New Jersey Highlands Water Protection and Planning Council

Lake Management Plan Guidance

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Abstract

This technical document is intended to be used by planning and science professionals within a municipality to aid in the development of an Adaptive Lake Management strategy, by providing the tools to analyze lake management needs, set corresponding goals, identify appropriate solutions, implement those solutions, and establish ongoing monitoring and management tactics.

Although this document is intended primarily for use by municipalities within the Highlands Region (and grant funding is available to support associated work for municipalities that are conforming with the Highlands Regional Master Plan) the principles, strategies and methods outlined within are applicable to any municipality and may be of interest to other stakeholders.

Highlands Council New Jersey

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Statutory Platform, Purpose and Funding

Through the passage of the New Jersey Highlands Water Protection and Planning Act in 2004, the NJ Highlands Water Protection and Planning Council (the Highlands Council) was created and charged with developing a Regional Master Plan (RMP).* Adopted in 2008, the RMP serves as the guiding document for the long-term protection and restoration of the region's critical resources. This Lake Management Plan Guidance document was developed in accordance with Objective 1L6a of the RMP, which directs the Highlands Council to provide guidance related to watershed delineation, pollution sources, lake management techniques, and best management practices.

This is a technical document, intended to be used by planning and science professionals within a municipality to aid in the development of an Adaptive Lake Management strategy, by providing the tools to analyze lake management needs, set corresponding goals, identify appropriate solutions, implement those solutions, and establish ongoing monitoring and management tactics.

Funding to support this work within a municipality is provided through the Highlands Plan Conformance process. Municipalities with approved Plan Conformance Petitions are eligible for grant funding to cover the reasonable expenses of planning activities associated with the Conformance process and should contact their Highlands Council Municipal Liaison for additional information.

** Copies of the Highlands Regional Master Plan are available in most municipal offices and can be obtained by contacting the Highlands Council office.*

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Introduction

Within the boundaries of the New Jersey Highlands Region lies the greatest cluster of the largest lakes and reservoirs in New Jersey. A vast network of head-water streams, rivers, riparian corridors and wetlands are part of the watersheds draining to these waterbodies further defining and accentuating the natural resource value of these lakes. As per the Highlands Regional Master Plan (2008), cumulatively the region's lakes, streams and wetlands account for well over 122,000 acres and the associated riparian areas account for approximately two-fifths of the entire Highlands Region.

While some of the region's lakes are natural, geologically created features of the landscape, most are man-made impoundments. Many were constructed as far back as the Revolutionary War and helped shape the area's early land development patterns. Some had commercial importance providing hydro-power for local mills and foundries while others were an integral part of the barge canal transportation system that linked the eastern and western parts of the state. Many of the region's lakes, such as Lake Hopatcong, Lake Mohawk, Swartswood Lake and Greenwood Lake have long storied histories of serving as major recreational waterbodies, tourist destinations and local attractions. Today the lakes of the New Jersey Highlands Region are among the most heavily utilized water-based recreational facilities of the State.

In the latter part of the 1900s, the communities surrounding the majority of the Region's lakes transitioned from sleepy, summer enclaves to major population nodes. In almost every case this triggered changes in the character and ecology of these lakes. The features that originally attracted people to these lakes (clear water, natural shorelines, an abundant fishery, etc.) over time became compromised as land was cleared, developed and paved. Algae blooms became more prevalent, changes in the fish and wildlife communities occurred, and water quality in general began to deteriorate. These are all common results of the acceleration of the lake eutrophication process. While eutrophication, or the "aging" of a lake, is a natural occurrence, anthropogenic activities can radically speed up the process and cause a wide array of water quality and ecological problems that negatively affect the aesthetic and recreational attributes of the waterbody.

High standards have been set by both area residents and seasonal users for the region's lakes and ponds. The public mandates maintenance of a high level of water quality for each lake and pond, even with the increased transformation, encroachment, and development of their surrounding watershed. This makes managing the lake resources of the New Jersey Highlands Region very challenging. To meet these somewhat diverging goals, technically sound, pro-active lake and watershed management is needed. Accomplishing this objective is daunting and cannot be achieved without a properly prepared lake management plan.

A successful lake management plan requires good science, planning and engineering. It also requires an understanding of the functional goals, objectives and vision of the lake community. As such, the development of the plan is both a scientific and social effort. At the end of the process, if done correctly, the lake management plan becomes the ecological blueprint for the immediate and future proper care of the subject lake.

