacts and has the potential to affect the overall water budget of Sodus Bay is the exchange that occurs between the Bay and Lake Ontario. Unlike most freshwater waterbodies that have a single unidirectional discharge, Sodus Bay both discharges to and receives inflow from Lake Ontario. This type of two-way exchange of water with Lake Ontario has the ability to alter normal circulation and water exchange patterns and rates within Sodus Bay. The basic assumption regarding this exchange is that water level fluctuations in Lake Ontario, which are affected by a variety of factors both natural and anthropogenic, can affect whether the direction of flow is into or out of Sodus Bay.

To calculate inputs to Sodus Bay from Lake Ontario a slope-area discharge calculation was used. This type of model is frequently used in engineered culverts and spillways, but was applied to Sodus Bay because of the well defined inlet to the Bay that functions much the same way as a channel or slough. While water level data for the Bay itself was not available there was reliable hourly data for Lake Ontario for all of 2005. These data were the main input source used with the model. Two basic model assumptions applied in this analysis were that 1) the water level of Lake Ontario is a basic driver affecting

water levels in Sodus Bay and 2) that the water level fluctuations of Lake Ontario are mirrored in the Bay. In addition, the Bay’s water levels were assumed to exhibit a lag of approximately 24 hours such that the Bay’s water level was the average of the Lake’s water elevation measured over the preceding 24 hours. Although the slope-area discharge model calculated both influxes to and outputs from Sodus Bay the resulting data is used to represent the calculated discharge from the mouth of the Bay to Lake Ontario for the entire year.

Table 6.5 Lake Ontario Influx Summary	
Monthly Influx from Lake Ontario	
Month	Volume (Million M³)
January	91.7
February	54.0
March	42.9
April	91.6
May	36.7
June	44.7
July	50.9
August	56.1
September	57.9
October	46.5
November	62.4
December	50.0
Total	684.5

Using the lake level data, the resulting computed inflow from Lake Ontario to Sodus Bay suggests an exchange of nearly 685 million cubic meters of water over the course of a typical year. These data suggest that water elevations of Lake Ontario have a major affect of the Bay’s hydrologic dynamics.

To verify the results of this analysis, a secondary check was used to back calculate flow velocities in the channel inlet; the velocities averaged less than 0.5 feet per second which correlates closely to velocities observed but not directly measured between the breakwaters. A preliminary flow-vector analysis, which utilized flow data as well as basin morphology, indicates that while a large amount of water is exchanged with Lake Ontario the actual effect is not as great as the volumetric data (Table 6.5) would suggest, because the water coming in from Lake Ontario exhibits laminar flow characteristics. Laminar flow means that the water coming in is relatively smooth and exists as a relatively distinct physical lens, which sits on top of the Bay water. Laminar flows do not tend to vertically mix. While it is certainly true that a large amount of water enters the Bay from Lake Ontario, particularly when lake levels are rising, much of the modeled flow most likely represents a “sloshing” effect in the channel where the water moves

back and forth pattern without much true exchange. In addition, because of the Sand Point peninsula, it is likely that this flow is largely confined to the area immediately adjacent to the mouth of the channel and does not represent a significant zone of influence within the Bay. As such, although numerically very high, the effects or interactions of Lake Ontario on the Bay's water quality are perhaps not as great as the water budget data implies. However, as discussed below, the inflow and outflow of Lake Ontario water to and from Sodus Bay does have the ability to affect its hydraulic retention times. Further study is warranted of this relationship though, including an investigation using a three-dimensional flow dynamic model that includes a component for the analysis of nutrient and biotic exchanges.

6.3.6 Hydraulic Flushing Rate and Hydraulic Retention Period

The hydraulic flushing rate and the hydraulic retention period are often regarded as some of the most critical hydrologic data in describing both the hydrologic and ecological functions of a waterbody. In particular, both are valuable for assessing nutrient dynamics in lakes and can be used to quantify nutrient retention which is a basic descriptor in predicting water quality. These numbers are also critical in summing up water budgets in an easily understood format.

Both of these calculations are easily performed. Flushing rate, which is a measure of the amount of times a waterbody flushes or volumetrically exchanges, is calculated by dividing the total volume of the annual inflow by the volume of the waterbody. Hydraulic retention period is the inverse metric that shows the retention period; essentially how long a single drop of water is expected to remain within a waterbody. This is calculated by dividing the volume of the waterbody by the total annual inputs and multiplying the result by a time, generally days in a year.

Hydraulic flushing rate and hydraulic retention period were calculated under a variety of hydrologic loading conditions in an attempt to best define the role of the various components of the Bay's hydrologic budget. The condition that appears to most accurately define the Bay's flushing and hydraulic retention attributes is that computed using the corrected modified rational data. The resulting flushing rate is 0.99 and the retention period is 368 days, meaning that Sodus Bay can be expected to volumetrically exchange approximately once per year.

These values apply to the Bay in general and reflect the expected hydrodynamic properties experienced under an average rainfall year. The computed values also assume on an annual scale the hydrologic interactions with Lake Ontario will balance out, even though at times flushing could be faster or slower depending on the Lake's elevation. In addition, spatial variation in flushing are expected to exist throughout the Bay. In shallow waters, especially those adjacent to tributary mouths there is a constant exchange of water and a fairly quick flushing rate because of tributary inputs, but this rate is likely to slow significantly during the summer when tributary contributions and runoff are significantly decreased. The deep waters and the middle portion of the Bay likely experience the lowest flushing rates and highest hydraulic retention closest to that

modeled from using the corrected modified rational method. Higher retention periods usually increase water quality impairment and allowed for greater nuisance phytoplankton and macrophyte growth due to the longer period available for plant nutrient uptake and decreased flushing of plankton blooms. As such, the littoral areas behind Leroy Island likely experience much slower flushing rates. Conversely, in the northernmost section of the bay, adjacent to the Lake Ontario inlet the flushing rate is very high and there is constant mixing with the bay. In general, the fairly high flushing rate of the open water areas of the Bay helps to mitigate water quality impairments caused by the high nutrient loading as discussed in Section 7.

Table 6.6 Hydraulic Flushing Rate and Hydraulic Retention Period Summary

Source of Inflow	Hydrologic Load - Million M³	Hydraulic Flushing Rate - Times per Year	Hydraulic Retention - Days
Corrected Modified Rational	66.8	0.99	368.41
Tributary Inflow Only Based on SUNY Measured Discharge 2004	38.9	0.58	632.77
Lake Ontario Influx ²	684.5	10.15	35.95
Sodus Bay ³	Volume Million M ³	67.4	
1 - Hydraulic Flushing (R) = Total annual Bay inflow/ total volume of Bay ; Hydraulic Retention = 365 days / R			
2 – Represents water flow into the upper part of the Bay attributable to changes in level of Lake Ontario			
3 - Sodus Bay Volume is calculated at the time of the bathymetric survey			

7.0 POLLUTANT LOAD MODELING

7.1 *Why Model, An Overview of the Pollutant Modeling Approach*

Quantifying and understanding the pollutant budget of Sodus Bay is critical to the proper design and prioritization of Bay and watershed management projects aimed at slowing the Bay's eutrophication rate. Although a number of earlier studies examined individual elements of the Bay's pollutant budget, especially with respect to phosphorus loading, none comprehensively examined the Bay's overall pollutant budget. Makarewicz, et al. (1991, 1992, 1993 and 1994) quantified the Total Kjeldahl Nitrogen (TKN) and Total Phosphorus (TP) load of the Bay's main tributaries, and Makarewicz and Lewis (1990) examined some of the limnological attributes of the tributaries with respect to the limnology of the Bay. More recently, work has been done to evaluate the role of the Bay's sediments in the internal regeneration and recycling of phosphorus (White, et al., 2002). However, little has been done to this point to compressively model and quantify the pollutant loads originating from all significant internal and external sources, and use these data to evaluate, select and prioritize pollutant load reduction measures. For example, as discussed in Section 4, at times the streams entering the Bay transport a fair amount of phosphorus and at times, due to deep water anoxia, an appreciable amount of phosphorus is pulsed into the water column from the Bay's sediments. Although this provides valuable information about the sources of nutrients to the Bay, it does not fully provide a quantitative appraisal of the relative importance of each source of nutrients, sediments or pollutants. As such, the information needed to make definitive management decisions is lacking.

The data generated through the modeling task of this project examined the Bay's phosphorus, nitrogen and sediment loads using a GIS platform. This project's modeling technique provided the ability to readily integrate land use, land cover and other watershed attributes that have a direct effect on the generation of pollutants. For the purposes of this project, the term pollutant will refer specifically to nitrogen, phosphorus, total suspended solids, lead and zinc.

As discussed in the introduction to this report, nitrogen and phosphorus are the two nutrients that are most responsible for the stimulation of algae and aquatic plant growth. As noted in the previous sections of this report, over the past decade there has been an increase in disproportionate aquatic weed growth and periodic intense algae blooms. This excessive weed and algae growth is responsible for the majority of Bay user's and resident's complaints. Total suspended solids (TSS) are a measure of particulate matter in the water (i.e. dirt or sediments). High TSS concentrations cause the Bay to appear "dirty" or "muddy". In given locations throughout the Bay, sediment deposits have led to the creation of deltas and sediment bars. These deltas and sediment bars result in the infilling of the littoral zone, which in turn has the potential to impact fish spawning and nursery areas, alter flow and circulation patterns and create habitat that further supports invasive aquatic weeds and dense stands of native plants and stalked algae.

Given that it is the pollutant load that stimulates eutrophication (i.e., nitrogen and phosphorus) and results in additional water quality impacts (i.e., turbidity, sediment

deposition and accumulation), proper quantification of the pollutant budget is critical to long term planning and the selection of management options. The pollutant budget data also serve as the foundation for the trophic state analysis, which is used to assess the applicability of both in-bay and watershed management techniques. As will be discussed later in this section of the report, the pollutant budget data provides the information needed to make objective, in-Bay and watershed management implementation decisions, support the prioritization of management recommendations and ensure that proper emphasis is given to those pollutant sources that significantly impact, impair or degrade the water quality, fishery, recreational use or aesthetics of Sodus Bay and its tributaries.

For this project, the pollutant budget of the Bay encompassed the development of loading data for each of the following sources of pollutants:

1. Overland runoff (stormwater)
2. Baseline Tributary
3. Internal Loading
4. Decomposition of Aquatic Plants
5. Septic Systems and any other potential nearby on-site wastewater system
6. Direct Precipitation

As illustrated above, the analysis included the quantification of phosphorus generated coming from both internal and external sources. This is important in that there is a significant concern regarding how internally generated and recycled phosphorus affects algae blooms and the role that this phosphorus may be playing in the growth of aquatic weeds.

7.2 Methodology

The Generalized Watershed Loading Functions (GWLF) model was used to quantify the pollutant sources entering the Bay from each of the main sub-watersheds and tributaries. The GWLF pollutant modeling approach is based on the premise that different land uses and covers contribute different quantities of pollutants through runoff. Basically, this translates to the simple premise that the more an area is disturbed or developed, the greater the amount of pollutants will be generated on a per acre (unit areal) basis. For this project, up-to-date GIS land use and land cover data were imported into the model. These data were field rectified and also confirmed through discussions with WCSWCD and WCWQCC representatives. These are the same data that were used in Section 5 to investigate the Bay's hydrologic budget. Figure 7.1 depicts the Sodus Bay watershed, sub-delineated into sub-watersheds, showing the predominant land cover and land use occurring within each subwatershed. A full scale map of the same is provided in the map pocket appendix located at the back of the report.

Figure 7.1 - Land Use and Land Cover Displayed on a Subwatershed Specific Level of Detail for the Sodus Bay Watershed.

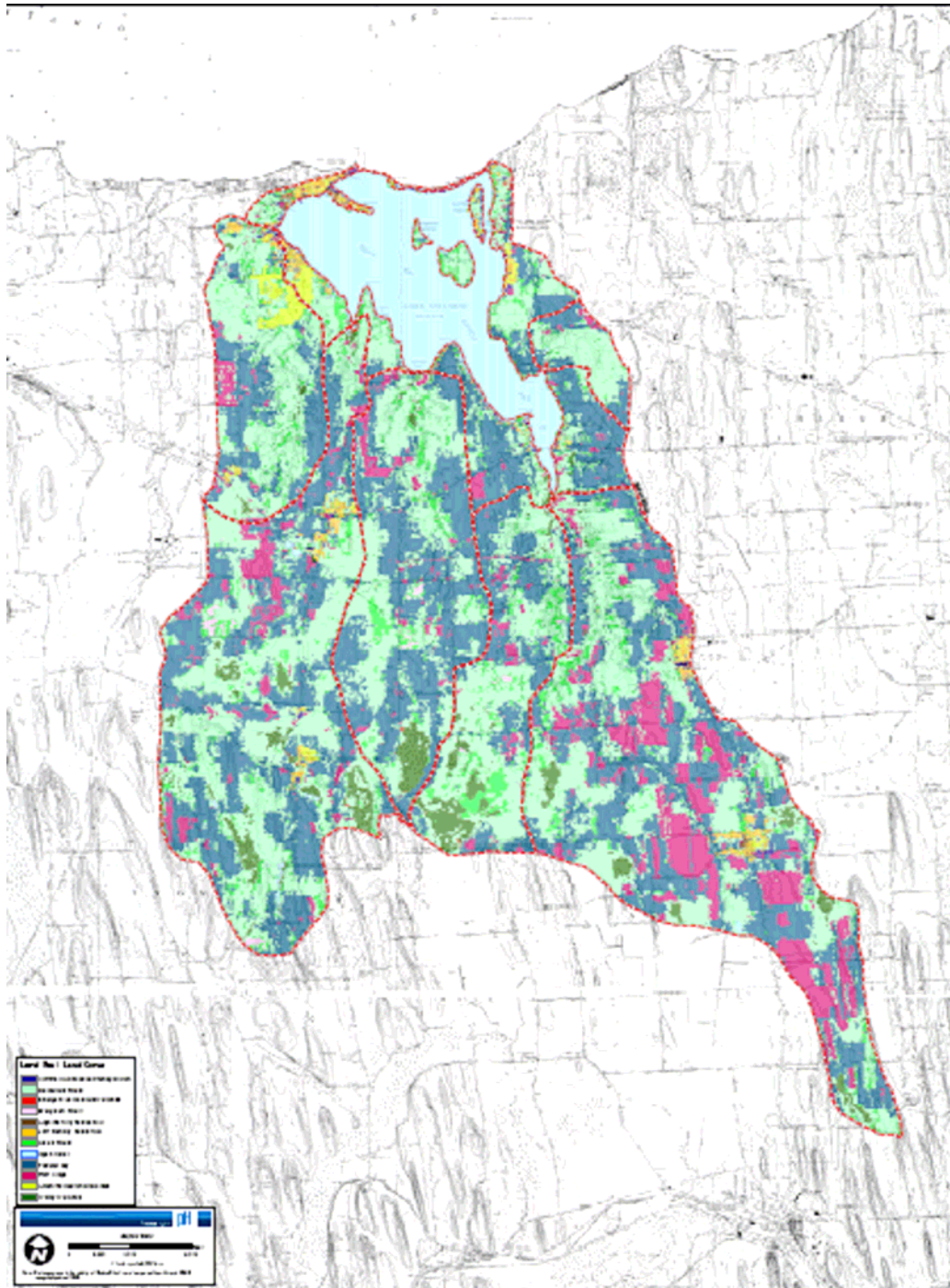


Table 7.1 – Major Land Use and Land Cover Designations and Area (Hectares) Occurring Within the Sodus Bay Watershed

Land Cover Type	Development Definition	Area (Hectares)
Developed	Low Intensity Residential	159.21
Developed	High Intensity Residential	19.82
Developed	Commercial/Industrial/Transportation	58.48
Forested Upland	Deciduous Forest	2,376.03
Forested Upland	Evergreen Forest	47.71
Forested Upland	Mixed Forest	921.32
Non-Natural Woody	Orchards/Vineyards/Other	4,771.21
Planted/Cultivated	Pasture/Hay	2,395.18
Planted/Cultivated	Row Crops	1,205.11
Planted/Cultivated	Urban/Recreational Grasses	131.98
Wetlands	Woody Wetlands	409.36
Wetlands	Emergent Herbaceous Wetlands	9.26
		12,504.67

The loading coefficients used to model the Sodus Bay pollutant loads using the GWLF model are empirical values reported by Uttormark, et al. (1974), USEPA (1980), Reckhow et al. (1980), Schueler (1996), Souza and Koppen (1984a) and information obtained through SUNY Brockport. However, none of the coefficients were used before they were closely reviewed in order to assure that the selected values were truly representative of land use conditions in the Sodus Bay watershed. This entailed a detailed reconnaissance of the watershed and the review of other related reports and data sources. Particular attention was given to prevailing land use activities, land cover attributes, soil and slope characteristics and other factors recognized as having an effect on the generation of pollutants, and thus the validity of the loading coefficients. Final selection of the coefficients was also aided by input obtained from the WCSWCD. The selected pollutant loading coefficients were then used thorough the GWLF model to compute each sub-watershed’s annual total phosphorus (TP), total nitrogen (TN), total suspended sediment (TSS), zinc and lead loading to the Bay. The resulting data were considered representative of annualized watershed generated loading attributable to both baseflow and storm flow contributions.