Although all lake and pond ecosystems benefit from proper management and maintenance, the approach taken when dealing with a relatively un-impacted lake will be different, though related, to the approach taken when dealing with a highly impacted lake. For the former, the effort will focus more on preservation and enhancement, while for the latter, restoration and mitigation will need to be emphasized. Basically, this means that there is no "standard" strategy or approach for the management of a lake. Although each lake and pond ecosystem is unique, certain strategies, such as nutrient load reduction, are fairly universal elements of most lake management plans. This is why each lake and pond needs its own management plan so that each waterbody's challenges can be correctly assessed and the proper remedial measures implemented.

Throughout this guidance document, the concept of Adaptive Lake Management will be emphasized. As will be detailed in Chapter 3, Adaptive Lake Management is a dynamic process that is grounded in the preparation of a technically sound database. The data define and quantify the key attributes of the lake and its watershed. The subsequent analysis of these data will lead to the correct identification of the waterbody's problems and the proper prioritization of the management and restoration measures needed to correct those problems. When approached in this manner, there is an increased certainty that the implementation of the selected restoration and management measures, actions and techniques will lead to sustainable improvements in lake quality. The plan's ultimate goal is the control of the eutrophication process. As will be demonstrated, a properly conceived and developed plan will enable a lake community to maintain the ecological requirements of the lake or pond and satisfy the aesthetic and recreational needs of the user community.

In summary, the purpose of this document is to provide the reader with guidance in the preparation of a lake management plan. It can be viewed as a "cook book" or "blueprint" that identifies the "what" and "how" of preparing a successful plan and then implementing that plan using an adaptive management approach. Following the Adaptive Lake Management approach, the plan itself is by definition intended to be modified over time to account for "lessons learned, successes, new information, changes in the lake and public input." It is thus organic and by design meant to aid the community in meeting existing lake management challenges while at the same time serving as the framework for ongoing management needs.

Chapter 1 — Lake Management within the Highlands Region: Historical Overview

1.1 The Lakes of the Highlands Region

There is a great diversity of lake ecosystems within the Highlands Region. Some waterbodies are relatively pristine (such as Wawayanda Lake in Vernon Township, Sussex County) and have remained unaffected by watershed development, while many others are highly altered and characterized by conditions clearly resulting from accelerated eutrophication. As such, the region's lakes span a broad range of biological productivity; often referred to by lake scientists as "trophic state." Those waterbodies with the least developed watersheds typically fall into the oligotrophic (low productivity) class. Those with moderately developed watersheds are often characterized as mesotrophic (medium productivity) waterbodies. The lakes and ponds having the most extensively developed watersheds range from moderately to highly eutrophic (highly productive) waterbodies.

As noted in the Introduction, the vast majority of lakes and ponds in New Jersey are man-made or man-enlarged. Most lakes were created by damming a river or by erecting a dam to expand the impounded area of a naturally created, glacial lake. Many of the region's ponds were excavated to tap into the groundwater or created by diverting water from an adjacent stream or wetland. Regardless of their origin, the region's lakes and ponds provide recreational, aesthetics, water power/supply or commercial functions and services to the surrounding communities. The fact that people are attracted to lakes is part of the reason why the watersheds of the Highlands Region's lakes became increasingly developed over the past few decades. However, as a watershed develops, the attributes that draw the public to these lakes become compromised. Increased human activity leads to changes in the ecology of the lakes and a decline in water quality. Sediment infilling, larger and more persistent algal blooms and greater aquatic weed growth are some of the more common impairments triggered by accelerated eutrophication. Although the public cannot easily relate to "elevated phosphorus levels" or "exceedances in total suspended solids," they do relate to the ramifications of algae blooms, nuisance densities of aquatic weeds, beach closures, declining fisheries and lost water depth.

The development of lands around the Region's lakes for the most part intensified in the 1950s. This led to stormwater and wastewater related issues that quickly started to negatively affect the lakes. With respect to stormwater runoff, the common practice was to essentially collect, concentrate and then discharge the stormwater into the lake with little thought given to the negative consequences of the sediments, nutrients and other pollutants present in the runoff. With respect to wastewater, treatment was accomplished using very rudimentary techniques. When present, septic systems tended to be undersized because the homes were intended only for summer use, not year-round residency. Because the Region's native soils have limited depth to groundwater or bedrock, the actual level of wastewater treatment provided by these systems tended to be limited as well. As the communities aged, development intensified, summer homes were converted to full-time residences, and stormwater and wastewater impacts became increasingly pervasive and significant.

The above noted changes in land use and watershed development have led to water quality problems and impairments. However, these problems are not unique to the lakes of the New Jersey Highlands Region, but have occurred nationwide. Presently, most of the water quality problems facing the nation's lakes are a function of non-point source pollution that can be directly linked to land development, inadequate stormwater management, suboptimal septic management and an ecological disconnect between the lake and its watershed. This decline in water quality is accompanied by a loss in the aesthetic attributes and recreational opportunities provided by these waterbodies.

As difficult as it may seem, facilitating multiple lake community goals including watershed development, social needs and expectations, and maintenance of the ecological integrity of a lake ecosystem can be achieved. To be successful, the long-term management of the causes and impacts of the lake's accelerated eutrophication must be correctly defined and quantified. This process begins with developing a clear understanding of the ecological and assimilative capacity of the lake ecosystem in question. Thus, before initiating any restoration efforts, a sound water quality database must be developed. This database must encompass the critical elements of the lake's hydrology, morphometry (shape), water chemistry, biota, pollutant load and trophic state. The management plan needed to correct the lake's problems and protect it from further degradation must evolve from these data. A lake management plan, when properly formulated, can provide the balance between the contradictory goals of watershed development and lake restoration.

Chapter 2 — An Overview of the Process and Impacts of Lake Eutrophication

2.1 Eutrophication

As previously discussed, the majority of the negative water quality impacts to the lakes of the Highlands Region are due to non-point source pollution and accelerated eutrophication. Other issues that necessitate the implementation of some form of management or planning on the community level include competing recreational uses, shoreline clearing/modification, and water level manipulation. However, it is excessive macrophyte and algae growth that lead to the lake quality impacts that most often trigger the need for lake management. This excessive growth and related problems are the direct result of nutrient loading, which causes lake eutrophication. In order to properly and successfully manage a lake, it is important to fully understand the process of eutrophication, from its causes to its ramifications.

Eutrophication is a natural process that affects all lakes, reservoirs and ponds. The North American Lake Management Society (NALMS, 2004) defines eutrophication as an increase in biological productivity stimulated by the introduction of inorganic nutrients and organic matter. This increase in biological productivity is typically reflected as an increase in the density of phytoplankton, filamenous algae and/or macrophytes (aquatic weeds). In northern New Jersey increases in phosphorus loading is most often the primary factor responsible for the enrichment of the waterbody leading to this increase in biological productivity. While eutrophication is commonly defined as increased biological productivity, there are a multitude of other symptomatic effects associated with eutrophication including increased sedimentation, declines in species diversity, altered water transparency, prevalence of invasive species and altered dissolved oxygen and nutrient dynamics. While the implications of eutrophication are far reaching, the causes of eutrophication are initially derived from the watershed.

2.2 Lake and Watershed Interactions

As introduced in Chapter 1, there is a direct linkage between a lake and its watershed. What is often lacking in lake management plans is the study and understanding of this linkage. NALMS promotes the notion that a "lake is a reflection of its watershed," meaning that the condition of a lake is directly related to the condition of the lake's watershed. Lakes categorized as low-productivity are usually associated with watersheds characterized by little if any disturbance, whether residential/commercial development or agriculture. Conversely, highly productive lakes are most commonly associated with watersheds that have become extensively developed or intensively farmed. As such, it is fair to state that eutrophication-related problems observed in a lake are primarily linked to the nature of the lake's contributing watershed. In short, there is a direct relationship between the rate of lake eutrophication and the intensity of development and related land uses occurring within the lake's watershed.

The reason for this direct linkage is the relationship that exists between land development and pollutant transport. Over time, as the lands surrounding a lake evolve from an undisturbed, forested state to farmland, suburban development and/or cityscape, there is an associated loss of the natural processes and ecological services once characteristic of the watershed. This is best reflected in increases in the volume and rate of stormwater runoff and the decrease in the recharge of precipitation that occurs as a watershed becomes progressively developed. This change is triggered by the loss of natural ground cover and vegetation, increased compaction of soils and an increase in the amount of impervious cover (pavement), and the direction of stormwater flows to concentrated channels. These types of land use changes promote the generation of stormwater runoff, as opposed to the infiltration and recharge of precipitation.

As previously noted, the resulting increase in runoff volume and the rate at which this runoff is generated during every storm event sets the stage for the increased mobilization and subsequent transport of "pollutants." Initially, as the vegetation and landscape of a watershed is altered from a natural state to a developed condition, most of these "pollutants" may be in the form of eroded soils and dissolved and particulate nutrients (phosphorus and nitrogen). As the watershed becomes increasingly developed, the concentration and total amount of these pollutants transported into the lake will increase. Depending on the type of development, the variety of pollutants will also increase and may include pollutants such as nutrients. pesticides, petroleum hydrocarbons, pathogens, and heavy metals. These pollutants not only affect the lake's productivity but can impair the lake's biota through decreasing species richness and create health-related issues for humans.