Additional baseflow data used in this project was derived from the field work conducted under the direction of Dr. Makarewicz during the summer of 2004 (Section 4) and reported in earlier studies of Sodus Bay (Makarewicz, et al. 1991, 1992, 1993 and 1994). A basic flow/concentration/load computation was used to estimate monthly nutrient loading occurring during baseflow conditions between May and September 2004. These

data provide in themselves an estimate of baseflow pollutant contributions that were also used to help cross-check and validate the GWLF modeled data.

As noted above, there is particular concern that a significant amount of phosphorus is internally recycled within Sodus Bay and that this phosphorus, in turn causes summer algae blooms and promotes weed growth. It is well documented in the literature that large amounts of phosphorus may be liberated from lake-bottom sediments when the proper conditions exist (Cooke, 1993, Nurnberg, 1984, Lubnow and Souza, 1999, and Souza and Koppen, 1984b). Although this phosphorus release can occur from both littoral (shallow water) and profundal (deep water) sediments, the rate of phosphorus liberation is significantly greater under anoxic (no dissolved oxygen) versus oxic conditions. As such, in the case of deep lakes, existing depositional sediments can be a major source of phosphorus loading. For Sodus Bay, the deep water areas are defined as those underlying waters at least 15' deep. The Bay's internal phosphorus load was therefore computed as part of this project. This was accomplished for Sodus Bay using a combination of modeling techniques (Nurnberg, 1984; Souza and Koppen, 1984b) and the measurement of temperature/dissolved oxygen profiles and deep water phosphorus concentrations.

Another potential source of internal loading is the decomposition of aquatic macrophytes (weeds). Given the nuisance densities that aquatic weeds attain in Sodus Bay, it was recognized this could be a significant source of nutrients, especially organic phosphorus, a form of phosphorus readily utilized by the summer bloom forming blue-green algae. For this project, the nutrient load attributable to the decomposition of aquatic weeds was computed using loading coefficients obtained from the scientific literature. However, data and information pertaining to the composition, density and distribution of aquatic weeds throughout Sodus Bay is based on a combination of recently (2006) collected field data, historical weed distribution data, and weed harvesting data. These sources of field data added to the accuracy of the model-quantified nutrient loads.

A fourth source of nutrient loading to the Bay that needed to be addressed was that originating from septic systems. Although most of Sodus Bay's immediate shoreline is sewerred, the Huron segment relies on individual on-lot wastewater treatment systems (septic systems). In addition, some of the more distal areas of the watershed continue to rely on septic systems. The USEPA reports that any septic system located within 300 feet of the lake or a tributary to the lake, has the ability to contribute nutrients. Again, for this study, the nitrogen and phosphorus related septic loads were computed using loading coefficients obtained from the scientific literature. Although this technique can not identify the occurrence or location of failing systems, it can be used to yield reasonably accurate estimates of the average, annual septic-related pollutant loading to Sodus Bay.

Rain and snowfall strip fine particulate pollutants from the atmosphere. Adsorbed to these fine particulates are nutrients. While the pollutant load attributable to precipitation falling directly on a lake is usually only a minor source of pollutant loading, for large waterbodies such as Sodus Bay, it can be an important and often overlooked portion of

the pollutant budget. As such, literature values for the wet fall / dryfall nutrient components of precipitation were used to compute the nutrient load contributed via precipitation. Sources for these, as well as some of the other, loading coefficients will include Schueler, 1992, Uttormark, et al. (1974), USEPA (1980) and Owe, et al. (1982).

A final step in the pollutant loading analysis was to compare loading data arrived at through the use of SUNY Brockport generated stream flow and pollutant concentrations (Task 3) with the combined results of the AGWLF computed loads. Specifically, a mass balance type of approach was used, whereby the pollutant concentrations measured during the 2004 monitoring program were multiplied by the respective hydrologic loads (Task 5). The resulting pollutant loads were then compared to the modeled loads. This provided us with a means of evaluating to some degree the validity of the modeled data.

7.3 Results and Findings

Although the loads were computed for phosphorus, nitrogen, sediment and metals, particular attention was given to the Bay's phosphorus load. Given its role as a limiting nutrient, the amount of phosphorus available at any one time for biological uptake and assimilation will greatly determine the Bay's overall productivity of the weed and algae growth that occurs in the summer. As such, with each component of Sodus Bay's pollutant budget quantified as outlined above, the pollutant budget of Sodus Bay could be evaluated both in its entirety and on the basis of each contributing portion's relative importance. For Sodus Bay, special attention was given to the relative role of the external and internal phosphorus loading. As noted above, the external phosphorus load represents the amount of phosphorus derived from watershed sources. For Sodus Bay, most of the externally originating phosphorus makes its way into the Bay as a result of stormwater runoff and tributary flow. In contrast, phosphorus regenerated liberated from deep-water, anoxic sediments and the phosphorus released from decomposing aquatic weeds and algae are the Bay's two main internal loading sources.

Synthesis of the annual pollutant budget for Sodus Bay revealed the key sources of loading to Sodus Bay. The data (Table 7.2) not only helps to establish the relative magnitude and importance of these various sources, but provides the qualitative basis for the prioritization of various pollutant management and remediation objectives. Again emphasis is given to the influx of phosphorus to the Bay, given the role of this nutrient in the stimulation of algae blooms and weed growth. As detailed in Table 7.2, the cumulative modeled annual total phosphorus load for Sodus Bay is 12,966 kg. As illustrated in Figure 7.2 and detailed in Table 7.3, approximately 55% of this load (7,112 kg/yr) is associated with external sources (tributary, direct runoff, atmospheric and septic system inputs). The remainder (5,854 kg/yr) comes from internal sources (Figure 7.2). These include the release of phosphorus from the sediments under oxic and anoxic conditions and the phosphorus released from decaying aquatic plants.

Table 7.2 - Summary of Annual Pollutant Load Budget

Source of Loading	Computed Annual Load (Kg/yr)		
	TP	TN	TSS
Subwatershed - Direct Drainage*	678	8,642	1,032,030
Subwatershed - Tributary Drainage	5,707	77,285	9,247,003
Atmospheric Directly on Bay	559	9,960	8,893
Shoreline Septic	168	2,802	0
Oxic Sediment Load	2,554	0	0
Anoxic Sediment Load	394	0	0
Plant Senescence	2,906	13,871	0
Annual Total	12,966	112,560	10,287,926

* Direct overland runoff into the Bay, non-tributary inflow

Figure 7.2 Percent of Total Phosphorus Loading By Source

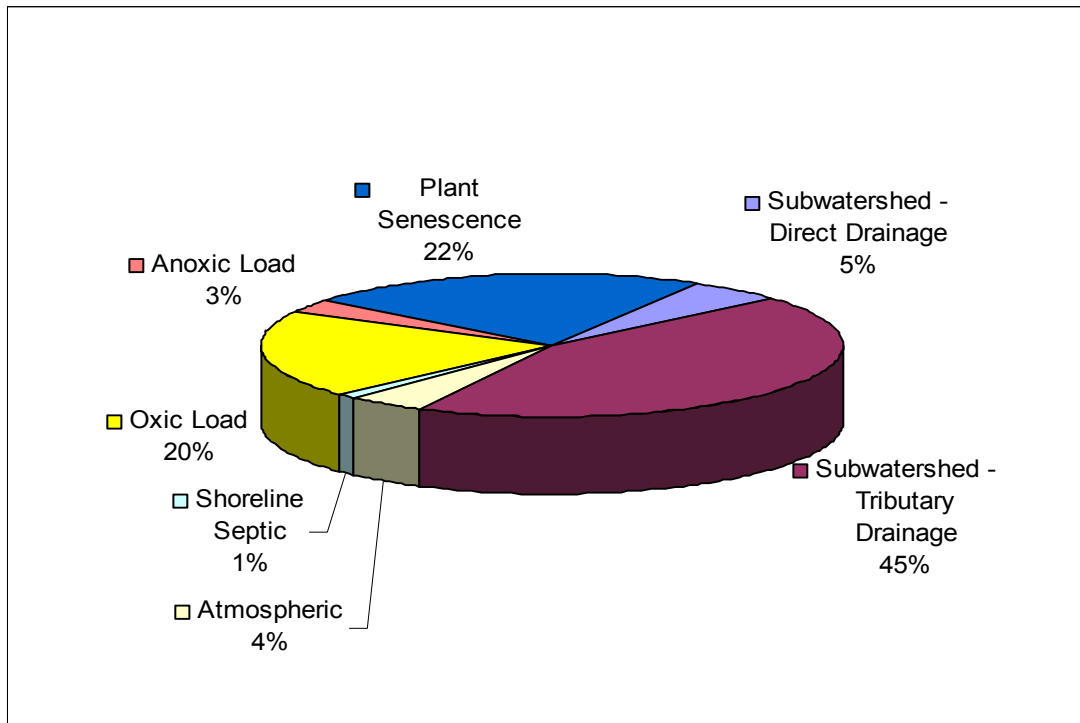


Table 7.3 Relative Percentage of Pollutant Loading to Sodus Bay by Source

Source of Loading	Percent of Annual Load By Source		
	TP (%)	TN (%)	TSS (%)
External Sources			
Subwatershed - Direct Drainage	5.23	7.68	10.03
Subwatershed - Tributary Drainage	44.02	68.66	89.88
Atmospheric	4.31	8.85	0.09
Shoreline Septic	1.30	2.49	0.00
Internal Sources			
Oxic Sediment Load	19.69	0.00	0.00
Anoxic Sediment Load	3.04	0.00	0.00
Plant Senescence	22.41	12.32	0.00
Total	100.00	100.00	100.00

As illustrated in the above Table 7.3 and Figure 7.2, the Bay’s internal phosphorus load resulting from sediment recycling is significant, accounting for approximately 23% of the annual total TP load. However, upon closer examination of the data it is apparent that only a small percentage the annual total TP load attributable to sediment recycling occurs under anoxic conditions. In Sodus Bay, phosphorus liberation from the sediments during oxic conditions comprises 93.3% of the total internal sediment loading, accounting for 2,553.5 kg/yr of phosphorus. The loading rate from oxic sediments is significantly slower than that from anoxic sediments (10% the rate of anoxic loading). Even if TP loading is seasonalized, and broken down to account for spring versus summer TP loading, the significance of the anoxic sediment load relative to the Bay’s overall summer TP load is minor. Thus even though much of the phosphorus recycled from sediments, once liberated into the water column, could be assimilated again by plants and algae, the impact that this has on the overall eutrophication of Sodus Bay is not as great as earlier speculated.

Sodus Bay’s water column can be divided into three distinct layers. The epilimnion is the upper most layer, where sunlight easily penetrates. The metalimnion is the middle layer where light penetration is reduced to less than 10%, less than that needed for photosynthesis. The metalimnion is also often the thermal breakpoint thermocline) between warm and cool water habitat. The hypolimnion is the deepest part of the water column. It is generally always cool and dark. This is the portion of the water column that periodically becomes devoid of dissolved oxygen (anoxic).

Because of its polymictic (mixes frequently) nature, the Bay is never thermally stratified for a significant period of time. For this reason, a strongly anoxic hypolimnion (deep water) never develops in Sodus Bay. However there are punctuated periods between June and September when the Bay will stratify enough to form an anoxic layer below 10 meters. Since only 8% of the Bay is at 10 meters depth or greater, and

since the periods of anoxia are relatively short, anoxic TP release plays a relatively small role in the Bay's internal TP load. Specifically, anoxic sediments contribute only 393.9 kg/yr or 6.7% of the total internal sediment load. Even so, this load cannot be overlooked. However, the mixing regime of the Bay and the nutrient release from anoxic sediments occur during the peak of the growing season. This results in phosphorus being introduced into the water column at just the time algae and plants need it the most for explosive growth. During the course of the summer the Bay's deeper waters alternate between a stratified and unstratified condition. This allows for phosphorus release, and its subsequent mixing from the deep waters to the surface waters. The intermittent "pulsing" of phosphorus into the water column increases the availability of this nutrient by plants and algae throughout the summer growing season. Although efforts to control the release of phosphorus originating from anoxic sediments need not be prioritized, little consideration needs to be given to open water, water column alum treatments or the installation and operation of hypolimnetic aerators. Nonetheless, this source of phosphorus is affecting the productivity of the Bay, but at a scale much less than originally speculated.

Similarly, the loading associated with the decay of aquatic plants needs to be evaluated in context of the seasonality of this loading. First, not all of this phosphorus enters the Sodus Bay system at once. Although much of the plants die-off in the fall, there is a fraction, either due to the life-history of specific plants or their damage over the course of the growing season, some of this phosphorus is entering the system from May through late fall. However, even if the bulk of this phosphorus enters the Bay at once, it occurs later in the growing season. Some of this phosphorus will become complexed with iron compounds and settle out of the water column, while some will remain in the water column until the following spring in a dissolved, easily assimilated form and be used in the late winter/early spring by such plants as the invasive species Curly-leaf pondweed (*Potamogeton crispus*). As such, its relevancy for stimulating plant and algae growth is actually greater for the following spring, especially if these nutrients are not flushed from the Bay. The magnitude of the plant related phosphorus load also emphasizes the importance of the WCSWC's weed harvesting program. Removal of plant biomass from the Bay not only promotes better access and recreational use, but also decreases the magnitude of this important phosphorus source. Macrophyte abundance has increased 33% since the last survey conducted by Dr. Gilman in 1988 (Princeton Hydro, 2006). Increased abundances of macrophytes, especially invasive species, must be addressed in Sodus Bay. This could be accomplished through alum treatment of the Bay's anoxic sediments and measures that reduce the Bay's plant biomass. The significance of the latter is that the less plants that senesce in the fall, the less phosphorus available for plant uptake in the spring.

As noted above, the phosphorus influx to the Bay from the tributaries or as runoff from the Bay's direct drainage areas accounts for approximately 50% of the Bay's annual total load. Contrary to what was earlier speculated, this external load is especially important in terms of defining the Bay's overall trophic state and rate of eutrophication. As such, long-term management efforts must focus on the continued control and reduction of

external, watershed based sources of phosphorus loading to the Bay.

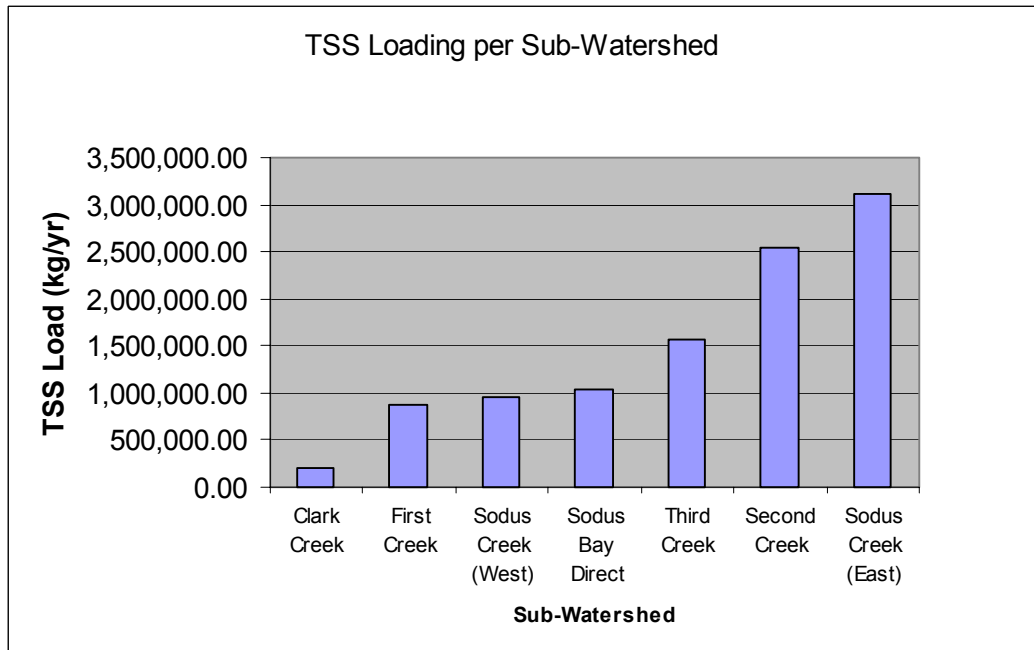
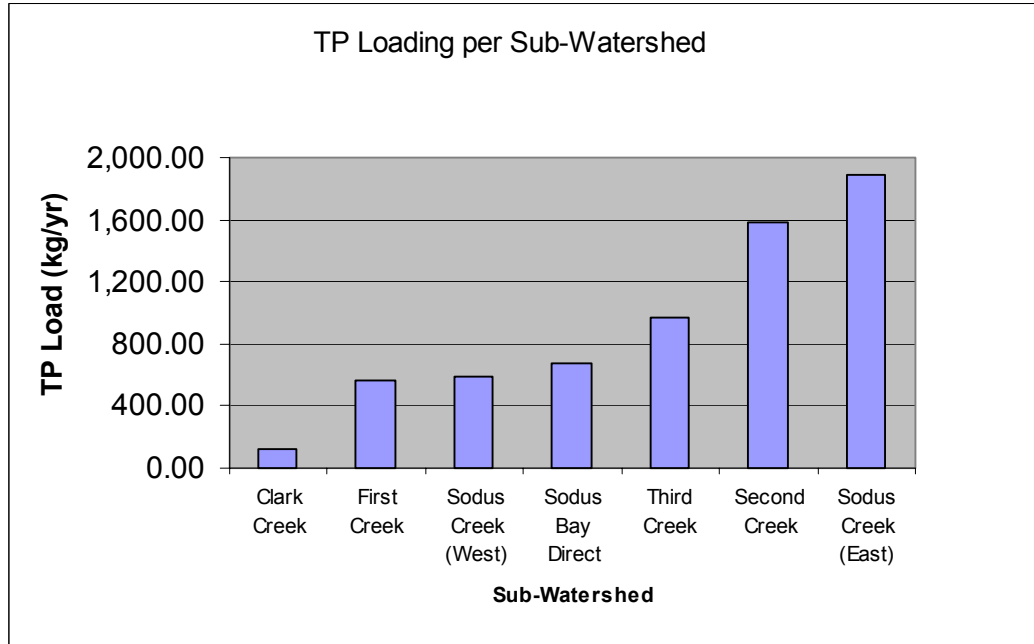
In addition, it appears based on the TSS loading data, more so than the TSS water quality data, that a majority of the nutrients entering the Bay with stormwater runoff is in a particulate form absorbed, adsorbed or attached to sediment particles. Although particulate phosphorus is a less accessible and less easily assimilated form of phosphorus than is dissolved or soluble reactive phosphorus, it is nonetheless very important in stimulating productivity throughout the Bay. For example, as sediments and associated particulate phosphorus settle to the bottom of the Bay or at the mouth of the tributaries, this particulate phosphorus eventually becomes reduced via bacterial activity. Once released into the water column in a dissolved form, the phosphorus becomes available for subsequent uptake by phytoplankton, weeds and certain forms of benthic algae. So although not as immediately important as is the phosphorus liberated from anoxic sediments, the Bay’s particulate phosphorus load is an important source of nutrients for weeds. As will be subsequently discussed, there is therefore merit in taking management actions which sequester and contain this source of phosphorus, and limit its subsequent release into the water column or its uptake by the roots and rhizomes of aquatic plants.

For the perspective of prioritizing management efforts it is valuable to examine the per unit area load (Table 7.4). When examining the specific pollutant loads generated by each subwatershed, it is obvious that the larger the sub-watershed, the greater the total annual load (Figure 7.4). This essentially decreases the computational and scoring bias that arises simply due to the size of the subwatershed. When this “correction” is made, data show the Sodus Bay Direct watershed has the greatest per unit area nutrient load followed by Sodus Creek (East) and then Third Creek. This means that on a per acre basis, these three subwatersheds contribute the greatest amount of pollutants to the Bay. As such, these subwatersheds should command the greatest management attention.

Table 7.4 Subwatershed Rank Based on Unit Areal Phosphorus Loading				
Subwatershed	Area (Ha)	TP Load (kg/Yr)	Unit Area Load	Rank
Clark Creek	242	126	0.52	2
First Creek	1,120	559	0.50	6
Second Creek	3,131	1,583	0.51	5
Sodus East	3,620	1,884	0.52	2
Sodus West	1,266	586	0.46	7
Sodus Direct	1,281	678	0.53	1
Third Creek	1,872	970	0.52	2



Figure 7.4 – TP and TSS Loading By Subwatershed



The reasons why these subwatersheds generate so much of the pollutant load is evident upon closer examination of the predominant land use and land cover. In the case of Sodus Bay Direct, the magnitude of the pollutant loading is a direct function of large amount of impervious cover and residential development that characterizes this subwatershed. The relatively higher amount of impervious cover characteristic of the lands directly bordering the Bay leads to the generation of more runoff. The larger volume of runoff results in the greater mobilization and transport of pollutants into Sodus Bay. In addition, developed land tends to generate more pollutants than undeveloped, and in some cases, even farmed land. This is because particulate materials build up on paved surfaces between storm events. The accumulated particulates are then washed off or “flushed” from the paved areas during a storm event. The Sodus Bay Direct subwatershed areas encompass a large amount of residential and commercial land usage. Typically, pollutant loading of this nature can be easily managed by installing best management practices and other storm sewer retrofits. However, because little of the Sodus Bay Direct sub-watershed relies on storm sewers to collect and direct stormwater runoff into the Bay, management of this source of phosphorus loading cannot be accomplished through the installation of conventional stormwater management devices.



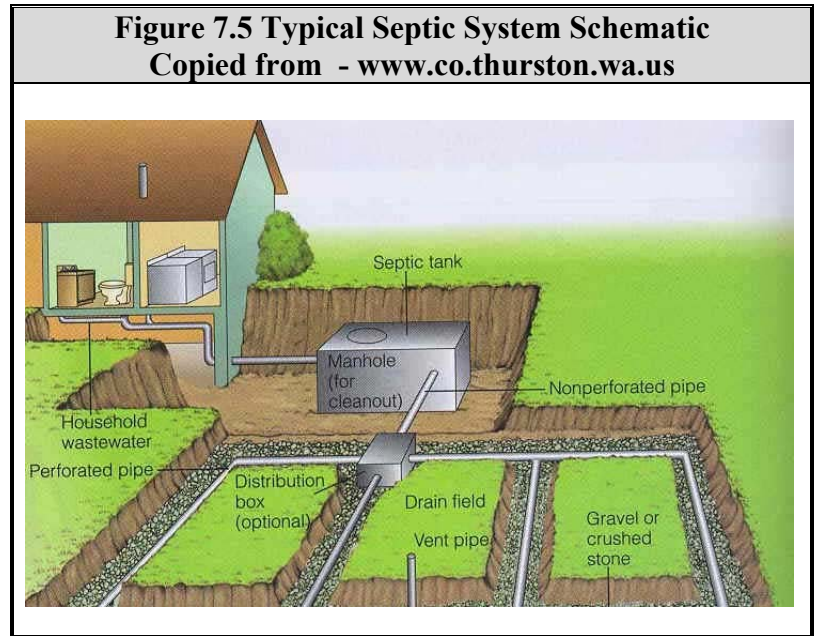
The other two subwatersheds that generate a disproportionate amount of the pollutant load to the Bay are Sodus Creek (East) and Third Creek. In contrast to Sodus Bay Direct, these two subwatersheds do not encompass a large amount of impervious cover or residential development. Together these two subwatersheds contribute 54% of the externally derived annual phosphorus load, but only encompass 44% of Sodus Bay’s entire watershed area. Land use in these two subwatersheds is dominated by orchards and pasture/hay fields. Contribution of TP through Sodus Creek (East) and Third Creek watershed appears to be largely due to erosion and associated sediment transport as these subwatersheds respectively rank 1st and 2nd in TSS loading into Sodus Bay (Figure 7.4).

This is an important characteristic in the nutrient loading model as phosphorus is commonly bound to soil particles and therefore readily mobilized by erosion. The best way to control this source of phosphorus, sediment and nitrogen loading to the Bay is through measures that rectify soil erosion and stream bank failures. Therefore, the continuation of the programs implemented by WCSWCD that aim to control erosion and sedimentation of Wayne County’s waterbodies are imperative. Services offered by WCSWCD such as stream bank



stabilization/erosion control, the agricultural group drainage program, and installation of animal crossings on streams that flow through farmland are crucial to reduction of sediments and associated phosphorus while preserving precious, nutrient rich topsoil.

Shoreline septic systems account for only 1.3% of the total TP loading to Sodus Bay. Despite the relatively low loads compared to other sources, septic wastewater discharges are still an important component of the load and an important area for monitoring and mitigation. Although of low magnitude in terms of nutrient contributions, the maintenance and upkeep of septic systems should be emphasized not only as a matter of public health, but as a matter of controlling a potential pollutant source to the Bay.



Sodus Bay is characterized as having a large shoreline development index with all residences but those located on Sodus Point being unsewered. Even with properly functioning sewer systems, if the groundwater is shallow or the slopes steep, the effluent released in the treatment field can leach nutrient rich water into the Bay. In some situations, the septic related nutrient load can be great enough to stimulate near shore algal blooms and dense weed stands. These shallow, near shore areas are the same areas most heavily utilized by bay shore residents. Thus, although on a large scale septic related nutrient contributions may seem minimal, on a localized scale they can be important and therefore warrant control. Therefore efforts to properly manage septic systems remain important. This will be discussed in greater detail in Section 8 of this report, but encompasses such activities as routine inspection and pump out, as promoted in the Wayne County, WQCC model septic management ordinance.

Another external source of phosphorus and nitrogen loading that was investigated was the loading attributable to pleasure boats. The resulting loads are not included in this report owing to difficulties in developing estimates that appeared accurate. This is largely due to the transient nature of large boat (greater than 25') usage of the Bay. As per the Great Sodus Bay Harbor Management Plan (2006), there are 17 major marinas servicing Sodus Bay. These marinas provide 1,381 boat slips, of which 173 are labeled as transient. Of these, the following six (6) have a marine sanitation device pump-out system.

- Amey's Marina
- Fowler's Marine Sales and Service
- Krenzer Marine

- Oak Park Marine
- Pier Pointe West and East
- Katlynn Marine Inc.

The WCSWCD also maintains a portable marine sanitation device pump-out system. The illicit discharge of sanitary waste and gray water from large boats is recognized to be a potential contributor of nutrients and bacteria in in-land waterbodies. As documented by the USEPA (1985), marinas can themselves, due to the servicing and maintenance of boats and water craft, also have the potential to contribute to water quality problems. Sediments, nutrients, petroleum hydrocarbons and heavy metals are pollutants associated with marina operations. Some of these pollutants are generated due to ancillary activities (such as vehicle parking), whereas others are directly attributable to marina operations (such as refueling). The boats themselves which utilize these marinas can also create environmental impacts due to prop wash (turbidity, nutrient resuspension from sediments), spills or illegal discharge of sanitary wastes.

An attempt was made to model the pollutant load attributable to illegal boat discharges and marina operations utilizing the method contained in the USEPA Coastal Marina Assessment Handbook (1985). The Harbor Management Plan reports that there are 904 resident boats greater than 25' registered on Sodus Bay. However, it was unclear how many transient boats of this size frequent the Bay and how long these transient boats remain in the Bay. In addition, it is well known that during the summer large contingents of boats anchor at a number of locations throughout the Bay. Reportedly on any summer weekend well over 100 boats commonly anchor near Sand Point and Charles Point, behind Newark Island and east of Thornton Point are other popular anchoring locations. The boats anchored in these areas often remain overnight thereby setting the stage for concern regarding illicit sanitary and gray water discharges.

Because the coefficients utilized to compute boat related pollutant loading is time dependent and a function of boat size, insufficient information was available to allow for the accurate assessment of marine related nutrient and bacteria loading. As such, this is a particular area of study that the WCSWCD and the WCWQCC could focus more attention on in later projects. In Hempstead Harbor, NY, as based on a resident fleet of 800 25' or larger boats, the projected coliform bacteria loading to that waterbody was estimated to be in the range of 500 colonies/100 ml, and annual heavy metal and petroleum hydrocarbon loading in the range of 122 kg/yr and 12,720 kg/yr, respectively (Princeton Hydro, 1998). The bacteria loading estimates provided in Hempstead Harbor study purposely did not account for the reductions attributable to the use of marine sanitation device pump out systems. As the resident large boat fleet of Hempstead Harbor is similar to that of Sodus Bay, it is obvious that promotion of the use of marine sanitation device pump out systems is important. This



will be discussed further in Section 8.

7.4 Trophic State Index

The trophic state of Sodus Bay is a metric of its overall productivity. It essentially represents how “fertile” or “green” the Bay may be as based largely on its annual nutrient load, evaluated in concert with its hydrology and morphometry. The utility of establishing a trophic state value is that it provides a definitive ecological point of reference for the Bay. Computation of this value following a standardized modeling technique also provides a means of effectively comparing Sodus Bay to other waterbodies or to an established standard. In essence this provides us with a means of stating “where are we?” and “where do we need to be” in terms of the control of the Bay’s eutrophication.

There are a variety of models and equations that can be used to evaluate trophic state. One of the more commonly used techniques is the Carlson Trophic State Index (TSI) developed by Dr. Robert Carlson of Kent State University (Carlson, 1977). TSI can be computed on the basis of Secchi disk depth, Chlorophyll *a* concentration or total phosphorus concentration. For Sodus Bay, emphasis was placed on total phosphorus in the computation of TSI. It was determined that TP concentrations provided a far better assessment than Secchi depth or Chlorophyll *a* due the Bay’s typically good clarity and the manifestation of productivity in the form of weed growth more so than algae growth. The following graphs (figure 7.6-7.10) show the changes in TSI over the 2004 growing season, as computed on the basis of the SUNY-Brockport TP data. The analysis was limited to Stations 5 and 9, the two deep water stations. Doing so enabled us to examine the impact of internal TP release from the Bay’s hypolimnion. Table 7.5 provides a standardized interpretation of TSI values as adapted from the USEPA and North American Lake Management Society publications.

Table 7.5 Interpretation of TSI Values		
TSI	TP mg/L	Condition of Waterbody
<30	<.06	Oligotrophic, low productivity, DO in hypolimnion year-round, supports trout fishery, clarity always > 8 m
30-40	.06-.012	Borderline oligotrophic, DO rarely depleted in hypolimnion, trout may be stressed in summer, clarity 4-8 m
40-50	.012-.024	Mesotrophic, moderate clarity (2-4 m), hypolimnion frequently anoxic, difficult to sustain carryover trout fishery
50-60	.024-.048	Moderately eutrophic, anoxic hypolimnion, macrophyte problems possible, Warm-water fisheries only. Bass may dominate.
60-70	.048-.096	Eutrophic, blue-green algae dominate, algal scums and macrophyte problems, impacted recreational use
70-80	.096-.192	Highly eutrophic, light limited productivity, dense algae and macrophytes, rough fish dominate

Figure 7.6 is based on data collected at Station 5, the Bay's deepest sampling station. At this station, at depths greater than 8 meters between June and September, anoxia is expected (Section 4), although the duration and extent of anoxia is highly variable. The blue line in both graphs represents TP levels with and without the inclusion of the hypolimnetically released TP. The pink line represents TP levels when the macrophyte related load is factored into the analysis.

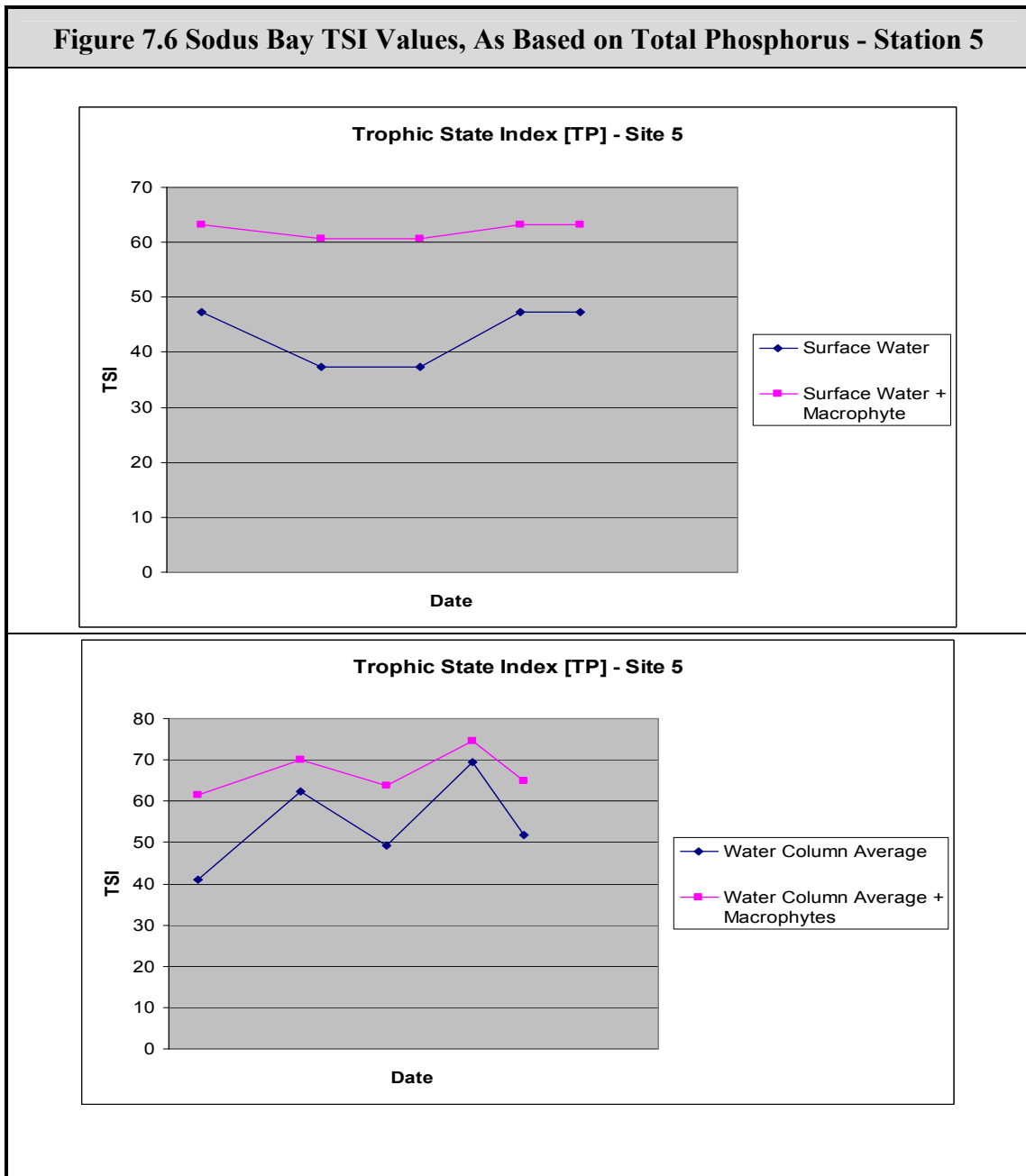
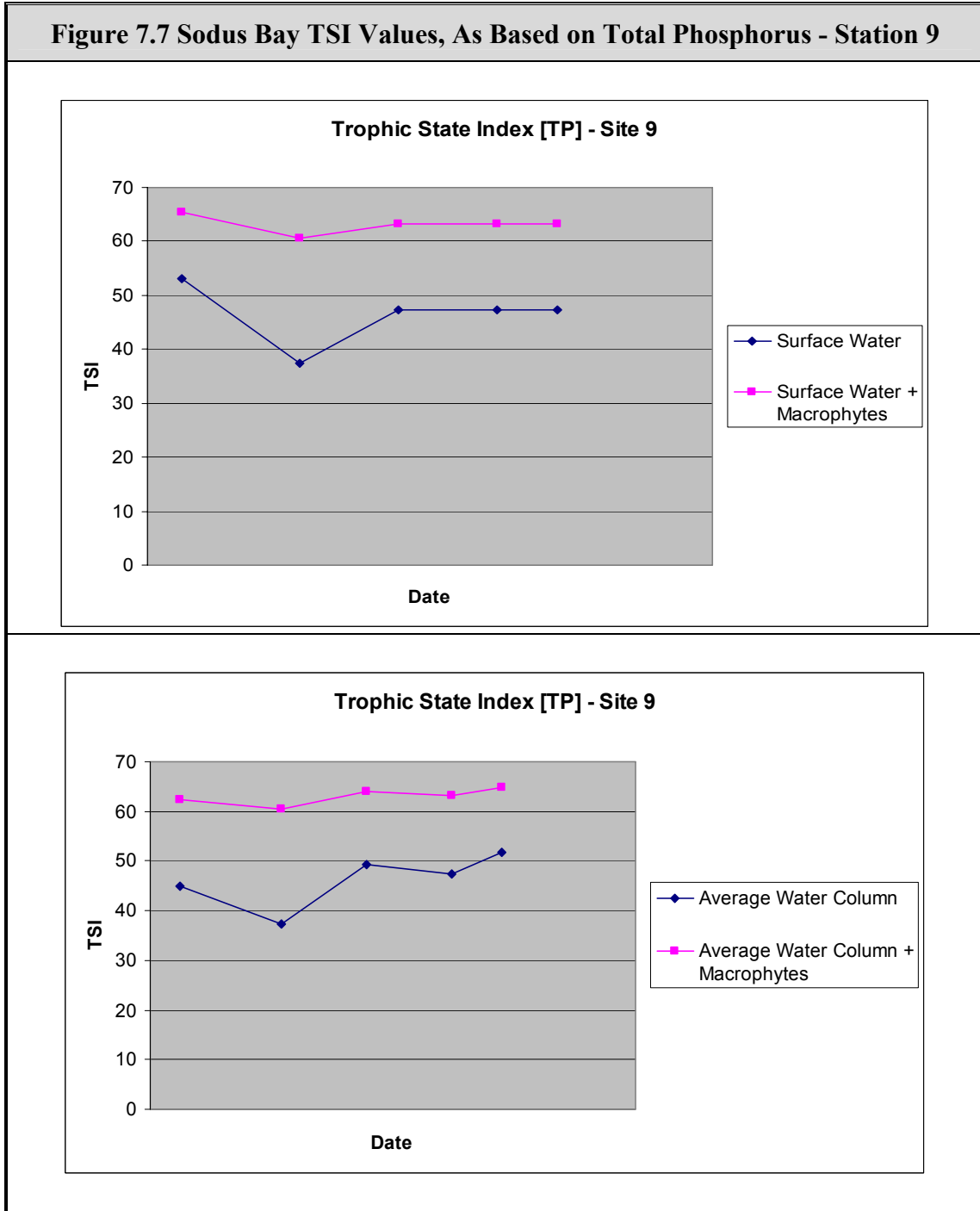


Figure 7.7 presents similar data computed on the basis of the Station 9 data; the other deep water, open-Bay sampling station.



The Station 5 and 9 data differ primarily due to the limited amount of deep water TP release experienced at Station 9, due largely to its slightly shallower depth. Overall, the

data summarized in Figures 7.6 and 7.7, when assessed relative to the information contained in Table 7.5 shows that the Bay, when evaluated on the basis of TP measured at the surface in the open water areas of Sodus Bay has TSI values typically ranging between 40 and 50. Based on this level of analysis Sodus Bay is classified as a mesotrophic waterbody. However, when the TP loading from anoxic sediments and macrophytes are accounted for, the TSI values increase, ranging typically between 60 and 70. This puts Sodus Bay into eutrophic range.

Again referring to the standardized trophic state attributes contained in Table 7.5, it is obvious that the TSI values offer a fairly accurate assessment of the Bay's existing trophic state and overall condition. If one evaluates the Bay only on the conditions observed in the open water areas, Sodus Bay shows all the characteristics of a mesotrophic waterbody. However, when one takes into account the TP originating from additional internal sources, and focuses the trophic evaluation of the shallower, littoral reaches of the Bay, the observed conditions coincide with those associated with a eutrophic waterbody. Overall, what the TSI data demonstrate is that the Bay is approaching a tipping point. Open, deep water areas still have the characteristics of a mesotrophic, moderately productive waterbody. However, the shallower, less flushed areas of the Bay have all the characteristics of a eutrophic waterbody. The TSI data also point out the importance of controlling TP loading to the Bay and the role that the macrophytes play not only in directly impacting recreational use, but in defining the Bay's trophic state.

8.0 RECOMMENDED MANAGEMENT PRACTICES FOR SODUS BAY AND ITS WATERSHED

8.1 The Framework of The Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan

It is widely recognized that the most significant problems affecting the ecology, water quality status and use of Sodus Bay are the density of weed and mat algae growth occurring in the Bay's littoral zone. Section 3 of this report provide details of the data compiled not only as part of this project, but by the WCSWCD weed harvesting operation, observations and measurements made by the WCWQCC and studies conducted by other researchers including those conducted by SUNY Brockport and FLCC. Each of these sources of information definitively show that the Bay's weed problem is becoming increasingly worse, and that a greater level of management is needed if the resulting, use, aesthetic, ecological and water quality problems are to be abated. Section 3 closes with a listing of management and maintenance action items recommended for the Bay as based on the aforementioned data and input from the Bay's users and the residents of the Sodus Bay watershed.

It is fully recognized that the management and control of invasive aquatic weeds and nuisance algae blooms are not the only things needed for the long-term management of Sodus Bay. Weed and algae growth are largely a symptom of eutrophication. Thus eutrophication, is to be slowed and the weed and algae problems impacting the Bay reduced over time, the sources of the Bays' eutrophication needs to be addressed and decreased. Simply put, the eutrophication of Sodus Bay is the function of too much nutrient and sediment loading. However, as discussed in Section 1, and reinforced throughout this report, nutrient, sediment and pollutant loading to Sodus Bay does not occur as a result of one or two easily identified sources, but is ubiquitous and includes both internal and external sources. Not only does this complicate attempts to establish the origin of pollutants, but increases the difficulty of prioritizing the management of each potential source. Since the ultimate goal of any management effort implemented as part of short and long-term objectives of the Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan is to curb the Bay's future eutrophication, emphasis of pollutant control is imperative.

The significance of the environmental impacts of nutrient and sediment loading on the eutrophication of waterbodies in general was clearly demonstrated by the National Urban Runoff Program (NURP) studies of the mid-1970's. Based on actual field sampling of numerous storm events throughout the country under different land use settings, the NURP studies documented that the concentrations of contaminants, (including nutrients and sediments) in stormwater runoff often exceeded established public health and/or environmental protection standards. Furthermore, the NURP findings also showed that as watershed development increased, so did runoff-related pollution and the severity of the resulting water quality impacts. This in part explains some of the problems currently affecting Sodus Bay.

Examination of Sodus Bay's existing and historical water quality data (Sections 4 and 7)

revealed a relationship between water quality impacts and the increased urbanization of the watershed. The following exemplify some of the water quality problems that can be largely attributed to external sources of nutrient and sediment loading:

- Dense weed growth and algal blooms due to excessive nutrient loading.
- Degraded riparian habitat caused by sedimentation.
- Periodically depressed hypolimnetic dissolved oxygen concentrations.
- Impaired recreational utilization.

Nutrient loading and trophic state modeling data (Section 7) increase the ability to objectively analyze the inter-relationship of pollutant contributions and water quality degradation. The data generated by the models concluded that the Bay's majority of phosphorus loading is from external sources, and the subwatersheds that are more greatly developed are responsible for the majority of the loading the Bay. Although nutrients and other pollutants originate from other external and internal sources the loadings from these sources are far less than those associated with tributary inflow and runoff from residential lands.

Although some of the data need to be further refined, the results of the nutrient modeling effort proved extremely useful in identifying, quantifying and prioritizing the Bay's nutrient sources (Section 7). These data serve as the foundation for management recommendations associated with the control or reduction of sediment and phosphorus loading Sodus Bay. Knowing what has caused and continues to contribute to the degradation of the Bay's water quality is extremely important, but is only part of what is required to prepare a resource preservation and watershed enhancement plan for Sodus Bay. Understanding what to do about correcting existing water quality, recreational use and aesthetic impairments is another key part of the plan. For this, it is necessary to identify those measures and actions best suited to reduce the impacts attributable to invasive aquatic weed growth and nuisance algae blooms (Section 3).

In this final section of The Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan, recommendations for the long-term management of the Bay and its watershed are presented. While the plan is intended to correct existing nutrient and sediment loading problems and protect the Bay from future impacts, its focus is on suggested projects that restore the natural resources of the Bay, provide increased relief from algae and weed problems, and enhance and improve Sodus Bay's recreational potential. Although most of the recommendations are objectively based on the findings of past water quality and aquatic weed studies and the results of the modeling effort, some are based on a more subjective assessment of the community's perceptions and needs for weed and algae control. Our recommendations are divided into three distinct but inter-related components:

- Policy Environment
- Watershed Programs, and
- Weed and Algae Control (presented in Section 3)

It should be noted that the WCSWCD and the WCQCC have already put into effect a number of programs and policies and have been working diligently with the community to stem the influx of nutrients and sediments into the Bay. Examples of the WCSWCD projects already in place that have had great success are:

- Erosion Control and Stream Stabilization Projects
- Agricultural Runoff Management Projects
- Forever Green Tree Seedling Program
- Shoreline Stabilization,
- Municipal Salt Storage Facilities,
- Constructed Wetlands for treating wastewater,
- Whole Farm Planning
- Septic Management
- Preparation of Model Septic and Stormwater Management Ordinances

Example Stream Restoration and Repair Projects Conducted By the WCSWCD



Similarly, the WCWQCC has implemented a number of successful initiatives all of which are intended to slow the influx of nutrients and sediments into Sodus Bay from the surrounding watershed. These include:

- An agricultural stream bank buffer initiatives,
- Stabilization of eroded stream banks,
- Publication of the Wayne County Watershed Management book (a comprehensive 87-page document),
- Support of the Town of Rose wellhead protection project,
- Acquisition of grant money used to sponsor and coordinate agricultural pesticide amnesty program, which promoted the correct disposal of un-used pesticides.

These are but a few examples of the work conducted by both groups. At the same time both groups have worked closely with the community and the various resident associations (e.g., Save Our Sodus) to stimulate dialog, educate and promote local planning and government initiatives to decrease pollutant loading to Sodus Bay. In turn

the resident lake association groups, as exemplified by Save Our Sodus, have been involved in a wide variety of efforts to protect and enhance Sodus Bay including environmental advocacy, local government initiatives, active participation in regional planning groups, donation of private funding and public education of the residents of the watershed and the users of the Bay. The following sub-sections provides information concerning additional efforts and measures that can be incorporated into or used to enhance existing initiatives that will further reduce pollutant loading to Sodus Bay and slow the Bay's rate of eutrophication.

8.2 Sources and Controls – An Overview

The successful implementation of both the phosphorus load reduction and weed/algae control aspects of The Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan requires a supportive policy environment and engaged stakeholders. The projects and initiatives discussed herein are consistent with the non-point source (NPS) and Coastal Zone Management recommendations of the EPA and NOAA as stated respectively in Section 319 of the Clean Water Act and Section 6217(g) of the Coastal Zone Reauthorization Amendments of 1990. They are also consistent with the directives and recommendations contained in the EPA Clean Lakes Program (Section 314 of the Clean Water Act) and the State's goals and objectives for the management of its freshwater resources. The Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan can accomplish long-term management of external sources of nutrient loading, as well as the influx of sediments and other pollutants, only through the combined use of revised development policies, public education, source control and delivery reduction techniques. In evaluating what pollutant loading strategies will work for Sodus Bay, a number of factors were taken into consideration including cost, physical site characteristics, land availability, level of effort required for operation and maintenance, regulatory permits, design considerations, policy environment and public acceptance. It should be stressed that since this document's function is a largely a planning and management tool, specific construction designs or ordinances are not within its scope. However, as was the intent of this project, guidance is provided herein concerning how each of the major nutrient and sediment sources should be addressed and prioritized for management.

As illustrated in Table 8.1, each category of contaminants potentially affecting Sodus Bay is associated with some form of land use activity. As detailed in Section 7, certain sub-watersheds contribute greater amounts of pollutants than others. Clearly the pollutant modeling data showed that the more impervious (or developed) areas of the Bay's watershed generated on a unit basis the greatest amount of pollutant loading. Unfortunately some of the greatest amount of pollutant loading was generated by the sub-watersheds draining directly into Sodus Bay; these are developed shoreline areas that lack and defined stormwater collection and conveyance system. The lack of an extensive storm sewer system impedes the ability to implement delivery control strategies (e.g., advanced catch basin, stormwater BMPs, etc. as detailed NYSDEC's stormwater management manual).

Table 8-1 Overview of Potential Pollution Impacts to Sodus Bay			
Pollutant	IMPACTS AND SOURCES		
	Impacts To The Environment	Impacts To User Community	Common Sources of Pollutant
Nitrogen	Algae blooms, Contaminated groundwater	Algal scums, contaminated drinking water and potable wells, toxicity of aquatic organisms	Septics, sewer overflows, road runoff, vehicle emissions, pet & waterfowl feces, leaves, grass clippings
Phosphorus	Algae blooms	Algal scums, accelerated eutrophication of ponds and streams	Fertilizers, pet & waterfowl feces, leaves, grass clippings road runoff
Sediment	Loss of aquatic and wetland habitats, fouling of the gills of fish, impact to aquatic organisms, shading of beneficial aquatic vegetation	Turbid water, build-up of deltas impede boating, loss of shellfish or recreational fishery	Construction sites, unstable steep slopes, road grit and sand, eroded stream channels, illegal filling, uncontrolled runoff from agricultural sites
Heavy Metals	Toxicity of aquatic organisms and waterfowl	Build-up (bio-concentration) in tissues of shellfish and fish	Emissions, road and parking lot runoff, marinas (paint/fuel)
Petroleum Hydrocarbon	Toxicity of aquatic organisms and waterfowl	Build-up (bio-concentration) in tissues of shellfish and fish	Fuel spills, road runoff, marinas (fuel/lubricants), illegal disposal of used oil
Bacteria	Viruses, bacteria, communicable diseases, beach closures, drinking water contamination	Loss / impact to contact recreation, contaminated wells, sickness	Pet & waterfowl feces failing septic, illegal boat discharge, road and parking lot runoff

Understanding how different land use activities contribute to the generation of pollutants or create/exacerbate water quality impairments within the Bay or its tributaries aids in the preparation of technically feasible watershed management strategies. Table 8.2 provides an overview of the inter-relationships of land use, the generation of pollutants and some of the potentially appropriate techniques that could be used to control pollutant loading to Sodus Bay.

Table 8.2 Examples of Potential Pollution Management Techniques for Sodus Bay				
Pollutant Source	POLLUTANT MANAGEMENT TECHNIQUES			
	Source Control	Public Education	Regulations and Ordinances	Pollutant Treatment
Agricultural Runoff	Soil conservation farming practices, feedlot/manure management	Relationships between surface and groundwater impacts and agriculture	Stream corridor protection, erosion control	Bioretention basins, filter strips, stream buffers
Commercial Land Use	Street sweeping, spill containment	Solid waste management, spill response, erosion control	Storm water quality management, erosion control	Sand filters, water quality inlets, recharge basins, bioretention basins, stormwater manufactured treatment devices
Residential Land Use	Reduced use of fertilizers and pesticides, water conservation	Environmentally friendly lawn care, septic management, pet waste management, waterfowl management	Zoning, conservation easements, septic management and pet waste ordinances	Recharge basins, water quality inlets, filter strips, rain gardens, bioretention basins
Marinas and Boating	Fueling/ painting operations, site maintenance, erosion protection, habitat conservation	Storage of fuel, toxic materials, spill response, solid waste management, use of MSD pumpout stations	MSD pumpout, EIS and env. review, storm water quality management ordinances	Pumpout stations, sand filters and other stormwater management structures at marinas, stormwater manufactured treatment devices

As noted above, some of these techniques are currently being implemented through the auspices of the WCSWCD. In general, the following provides further insight into what is causing the eutrophication of the Bay, as identified on a watershed use basis.

- **Residential and Commercial Development** – Runoff from residential and commercial areas may transport pesticides, nutrients, sediments, heavy metals, bacteria, organic and inorganic debris, and other assorted chemicals and pollutants into the Bay. These pollutants and debris accumulate on impervious surfaces between storms and are then washed off by rain. The sources of these pollutants are numerous. Some nutrients and bacteria inputs are associated with pet droppings, leaf litter, and debris that collect in road

gutters and swales. Heavy metals and petroleum hydrocarbons are in part contributed by automobile crank case drippings and vehicular exhaust. Septic systems contribute nutrients and, in some situations, bacteria. Even simple lawn maintenance can lead to the generation of nutrients and pesticides. Residential and commercial land use within the Sodus Bay watershed is limited to the areas directly adjacent to the Bay. What hampers the implementation of stormwater interception and treatment techniques within the residential and commercial developed sections of the Sodus Bay watershed is the lack of any very well defined stormwater collection and conveyance system. Most runoff into the Bay from residential and commercial development, or even the major roadways, occurs as overland runoff, runoff directed to swales or sheet flow from properties into the Bay. That is, stormwater runoff from these areas is largely discharged directly into the Bay with little opportunity for its detention or treatment. Adding to the problem is that these areas are often characterized by steep slopes, which either exacerbate the generation of pollutants or facilitate their rapid transport into the Bay. The long-term management of pollutant loading from residential and commercial sections of the watershed remains of particular significance. The prevailing terrain and lack of a stormwater collection and conveyance infrastructure, coupled with the lack of available open space that could be used for the construction of regional basins or other types of stormwater BMPs impede the ability to implement standard structural, delivery control techniques capable of intercepting and treating runoff. This stresses the importance of planning, regulatory and educational pollutant control techniques as primary vehicles for the reduction of pollutant loading to Sodus Bay.

A recommended follow-up to this project pertaining to the control of pollutants from residential and commercial sites is the implementation of a detailed stormwater system mapping effort. Knowing the locations of major outfalls to the Bay and the size and predominant land use of the outfall's contributing drainage area could identify opportunities for the upgrade or retrofit of the existing stormwater collection system or for the location of the construction of a regional type of stormwater management BMP. Although the opportunities may be limited, such actions could have a significant local impact.

- **Agriculture** - Agricultural non-point sources are very common throughout the more distal reaches of the Sodus Bay watershed, in particular along the stream corridors of the Bay's main tributaries. The modeling effort conducted as part of this project demonstrated that pollutant loading from agricultural lands is significant and is a source of pollutant loading to the Bay that requires additional attention. As noted above, there are a number of projects being conducted right now by the WCSWCD to reduce agricultural loading, and the agricultural community has demonstrated a desire to participate in such programs. Some of the BMPs suitable for use in agricultural settings include:

- Use of vegetative buffers to segregate pollutant sources (e.g., feed lots, manure storage areas) from receiving waters,
- Conservation tillage practices,
- Maintenance, enhancement and expansion of streamside buffers,
- Routing of drainage through filter strips, created wetlands and similar biofilters,
- Interception and treatment of runoff from feedlots and manure storage areas, and
- Implementation and enforcement of erosion control practices.

As noted above, many of these agricultural BMPs are already being implemented throughout the Sodus Bay watershed via various grant and cost-share supported programs conducted by the WCSWCD. Additional funding for the continuation of such projects is highly warranted as reflected in the excellent participation of the agricultural community in these projects and the WCSWCD's success stories.

- **Marinas and Boating** - As previously discussed, the pollutant contributions to the Bay directly attributable to boating needs to be calculated more accurately than was possible as part of this study. Marinas can contribute a variety of pollutants ranging from heavy metals and petroleum hydrocarbons to bacteria. It is recommended that a dilution/dispersal study (as detailed in USEPA, 1985), be conducted by the WCSWCD for both the confined marinas and dense open water anchorages. By accounting for the dilution and flushing properties of the Bay, such a study could accurately assess the amount of marine related pollutants contributed to the Bay and the ultimate concentration of pollutants in the water column. These data could be used to identify water quality problem areas, and, more importantly, to support pump out station use and environmentally friendly boating practices.

8.3 Pollutant Load Reduction Techniques for Sodus Bay

What is evident from the above synopsis of the sources and impacts of pollutant loading to Sodus Bay is that significant improvements in the Bay's water quality and the long-term protection of its resources can be greatly enhanced through the implementation of non-point source pollution control and stormwater management initiatives. The focus of these must be the reduction of existing and future inputs of phosphorus and sediment loading. As outlined above in Table 8.2, the stormwater management initiatives that could be implemented throughout the Sodus Bay watershed can be grouped into three main categories: education, source control, and stormwater interception and treatment (delivery control). Again, there is currently little opportunity within the residentially and commercially developed sections of the watershed to implement any significant level of stormwater delivery control due to lack of any substantial amount of stormwater infrastructure. As such, the management options for the control of the Bay's external pollutant loading that have the greatest potential are educational and source control management

measures. It is recognized that there are numerous initiatives being implemented by the WCSWCD, WCWQCC, local government and private groups (e.g., SOS) to control the influx of pollutant's to the Bay. This report is not intended to characterize or summarize these ongoing initiatives, but rather to emphasize the importance of these measures and provide suggestions of additional techniques or measures beneficial to the overall management of Sodus Bay and its watershed. When implemented in concert with the weed control measures recommendations presented in Section 3, source control, delivery control and educational best management practices support the core of The Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan. Together the recommended weed control measures and pollutant management measures foster the desired positive goals of the plan and everyone's desire for a sustainable and enjoyable Sodus Bay.

The NYSDEC's storm water management manual (NYSDEC, 2003) includes not only examples of commonly utilized structural BMPs, but also local government planning strategies, ordinances, and regulations (source control techniques). These source control techniques prevent or decrease existing and future non-point source pollution loads. Both the USEPA and the NYSDEC promote the combined use of source control and delivery control techniques as an "integrated, holistic approach" to watershed protection. Furthermore, the USEPA emphasizes that public education plays a very important role in the management of pollutant loading, and identifies educational programs as part of the Federal government's agenda for the management of non-point source pollution (USEPA, 1989). For a watershed such as that of Sodus Bay, public awareness programs can be considered "the key to action" in the control of non-point source pollution. Thus, as emphasized by both the State and Federal governments, successful pollutant load management extends beyond the implementation of structural BMPs. It includes public education, land use planning and regulation, schedules of activities, prohibitions of practices that cause non-point source pollution, as well as maintenance procedures and other practices that prevent or reduce NPS pollution (NYSDEC, 2003). This same type of approach is fundamental to the model stormwater management ordinance recently developed by the WCSWCD with assistance from the WCWQCC.

Basically, source control involves decreasing the actual generation of pollutants by altering existing practices or habits. Most source control techniques focus on the creation of a policy environment that is watershed cognizant. This means having fairly unified local planning, zoning, and environmental regulations that works in unison, regardless of political boundaries, to decrease pollutant loading before it actually occurs. To some extent, source control strategies also involve public education, as it is necessary to garner public acceptance and approval for the adoption, and passage of environmental regulations and ordinances. In addition, since the actual enforcement of certain ordinances may be difficult or cumbersome (e.g., "pooper scooper" laws or septic management regulations), public support will greatly determine the success of certain source control measures. In the following sub-sections, recommended public education and source control initiatives are presented and discussed with respect to the long-term restoration

and management of Sodus Bay.

8.3.1 Public Education

Several studies have suggested that “grass root” implemented pollutant load reduction measures such as septic management and lawn care management can reduce pollutant loading by as much as 30 to 35 percent. Public education is the key to successful implementation of source control strategies. Educating, empowering and providing the residents of the Sodus Bay watershed with the proper information has the ability to yield significant positive effects on the control of pollutant loading to the Bay. There are numerous public education initiatives currently being implemented by the WCSWCD, WCWQCC and SOS (as well as local government). For example the WCSWCD and the WCWQCC have recently done the following:

- Delineated local watershed boundaries with road signs thereby promoting social awareness of the watershed and enhancing an understanding of watershed / Bay water quality related concerns and problems,
- Developed a septic system model ordinance,
- Developed a stormwater model ordinance,
- Made use of local television and radio outlets to promote watershed awareness,
- Prepared newsletter and newspaper articles, and
- Coordinated and sponsored symposia, workshops and presentations focusing on the ecology of Sodus Bay.

Additional efforts that could be taken by the WCSWCD with assistance from the WCWQCC, SOS, local government and local business owners include:

- Publication of short, concise and insightful fact sheets that directly deal with issues specific to the long-term management and restoration of Sodus Bay. These in turn could be posted on the websites of each group as well as local government websites.
- Develop a watershed policy pertaining to integrated pest management (IPM) emphasizing what can be done by municipal government and watershed residents in the management of private lawns, playing fields, and municipal, school and public grounds to limit the use of pesticides and fertilizers.
- Prepare a Watershed Management Curriculum for use by the local school systems. Individual curricula that include a detailed Teacher’s Manual along with specific lessons, activities experiments, and field projects could be prepared for the grammar, middle and high school age groups. Individual units dealing with the physical, chemical and biological attributes of the Bay, characteristics of the watershed, the impacts of eutrophication and non-point source pollution, and the management and restoration initiatives in place or proposed for Sodus Bay could be tailored for each targeted age group. The curriculum would serve as an excellent means of stimulating community

involvement, and be an excellent means of educating future generations about the ecological uniqueness of the Bay and the environmental linkages that exist between the Bay and its watershed.

- Coordinate and sponsor an annual “Save the Bay Day”. Such an event could be used to focus attention on the management and restoration efforts of the WCSWCD and serve as a less technical supplement to the annual Wayne County Freshwater Resources Conference. It is suggested that the Save the Bay Day include an activity such as a 2 or 5-mile race along the Bay to increase attendance by the public.

8.3.2 Source Control Best Management Practices

Source controls are highly effective BMPs that are intended to reduce or eliminate pollutants before they are mobilized by storm water runoff. Limiting the entry of pollutants into Sodus Bay is ultimately preferable to attempting post-discharge mitigation or management of pollutants. This is especially true in this watershed given the limited opportunities that currently exist to locally or regional collect and treat stormwater runoff. Some excellent examples of the source control initiatives already in place throughout the watershed are the feed lot projects, stream restoration/stabilization projects and the stormwater erosion mitigation efforts being implemented by the WCSWCD. Source control must continue to be an integral component of Sodus Bay’s Resource Preservation and Watershed Enhancement Plan. Implementation of the following source control techniques would be highly beneficial and are consistent with the objectives of the Plan.

Storm Water Quality Management

Successful stormwater quality management in urbanized areas largely relies on the ability to intercept and pre-treat runoff prior to its discharge to the environment. As part of the environmental review associated with major sub-divisions, opportunities often arise to evaluate the potential water quality impacts of storm water and NPS loading, and mandate the implementation of storm water quality management measures. The new State-wide stormwater management rules have created the legal mandates and performance standards needed to control future NPS inputs to Sodus Bay. The following are recommended stormwater related practices for the Sodus Bay watershed:

- A priority action item for the WCSWCD should be the passage of uniform local regulations that limit the increase in development related pollutant loading following development. Current NYSDEC performance standards for the treatment of runoff focus on total suspended solids (TSS) removal. Performance standards also are needed in the case of Sodus Bay for the control of phosphorus loading. The NYSDEC storm water manual establishes structural BMP water quality design standards that deal with the interception and treatment of the “first flush” or “the first ½” of runoff generated by the

1-year, 24-hour storm. Management of these “water quality events” is preferable when dealing with phosphorus loading to the Bay. What is recommended is the local adoption of a phosphorus control performance standard for new development of 40-50% TP removal, as applied to the runoff generated by the water quality event.

- In keeping with the above recommendation, the Chesapeake Bay initiatives in place in Virginia and Maryland now require developers to conduct pre-and post-pollutant loading analyses (using similar methodologies to that used in the computation of Sodus Bay’s existing nutrient and sediment loads). These data are utilized to quantify the magnitude of anticipated pollutant influx and support the need for storm water quality management BMPs. The Lake Carmel Park District, through the auspices of the Town of Kent, NY Planning Board, has done the same as part of their evaluation of potential development related impacts on Lake Carmel. The member municipalities of the Sodus Bay watershed should require NPS pollution loading analyses as part of all major sub-division reviews. As with the examples noted above, in some situations the request for such an analysis could be made during either the municipal or county level of review of a development plan.
- IPM and other similar source control regulations or ordinances that facilitate stormwater quality management should continue to be promoted. Limiting, in the first place, the amount or types of pollutants generated from the watershed works perfectly in concert with the construction or implementation of structural stormwater management techniques. The overall end product is the creation of a policy environment aimed at the reduction of NPS loading through the use of both source and delivery control strategies.

Septic Management

The vast majority of the watershed’s population is serviced by septic systems. Septic management should therefore be implemented to help minimize nutrient loading to the Bay and protect against septic failures that could result in bacterial inputs. Such efforts are underway, for example in the Town of Huron and the initiatives detailed in the Sodus Township Comprehensive Master Plan.

Successful septic management involves the integration of public education, product modification, septic system inspection and maintenance, and water conservation practices. In addition, it may rely on the use of advanced on-site wastewater renovation/treatment designs to correct failing systems or to dictate the construction of new systems in environmentally sensitive sections of the watershed. Managing the performance of septic systems to decrease phosphorus loading and associated water quality problems, would also be consistent with the overall phosphorus reduction objectives needed for Sodus Bay.

Product modification usually refers to the use of non-phosphorus or low phosphorus products that minimize septic-related phosphorus loading to the environment. However, it also applies to the use of septic tank chemical additives, or the disposal of paint, solvents or left over household chemicals and cleaning products in septic systems. In reviewing the local policy environment, it does not appear that any of the municipalities have specific regulations pertaining to the disposal of such materials in septic systems. Public education fliers and brochures would prove beneficial in this respect. All residents who rely on some form of on-site wastewater disposal system should be educated about the serious impacts of household chemicals and degreasing agents improperly disposed of in septic tanks. These products can cause serious upsets to the biological treatment processes that occur in cesspools, septic tanks and in the soils of the leaching area. Equally important, these products can result in serious groundwater pollution and the contamination of drinking water wells. An excellent example of such is the Town of Oyster Bay's (Long Island, NY) S.T.O.P. brochure that discusses the environmental and health consequences of pouring contaminants on the ground or into septic tanks or cesspools. Additional related public information fact sheets of this nature can be obtained through the EPA's Small Flows Clearing House, which specializes in the dissemination of information pertaining to septic systems and other types of on-site waste water treatment systems.

Also, the public should be educated concerning the lack of any benefit associated with enzymes, bacteria inoculants, or other products advertised as septic tank supplements. Such information should be made available through the WCSWCD to residents relying on on-site disposal systems. As demonstrated by the EPA (USEPA, 1997), these products do very little to enhance septic system operation. They also give a false sense of maintenance to the property owner and may actually dissuade them from regularly pumping or inspecting their system. Also, residents should be cautioned about the use of garbage disposal units/grinders. Excessive or improper use of these devices can increase organic loading and further stresses the system's operation by adding to both the sludge and grease layers. Furthermore, once ground up, the disposed solids can be converted into fine particulate material that resists settling. This can decrease the operational efficiency of a septic system and accelerate the clogging of the leach field.

Inspections and routine maintenance are usually the two controversial elements of most septic management programs. There is an innate resistance by homeowners to allow periodic inspections or to comply with a mandatory pump out schedules. Basically, the prevailing thought among most homeowners is "if it flushes, it's OK". However, as has been demonstrated in studies conducted as part of nationwide septic management studies, routine inspections help decrease the occurrence of large scale failures by identifying the more easily corrected, less costly problems early on (NYSDEC, 1994). Similarly, routine pump outs decrease the build up of sludge and grease in the septic tank itself, both of which can be transported into the leach field and create clogging problems. In general, the inspections and pump outs should be viewed as an insurance policy for the long-term proper operation of the septic system and not an imposition of the property rights of a homeowner. It should be noted that for older tanks, there may be some

liability associated with their pump out. For example old metal tanks that have become corroded or hand built cesspools can collapse once the liquid and sludge has been removed.

Water conservation measures are intended to reduce hydrologic loading to the leach field. Included in this category are the use of low flush toilets, flow reduction fixtures and other similar devices designed to reduce water usage. It can also encompass lifestyle habits such as spreading out laundry wash loads over a number of days, shorter showers, and other similar cooperative techniques.

Minimizing Site Disturbance and Utilizing Alternative Landscaping

Minimizing disturbance and utilizing alternative landscaping are preventative pollutant load management techniques. If these techniques are properly implemented they can eliminate the need for the repeated fertilization of lawns, decrease the rate or frequency of pesticide applications and decrease irrigation requirements. In already developed areas of the watershed, especially the residential areas immediately adjacent to Sodus Bay, homeowners should be encouraged to allow nature to take its course in a portion of the property. Focus should be placed on maintaining natural ground covers in lieu of manicured lawns, and supplementing areas having sub-optimal ground cover with selected plantings. This practice can help minimize lawn areas and the associated use of nutrients and pesticides. By maintaining properly stabilized vegetative cover, a reduction in localized soil erosion can be achieved. Such measures should especially be promoted at transition points to wetlands and streams. By utilizing a combination of design, plants and mulches, homeowners and landscapers can create a landscape that decreases maintenance, is aesthetically pleasing and is environmentally suited to the area.

Fertilizer and Pesticide Management

As discussed above and factored into the pollutant loading analyses conducted in Section 7, environmental conditions conducive to the direct transport of nutrients and pesticides into the Bay prevail in the residential areas located along the shoreline of Sodus Bay, in particular the islands and the more steeply sloped sub-watersheds that immediately drain into the Bay. This reinforces the need for the implementation of IPM techniques in upland areas within 300 feet of the Bay, its streams, wetlands, and tributaries. Integrated pest management (IPM) is a common sense, but technically well structured approach to the use of fertilizers and pesticides. It can be used at the individual home level, but is more commonly utilized in respect to the maintenance of large intensive use areas such as golf courses, public parks, and ball fields. Central to the success of IPM, as a source control strategy, is the employment of environmentally friendly methods to maintain pests below defined damage levels. Unfortunately, a considerable amount of over application of pesticides and fertilizers occurs during the routine care of residential lawns. Homeowners often operate under the assumption that if “a little is good, more is better”. This leads to the over-application of products and an increased potential for off-site transport of

pesticides and fertilizers. Lawns should be considered part of the Sodus Bay ecosystem. Maintenance of lawns and large areas of turf (e.g., playing fields and golf courses) should be viewed as a means of complementing natural checks and balances, as opposed to the need to completely eliminate pest species. The mere presence of a pest species is not a cause for alarm. An acceptable damage level or pest level must be determined. Beyond that level, the proper pesticide level needed to control the pest may be selected. Potential environmental impacts must be weighed against the effectiveness of the chemical.

In addition to pesticide control, a key element of IPM is the limitation of the use of fertilizers, or the use of specific types of fertilizers. By applying only the quantity of fertilizer necessary for optimum plant growth, the amount that can potentially be mobilized and transported to surface and groundwater resources is minimized. Use of non-phosphorus fertilizers or slow-release nitrogen fertilizers also decreases the loading to receiving waters. The effectiveness of fertilizer management is dependent upon cumulative effects within the watershed, and requires commitment on an area-wide basis. Not only is non-point source pollution (fertilizers, nutrients) reduced with this practice, but the homeowner will also save money. Thus, homeowners and lawn care services must be educated regarding proper lawn maintenance. For example, slow release lawn fertilizers are very appropriate for use in the near shore areas of the watershed or areas abutting wetlands and stream corridors. These types of fertilizers allow a more complete utilization of nutrients by lawns, thus decreasing the amount transported into the Bay or a tributary of the Bay.

Fertilizer applications must also be timed properly to account for plant needs and to anticipate rainfall events. For example, nutrients are most needed in the spring and fall, not throughout the summer. Also, rain induced fertilizer losses are greatest immediately following an application because the material has neither become adsorbed by the soil nor taken up by the plants. Fertilizer uptake and retention is promoted by proper soil pH. The WCSWCD offers general soil assessments, and many lawn care services will conduct such testing and adjust the soil pH accordingly in advance of fertilizer applications to promote product retention and uptake. A detailed survey of homeowners in Virginia commissioned as part of the Chesapeake Bay initiatives, found that less than 20% actually tested their soils to determine whether fertilization was actually necessary (Watershed Protection, 1994). Although soil pH can have a significant bearing on the ability of soils to retain nutrients, such testing is not commonly conducted by homeowners. The application of lime can improve phosphorus uptake and retention. Other non-chemical lawn care treatments such as de-thatching and aeration are also rarely conducted (Watershed Protection, 1994). Urban soils, even those associated with lawns, can become compacted and function almost no differently in respect to the generation of runoff than impervious surfaces (Schueler, 1995). Aerating lawns helps promote better infiltration and the generation of less runoff.

An additional means by which to decrease fertilizer and pesticide use and the subsequent

transport of these pollutants to the Bay is through the use of alternative lawn cover. Where appropriate, the use of native plants or plants that have lower irrigation needs than typical suburban lawns needs to be promoted. As part of the ongoing strategy to reduce the influx of lawn related pollutants into Chesapeake Bay, the National Park Service has started to use native ground covers to reduce the need for fertilization and irrigation (NPS News-Notes, 1996). Similar types of low maintenance vegetative cover have been promoted by New Jersey DEP (NJDEP, 2004) and the Metropolitan Council of Governments (Schueler, 1987) as part of an overall strategy of reducing NPS loading.

IPM and fertilizer management ordinances, especially those that pertain to private, residential lawns, tend to be highly contested, and subject to extensive public opposition. These ordinances, similar to littering or pet waste ordinances tend to be difficult to police and enforce. The public's voluntary participation is therefore needed if IPM and fertilizer management ordinances are to be successful. This starts with the implementation of a well-structured public education effort. Specific recommendations developed for the Sodus Bay watershed relating to fertilizer management are as follows:

- Develop a true IPM ordinance for application initially at all commercial properties or large, intensively managed public open space areas (playing fields, golf courses, etc.). As the public becomes educated about the importance of IPM, consider extending the ordinance to include private lawns.
- Conduct a public education program that informs all the residents of the benefits of fertilizer and pesticide management, stressing the low cost alternatives and environmental benefits of such techniques. Encourage soil pH and nutrient testing be performed before engaging in fertilization and emphasize the benefits of nutrient retention as a result of liming, aeration, thatch control, and other non-chemical lawn care measures.
- Encourage xeriscapes, native vegetation, and alternative ground covers and ornamental plantings that require less maintenance and less chemical management than conventional lawns.

8.4 Marina and Boating Related Waste Control

According to the New York State Clean Vessel Act Plan (NYSDOS, 1996), “sewage discharged by recreational vessels because of an inadequate number of pump out stations is a substantial contributor to localized degradation of water quality in the United States.” Vessel waste pump out stations are facilities that pump or receive sewage from Type III marine sanitation devices (MSD) installed on vessels. Type III MSDs include equipment such as recirculating and incinerating MSDs and holding tanks, and are defined as any equipment specifically designed to receive, retain and discharge sewage (Figure 6-1). A dump station is a facility designed to receive sewage from portable toilets that are carried on vessels.

The Clean Vessel Act requires that coastal states, including New York, prepare a plan for distributing funding for pump outs and dump stations to the appropriate parties. Under this act, funds are provided to states for grants for public and private marina operators to install, renovate, operate and maintain pump out stations and other vessel waste discharge facilities.

The importance of marine and boating related waste management has been promoted for some time in Sodus Bay. WCSWCD, the WCWQCC and others are well informed about the consequences of marine wastes on the water quality of Sodus Bay. In fact one of the very first recipients of a Clean Vessel Assistance Program grant in New York was Arney’s Marina, located in Sodus Point. The EPA suggested ratio of pump out facilities to boats is one per 300 to 600 boats (16 feet or greater). Based on the number of boats either registered on Sodus Bay or known to make use of the Bay (as per the Great Sodus Bay Harbor Management Plan) there appears to be an adequate number of pump out stations already located on Sodus Bay. In addition the WCSWCD has a mobile unit that can be used in areas not conveniently serviced by the marina based units.

Nonetheless, there is still the question as to whether boaters are making use of these stations. Thus, boater education concerning their role in nutrient and bacterial loading appears to be needed. Tanski (1989) reported that even when an adequate number of pump out stations were provided, only five percent of the surveyed boaters reported actually utilizing the facilities on a regular basis. This lack of use is clearly a function of inadequate boater education. Again, this reinforces the need to include education and public awareness type initiatives as part of the Sodus Bay Coastal Resource Preservation and Watershed Enhancement Plan. Public education regarding the effects of boat waste on the Bay’s ecology and water quality must be an integral part of the overall plan if the positive benefits of the pump out stations are to be realized.

Besides the wastewater related nutrient and bacterial loading, other pollution problems associated with marinas can be mitigated through source control and delivery control techniques at marinas and boat launching areas. The influx of oil, grease, heavy metals, and sediments from vehicular parking areas can be controlled through the construction of storm water management

BMPs. This includes the use of sand filters, water quality inlets, oil water separators, and the maintenance of vegetated buffers between impervious surfaces and the water's edge. Petroleum hydrocarbon and heavy metals inputs can be reduced by practicing "good housekeeping" around boat refueling and maintenance operations.

The specific recommendations developed for Sodus Bay concerning the control or management of marina related NPS pollution loading are as follows:

- As discussed in Section 7, conduct a more detailed modeling analysis of the pollutant contributions associated with the Bay's marinas and dense anchorages. Focus on quantifying bacterial, heavy metal and petroleum hydrocarbon loading.
- Require the installation of stormwater quality management devices (e.g. water quality inlets, oil/water separators, sand filters, etc.) at all new marinas, marinas that are proposing significant expansions, or marinas that appear before planning or zoning boards for variances or exemptions.
- Prepare public educational materials concerning the proper use and maintenance of MSDs and the implementation of other boating and marina operational "housekeeping" practices. Disseminate this material to boaters and marina operators. Use a "Save the Bay" type forum to distribute these materials, in addition to mass mailings and other types media (public access TV and radio spots, local newspaper articles, etc.).

8.5 Recommended Monitoring Program

In order to provide an objective means of evaluating the future environmental status of Sodus Bay's water quality, an annual water quality monitoring program should be implemented. Data in the past have been collected by SUNY Brockport, FLCC, WCSWCD and WCWQCC. The monitoring conducted by each of these entities has been impaired by budgetary limitations. In general, this has affected the frequency of sampling, and has limited the types of water quality parameters routinely tested. Obviously, cost plays a big role in defining a monitoring program. The following recommended monitoring program does not reflect any such funding limitations.

At least three monitoring stations should be established: upper, central, and lower Sodus Bay. Each of these stations should be monitored monthly from April through October, the period during which water quality impairment tends to have the greatest impact on the recreational use, water quality and ecology of the Bay.

Each station should be monitored in-situ (using a meter) for dissolved oxygen, temperature, pH, and conductivity. The in-situ data should be collected in profile, at 1-foot increments from the surface to the bottom. Water column transparency should also be measured at each station, using a secchi disc. Discrete water samples should be collected at each station at the surface, at mid-depth and at a depth of 2 feet above the bottom (to avoid inaccuracies caused by the resuspension of bottom sediments). These samples should be analyzed for Total Suspended Solids, Ammonia-Nitrogen, Nitrate-Nitrogen, Total Phosphorus, and Soluble Reactive Phosphorus. Additional samples should be collected at the surface and analyzed for Total Coliform Bacteria, Fecal Coliform Bacteria, and Chlorophyll *a*. Samples should also be collected to assess zooplankton and phytoplankton community composition. Both could be sampled either by towing plankton nets (63u for phytoplankton, 163u for zooplankton) or by collecting discrete water samples using a Van Dorn Bottle or Schindler Sampler lowered to depth 1 meter below the surface and at the limit of the measured Secchi clarity.

The above monitoring program would provide a database suitable for tracking the overall condition of Sodus Bay. In general, it is similar to the monitoring programs conducted intermittently since the late 1980s, but includes the often lacking the mid- and bottom-depth data critical to tracking internal phosphorus loading conditions.

Data collected through such a monitoring effort would enable the WCSWCD to evaluate short and long-term water quality trends, examine the spatial water quality relationships of the Bay, and analyze chemical/biological interactions. It would not, however, be capable of definitively examining the impacts of individual storm events or providing the data needed to identify contravention of State contact recreation bacteria standards. Even so, the resulting database would be suitably detailed to satisfy the WCSWCD's long-term management and planning needs.

It is estimated that the outlined monitoring program (3 stations, 7 sampling dates, and the combination of physical, chemical and biological data involving in-situ and discrete sampling) would cost in the vicinity of \$25,000 to \$30,000/year in field labor and laboratory costs. Data analysis and preparation of an annual detailed report would add approximately \$4000 to \$6000 to the total cost.

8.8 The Future Management of Sodus Bay and the Sodus Bay Watershed

Central to the success of any watershed management effort of the scope and diversity needed for Sodus Bay is the coordination of all project efforts through one, easily identified group that is recognized as the authority on the Bay and its watershed. The WCSWCD is that group. However, if the WCSWCD is to function in this capacity it will require more funding and additional staffing. Already the WCSWCD's ability to manage the Bay's weed control problems alone stretches its resources. More aggressive weed management and further intensive watershed management will only compound this. To facilitate the WCSWCD's role now and in the future, a guaranteed annual source of funding ear-marked for the management of the Bay and the implementation of the

recommendations set forth in the Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan is therefore required. Where and how this funding is obtained is not clear at this time. The past efforts of local, State and Federal representatives are to be applauded. At the same time their help going forward is needed and the past accomplishments of all must be used as a catalyst for future funding needs.

As documented throughout this report, the challenges involved with addressing the Bay's expanding weed problem, controlling internal and external phosphorus loading and managing the influx of other sources of NPS pollution are complicated and difficult. Presently, the most critical aspect of the Bay's management pertains to the control of invasive weed growth. As detailed in Section 3, this will require the concerted and integrated implementation of mechanical, chemical and homeowner based weed management techniques. Given the expansiveness and the aggressiveness of the infestation of certain species (specifically water chestnut and milfoil), the use of labor-intensive techniques (hand pulling, diver assisted removal, etc.) has become increasingly infeasible. Weed harvesting, although effective, is difficult to conduct on some of the weedier, shallow areas and the areas where there docks and piers are prevalent. The NYSDEC, must therefore become more accepting of chemical control strategies and innovative techniques that can be used in combination with harvesting and home-owner techniques to halt the spread of the damaging invasive species.

At the same time there is still much more that needs to be done to control the influx of sediments and nutrients from the watershed. Although there are a number of successful programs currently in place, these programs need more funding. Septic systems, agricultural runoff, boat waste and stormwater runoff are all documented sources of pollution to the Bay that require additional attention, whether that be in terms of further documentation or the implementation of definitive management action items. Although the Bay's internal load currently does not appear to play a very big role in its eutrophication, its impact on water quality is becoming increasingly obvious. This source therefore warrants further attention and assessment.

In summary, Sodus Bay is a unique resource of local, regional and State importance. It is also a resource that is threatened and impacted by many of the typical factors responsible for the acceleration of the eutrophication process. The data compiled within this study and used to support the recommendations of the Great Sodus Embayment Coastal Resource Preservation and Watershed Enhancement Plan clearly show that something needs to and can be done to enhance the water quality, ecology and recreational attributes of Sodus Bay. This must begin with better invasive macrophyte control and extend into the reduction of the Bay's pollutant sources and respective loads.

Bibliography and References Cited

- Boas, T. 2001. Aquatic vegetation control program- Wayne County. Wayne County Soil and Water Conservation District.
- Carlson, R.E. 1977. A trophic state index for lakes. *Limnol. Oceanogr.* 22:361-369.
- Cooke, G.D., E.B. Welch, S.A. Peterson and P.R. Newroth. 1993. Restoration and Management of Lakes and Reservoirs. 2nd Edition. CRC Press LLC. Boca Raton, Florida.
- Clayton, Jr. 1995. Stormwater Retrofits - A tool for Watershed Enhancement. Watershed Protection Techniques. 1(4): 188-191.
- Daniel, W.W. 1990. Applied Non-Parametric Statistics, 2nd Edition. PWS-KENT Publishing Company. Boston, Mass.
- Dierberg, F.E. 1992. The littoral zone of Lake Okeechobee as a source of phosphorus after drawdown. *Environmental Management* 16:371-381.
- Dierberg, F.E. 1993. Decomposition of desiccated submersed aquatic vegetation and bioavailability of released phosphorus. *Lake and Reservoir Management* 8: 31-36.
- F-E-S Associates. 2006. Great Sodus Bay Harbor Management Plan, Inventory of Existing Conditions. Great Sodus Bay Watershed Intermunicipal Committee.
- Gilman, B. and F. Smith. 1988. An Inventory of Macrophyte Communities in the Wayne County Bays of Lake Ontario, New York. Community College of the Finger Lakes.
- Gilman, B. 1986. Report on the Experimental Management of the Aquatic Weedbeds in Honeoye Lake and Recommendations on the Formation of a Lake Association, Community College of the Finger Lakes.
- Gilman, B. 2001. Significance of Deep Bottom Sediment to Phosphorus Dynamics in Honeoye Lake, Finger Lakes Community College.
- Kirchner, W.B. and P.J. Dillon. 1975. An empirical method of estimating the retention of phosphorus in lakes. Water Resour. Res. 11:182-183.
- Lubnow, F.S. and S.J. Souza. 1999. The General Ecology and Management of a Shallow, Polymictic Lake in Northern New Jersey. 19th International Symposium of the North American Lake Management Society. November, 1999, Reno, Nevada.
- Lubnow, F., S.J. Souza and G.C Holdren. 1994. The use of biological interactions in developing a lake management program. *Lake and Reservoir Management* Vol. 9, No. 2, 93 p.

- Maidment, D.R. 1993. Handbook of Hydrology. McGraw-Hill, Inc. New York, NY.
- Makarewicz, J. and T.W. Lewis. 1991. Nutrient Loading of Streams Entering Sodus Bay and Port Bay, NY, April 1990 through June 1991.
- Makarewicz, J. and R. Williams. 1994. Nutrient Loading of Streams Entering Sodus Bay and Port Bay, NY: A Summary of Port Bay and Sodus Bay Tributary Monitoring, dates covered include April 1990 through April 1994.
- Makarewicz, J. and Lewis, T.W. 2004. Interim Data Report: Sodus Bay Limnology, Lake Chemistry, Phytoplankton Abundance and Nutrient Soil Losses from the Watershed, 2004. Center for applied Aquatic Science and Aquaculture, Dept. of Environmental Science, SUNY Brokport.
- Martin, M. and C. Stager. 2005. The use of hand harvesting to control Eurasian milfoil in Upper Saranac Lake, Franklin County, NY. Presentation at the Northeast Aquatic Plant Management Society, Annual Conference, Saratoga Springs, NY.
- North American Lake Management Society (NALMS) and the Terrene Institute. 2001. Managing Lakes and Reservoirs, Third Edition.
- NYSDEC. 2005. A Primer on Aquatic Plant Management in New York State.
- Madden, J.D., et. al. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* 444: 71-84.
- James, W. F. and J. W. Barko. 2000. Sediment resuspension dynamics in canopy-forming and meadow-forming submerged macrophyte communities. US Army Corps of Engineers, Aquatic Plant Research Program.
- James, W. F., J.W. Barko and H. L. Eakin. 2001. Direct and Indirect Impacts of Submerged Aquatic Vegetation on the Nutrient Budget of an Urban Oxbow Lake. ERDC TN-APCRO-EA-02.
- J. D. Madsen. 1999. Invasive Aquatic Plants: A Threat to Mississippi Water Resources. North American Lake Management Society; *LakeLine*, v. 20, no.1, pp 22-34.
- Nurnburg, G.K. 1984. The prediction of internal phosphorus load in lakes with anoxic hypolimnia. *Limnol. Oceanogr.* 29:111-124.
- Nurnberg, G.K. 1996. Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. *Lake and Reservoir Management* 12: 432-447.

- Nurnberg, G.K., M. Shaw, P.J. Dillon, and D.J. McQueen. 1986. Internal phosphorus load in an oligotrophic precambrian shield lake with an anoxic hypolimnion. *Can. J. Fish. Aquat. Sci.* 43:574-580.
- Reckhow, K. H., M. N. Beaulac, and J. T. Simpson. 1980. Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients. Report No. EPA-440/5-80-011. U. S. EPA, Washington, D.C.
- Schueler, T. 1996. Urban Watershed BMPs: A workshop on innovative watershed restoration and protection techniques. The Center for Watershed Protection and The Engineering Society of Baltimore, Inc. Baltimore, Maryland.
- Sheldon, S.P., and R.P. Creed, Jr. 1995. Use of a Native Insect as a Biological Control for an Introduced Weed. *Ecological Applications*. 5: 1122-1132.
- Sheldon, S.P. 1997b. Investigations on the Potential Use of an Aquatic Weevil to Control Eurasian watermilfoil. *Journal of Lake and Reservoir Management*. 13: 79-88.
- Souza, S.J., F.S. Lubnow and C. Borek. 2000. Integration of weed control and nutrient limitation techniques for the successful management of blue green algae blooms at White Meadow Lake, Rockaway, NJ. 20th International Symposium of the North American Lake Management Society. November, Miami, Fla.
- Souza, S.J., F. S. Lubnow, and J.P. Bell. 1998. Use of GIS to identify and prioritize Phase II watershed management restoration projects for the Lake Hopatcong and Lake Musconetcong watershed, New Jersey. 18th International Symposium of the North American Lake Management Society. November, 1998, Banff, Alberta, Canada.
- Souza, S.J. 1998. Pond Ecology. Course Session, *Pond Dredging, Maintenance and the Natural Landscape*. Office of Continuing Education, Cook College, Rutgers University. May, 1998
- Souza, S.J., F.S. Lubnow, and R.L. Conner. 1994. An innovative use of alum to control blue-green algae blooms in Lake Mohawk New Jersey. *Proceedings Abstracts: North American Lake Management Society*, Vol. 9(2).
- Souza, S.J., J.D. Koppen, and R. Conner. 1987. Aquatic weed harvesting: A cost-effective means of improving the recreational, aesthetic and water quality conditions of Lake Hopatcong. Seventh Annual International Symposium, North American Lake Management Society. Orlando, Florida.
- Souza, S. J. and P. A. Perry. 1977. Land and Recreational Development at New Jersey Sodus Bays. Water Resources Research Institute. Technical Publication A-043-NJ. Rutgers University, New Brunswick, NJ.

- US Army Corp. of Engineers. 2003. Great Sodus Bay Harbor, New York. Fact Sheet. USACOE, Buffalo District.
- USEPA. 1980. Clean lakes program guidance manual. Report No. EPA-440/5-81-003. U.S. EPA, Washington, D.C.
- USEPA. 1990. Lake and Reservoir Restoration Guidance Manual. 2nd Edition. Report No. EPA 440/4-90-006. U.S.EPA, Washington, D.C.
- USEPA. 1997. Compendium of Tools for Watershed Assessment and TMDL Development. EPA841-B-97-006. Washington D.C.
- Uttormark, P.E., J.D. Chapin, and K.M. Green. 1974. Estimating nutrient loading of lakes form nonpoint sources. Report No. EPA-660/3-74-020, U.S. EPA., Corvallis, OR.
- Walker, W.W. 1977. Some Analytical Methods Applied to Lake Water Quality Problems. Ph.D. dissertation, Harvard University.
- Wanielista, M.P., Y.A. Youseff, and J.S. Tylor. 1982. Stormwater Management to Improve Lake Water Quality. Report No. EPA-600/52-82-048, U.S. EPA, Municipal Env. Res. Lab., Cincinnati, OH.
- White, D.J., J.C. Malarewicz, and T.W. Lewis. 2002. The significance of phosphorus released from the sediments under anoxic conditions in Sodus Bay, NY. SUNY Brockport.
- Wetzel, R.G. 1983. Limnology 2nd Edition. W.B. Saunders Co., Philadelphia, PA.

www.dnr.state.md.us/bay/sav/water

www.co.cayuga.ny.us/wqma/weedswatchout/documents/benthicmatvacuuming.pdf

Photos/Graphics:

Robert Johnson, Cornell University. Ruthanna Hawkins, Cayuga Lake Watershed Association.

University of Florida at Gainesville

www.plants.usda.gov

Princeton Hydro, LLC

Rob Williams, Wayne County Soil and Water conservation District

Wayne County Water Quality Coordinating Committee

GLOSSARY OF KEY TERMS

- Acidity - The state of being acid that is of being capable of transferring a hydrogen ion in solution; solution that has a pH value lower than 7.
- Alkalinity - The capacity of water for neutralizing an acid solution. Alkalinity of natural waters is due primarily to the presence of hydroxides, bicarbonates, carbonates and occasionally borates, silicates and phosphates. It is expressed in units of milligrams per liter (mg/l) of CaCO₃ (calcium carbonate) or as microequivalents per liter (µeq/l) 20 µeq/l = 1 mg/l of CaCO₃. A solution having a pH below 4.5 contains no alkalinity. Low alkalinity is the main indicator of susceptibility to acid rain. Increasing alkalinity is often related to increased algal productivity. Lakes with watersheds having a sedimentary carbonate rocks geology then to be high in dissolved carbonates (hard-water lakes), whereas those in a watershed with a granitic or igneous geology tend to be low in dissolved carbonates (soft water lakes).
- Alternative management strategy
- Anthropogenic activities – Impacted by, created by or resulting from human activities.
- Aeration - A process which promotes biological degradation of organic matter in water. The process may be passive (as when waste is exposed to air), or active (as when a mixing or bubbling device introduces the air).
- Algae - Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. They are food for fish and small aquatic animals. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. They can affect water quality adversely by lowering the dissolved oxygen in the water.
- Alum Treatment - Process of introducing granular or liquid alum (*Aluminum sulfate*) into the lake water, to create a precipitate or floc that is used to strip the water column of fine particles and algae or used to treat the bottom sediment for the purpose of limiting the internal recycling of phosphorus.
- Ammonia - A colorless gaseous alkaline compound that is very soluble in water, has a characteristic pungent odor, is lighter than air, and is formed as a result of the decomposition of most nitrogenous organic material.
- Barrier to migration - A man-made structure consisting of cobble, wood, cement or other materials that impede the free movement of fish between stream sections.

- Bathymetry - (1) The measurement and mapping of water depths and bottom contours.
- Best Management Practices - Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include but are not limited to treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or wastewater disposal, or drainage from raw material storage. Practices or structures designed to reduce the quantities of pollutants -- such as sediment, nitrogen, phosphorus, and animal wastes that are washed by rain and snow melt from farms into surface or ground waters.
- Chlorophyll a - A green pigment found in photosynthetic organisms; used as an indicator of algal biomass.
- Clarity - The transparency of a water column. Commonly measured with a Secchi disk
- Composite water quality sample - A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.
- Debris - A broad category of large manufactured and naturally occurring objects that are commonly discarded (e.g., construction materials, decommissioned industrial equipment, discarded manufactured objects, tree trunks, boulders).
- Detritus - Any loose material produced directly from disintegration processes. Organic detritus consists of material resulting from the decomposition of dead organic remains.
- Dissolved oxygen - The amount of oxygen dissolved in a stream, river or lake is an indication of the degree of health of the stream and its ability to support a balanced aquatic ecosystem. The oxygen comes from the atmosphere by solution and from photosynthesis of water plants. The maximum amount of oxygen that can be held in solution in a stream is termed the saturation concentration and, as it is a function of temperature, the greater the temperature, the less the saturation amount. The discharge of an organic waste to a stream imposes an oxygen demand on the stream. If there is an excessive amount of organic matter, the oxidation of waste by microorganisms will consume oxygen more rapidly than it can be replenished. When this happens, the dissolved oxygen is depleted and results in the death of the higher forms of life.

- Dredging - Removal of sediment from the bottom of a water body.
- Epilimnion- The upper layer of water in a thermally stratified lake or reservoir. This layer consists of the warmest water and has a fairly uniform (constant) temperature. The layer is readily mixed by wind action.
- Eutrophication - A process that occurs when a lake or stream becomes over-rich in plant nutrient; as a consequence it becomes overgrown in algae and other aquatic plants. The plants die and decompose. In decomposing, the plants rob the water of oxygen and the lake, river or stream becomes lifeless. Eutrophication can be a natural process or it can be a cultural process accelerated by an increase of nutrient loading to a lake by human activity. Fertilizers, which drain from the fields, nutrients from animal wastes and human sewage are examples of cultural processes and are often the primary causes of the accelerated eutrophication of a waterbody.
- Erosion- The wearing away of land surface by wind or water. Erosion occurs naturally but can be caused by farming, residential or industrial development, mining, or timber-cutting.
- Fecal contamination - The presence in water bodies of living organisms (bacteria and viruses) or agents derived by fecal bacteria that can cause negative human health effects. Fecal contamination may be a result of wildlife, livestock, pet, waterfowl or septic and sewage discharges.
- Herbicides - A compound, usually a man-made organic chemical, used to kill or control plant growth.
- Hydrology - The occurrence, circulation, distribution, and properties of the waters of the earth, and their reaction with the environment. For lakes this is usually associated with the quantification of the water flow into and out of the system and the study of pollutant transport that occurs in concert with the inflow.
- Hypolimnion - Bottom waters of a thermally stratified lake. This layer consists of colder, more dense water. Its water temperatures remain relatively constant year around and it may experience little or no mixing with the upper warmer layers of the water body. The hypolimnion of a eutrophic lake is usually low or lacking in oxygen.
- Hypereutrophic - Pertaining to a lake or other body of water characterized by excessive nutrient concentrations such as nitrogen and phosphorous and resulting high productivity. Such waters are often shallow, with algal blooms and periods of oxygen deficiency. Slightly or moderately eutrophic water can be healthful and support a complex web of plant and animal life. However, such waters are generally undesirable for drinking water and other needs. Degrees of

Eutrophication typically range from *Oligotrophic* water (maximum transparency, minimum chlorophyll-a, minimum phosphorus) through *Mesotrophic*, *Eutrophic*, to *Hypereutrophic* water (minimum transparency, maximum chlorophyll-a, maximum phosphorus). Also see *Carlson's Trophic State Index (TSI)* and *(Mean) Trophic State Index (TSI)*.

- *In situ* water quality parameters - in place; in situ measurements consist of measurements of water quality parameters in the field, rather than in a laboratory.
- Invasive species - A species whose presence in the environment causes economic or environmental harm or harm to human health.
- Limnology - The study of bodies of fresh water with reference to their plant and animal life, physical properties, geographical features, etc. The study of the physical, chemical, hydrological, and biological aspects of fresh water bodies.
- Littoral zone - 1. That portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants. 2. A strip of land along the shoreline between the high and low water levels.
- Land use/ Land cover - The arrangement of land units into a variety of categories based on the properties of the land or its suitability for a particular purpose. It has become an important tool in rural land-use planning.
- Macroinvertebrates - An organism that lacks a backbone and can be seen with the naked eye.
- Macrophyte - A large macroscopic plant used especially of aquatic forms such as kelp (variety of large brown seaweed which is a source of iodine and potash).
- Mesotrophic - Reservoirs and lakes which contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.
- Nitrogen - An essential nutrient in the food supply of plants and the diets of animals. Animals obtain it in nitrogen-containing compounds, particularly amino acids. Although the atmosphere is nearly 80% gaseous nitrogen, very few organisms have the ability to use it in this form. The higher plants normally obtain it from the soil after micro-organisms have converted the nitrogen into ammonia or nitrates, which they can then absorb.
- Non-point source pollution - Water pollution that can not be traced to a specific source. Human-made or human-induced pollution caused by diffuse, indefinable sources that are not regulated as point sources, resulting in the alteration of the chemical, physical, biological, and/or radiological integrity of the water.

- Oligotrophic - Deep lakes that have a low supply of nutrients and thus contain little organic matter. Such lakes are characterized by high water transparency and high dissolved oxygen.
- pH - A measure of the acidity or alkalinity of a material, liquid or solid. pH is represented on a scale of 0 to 14 with 7 representing a neutral state, 0 representing the most acid and 14, the most alkaline.
- Periphyton abundance - Microscopic underwater plants and animals that are firmly attached to solid surfaces such as rocks, logs, and pilings. In smaller streams this can indicate nutrient and thermal enrichment.
- Phosphorus - An element that while essential to life, contributes to the eutrophication of lakes and other bodies of water.
- Photosynthesis - The process by which plants transform carbon dioxide and water into carbohydrates and other compounds, using energy from the sun captured by chlorophyll in the plant. Oxygen is a by-product of the process. Photosynthesis is the essence of all plant life (autotrophic production) and hence of all animal life (heterotrophic production) on the planet Earth. The rate of photosynthesis depends on climate, intensity and duration of sunlight, available leaf area, soil nutrient availability, temperature, carbon dioxide concentration, and soil moisture regimes.
- Phytoplankton - Very tiny, often microscopic, plants found in fresh and saltwater. Phytoplankton drift near the surface of the water where there is plenty of sunlight for growth. Phytoplankton form the basis for all food chains.
- Point source pollution - Easily discernible source of water pollution such as a factories, gas stations, etc.
- Pollutant loading - The amount of polluting material that a transporting agent, such as a stream, a glacier, or the wind, is actually carrying at a given time.
- Residential discharge - Any flow of surface water or the collective flow of residential development generated in single and multi-family homes. May include storm water collected from the roof, lawn, driveway, a basement sump pump, or effluent from a malfunctioning septic system.
- Secchi disc transparency - A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded Secchi disc transparency.
- Sedimentation - 1. Process of deposition of waterborne or windborne sediment or other material; also refers to the infilling of bottom substrate in a waterbody by

- sediment (siltation). 2. When soil particles (sediment) settles to the bottom of a waterway.
- Specific conductance - A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called conductance.
 - Stormwater runoff - Stormwater runoff, snow melt runoff, and surface runoff and drainage; rainfall that does not infiltrate the ground or evaporate because of impervious land surfaces but instead flows onto adjacent land or watercourses or is routed into drain/sewer systems.
 - Stratification - Formation of water layers each with specific physical, chemical, and biological characteristics. As the density of water decreases due to surface heating, a stable situation develops with lighter water overlaying heavier and denser water. During stratification, dissolved oxygen, nutrients, and other parameters of water chemistry do not mix well between layers, establishing chemical as well as thermal gradients.
 - Submerged aquatic macrophyte - Large vegetation that lives at or below the water surface; an important habitat for young fish and other aquatic organisms.
 - Suspended solids - 1) Solids that either float on the surface or are suspended in water or other liquids, and which are largely removable by laboratory filtering. 2) The quantity of material removed from water in a laboratory test, as prescribed in standard methods for the examination of water and wastewater.
 - Thermocline - The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the Metalimnion.
 - Turbidity - A cloudy condition in water due to suspended silt or organic matter often attributable to algae blooms or increased sediment loads.
 - Water quality - The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.
 - Watershed management - A holistic approach applied within an area defined by hydrological, not political, boundaries, integrating the water quality impacts from both point and nonpoint sources. Watershed management has a premise that many water quality and ecosystem problems are better solved at the watershed scale rather than by examining the individual waterbodies or dischargers. Use, regulation and treatment of water and land resources of a watershed to accomplish stated objectives.

- Weed harvesting – A mechanical means of controlling the growth of aquatic macrophytes. Involves both the cutting and removal of macrophyte biomass. Can be implanted on large scale using floating barge like machines or a small-localized scale using hand tools.
- Zooplankton - Tiny, sometimes microscopic, floating, aquatic animals. Zooplankton generally feed upon phytoplankton and each other.