Increased agricultural use also modifies watersheds, often through soil disturbance and fertilizer and pesticide inputs. Tilling of the soil may allow the creation of rills and gullies, transporting water faster to the streams feeding a lake. Although most of the Highlands Region's larger lakes have limited agricultural land within their drainage areas, there are a number of watersheds supporting a fair amount of agricultural uses.

The increase in the rate and volume of runoff associated with watershed development will also start to degrade the stability, ecology and water chemistry of the lake's tributary streams. Not only does this damage the environmental integrity of these waterways, but it increases the introduction of silt and sediment to the receiving lake as a result of stream bed and bank erosion. These problems are further exacerbated by encroachment of development into the floodplain and riparian areas associated with these streams. This increases the frequency and magnitude of flooding, stream bank erosion, and pollutant transport. The common response to the flooding and erosion of streams triggered by watershed development and floodplain encroachments has been to channelize the impacted streams, or even worse, place the flow from these streams into pipes and culverts. These types of "corrective actions" further disconnect the lake from all of the natural functions and ecological services of its attendant streams and contributing watershed resulting in only more runoff, erosion and pollutant related impacts. The resulting siltation can also reduce lake depth, which may facilitate excessive weed growth and increase boat damage.

In short, the anthropogenic alteration of a lake's watershed hastens the eutrophication process, a condition referred to as "accelerated cultural eutrophication." In addition to an increase in autotrophic productivity, there are additional water quality impairments associated with eutrophication such as increased sediment infilling, declining species diversity, and declines in water clarity. The water quality problems that then arise reduce the lake's ability to satisfy its ecological, recreational, and aesthetic functions. It is often at this point that the lake community realizes there is a problem and initiates actions intended to remediate the lake and restore its functions. Unfortunately, the management plans developed in response to declining recreational use and aesthetics tend to be very reactive and focused on addressing the symptoms of eutrophication. Such plans are never successful over the long-term.

Chapter 3 — Basic Tenants of an Adaptive Lake Management Plan

3.1 Introduction to Lake Management Planning

There are eight basic steps in the development of a lake management plan:

1. **Organize Stakeholders** – Bring together and organize stakeholders and others willing to participate actively in the management of the lake.

2. **Conduct a Situational Analysis** – This analysis involves the integration of the management goals of the lake community with the scientific attributes of the lake. Although the lake management plan will be largely based on the various limnological and watershed related data, valuable and insightful information and direction will be obtained through input obtained from the community of lake users and residents regarding their "vision" of the lake.

3. **Set Measurable Goals and Objectives** – A successful lake management plan must have clearly defined objectives and both short and long-term goals. The refinement of vision into clear, distinct, measurable objectives will allow for logical, systematic progress towards improving lake conditions and achieving the goals of the lake user community.

4. **Evaluate Solutions and Alternatives** – Given the complexities and intricacies of lake ecosystems, multiple options may exist by which short- and long-term management goals may be met. Prudent decision making during this step of plan development will help identify the most technically feasible and cost-efficient options to meet a specific management objective. Solutions should be evaluated in a holistic manner that addresses both the lake and its watershed. Doing so will often support the prioritization of watershed-based corrective actions in the advancement of the implementation of substantial in-lake management efforts (e.g., dredging versus sediment control).

5. **Identify All Regulatory Constraints and Required Permits** – Although lake restoration and management are environmentally positive actions, they are often regulated by Federal, State and Local rules, laws or ordinances. It is important to identify early in the process the regulatory constraints and identify any permits or approvals that will be needed in order to implement the various elements of the management plan. Thus it is imperative to review the plan and plan components within the context of Federal and State regulations, local zoning requirements and/or ordinances and other regulatory related factors that will come into play in implementation of the management plan.

6. **Take Action** – The implementation of corrective actions represents the crux of the lake management plan. As has been emphasized, these actions need to be pragmatic and achieve both long- and short-term goals. Best management practices that reduce nutrient loading or

otherwise help to correct lake impairment will often be prioritized. However, measures may also need to be taken to correct or control recreational use and aesthetic impacts. Although these may be short-term measures that address the symptoms rather than the causes of lake eutrophication, in many cases they will need to be elevated in terms of their prioritization in the plan given their direct benefit to the lake community.

7. **Evaluate and Monitor Effectiveness of Implemented Actions** – Lake management is not a precise and exact science. Lakes and their associated watersheds are extremely complex, dynamic systems. As such, implementation of even the best designed lake management plan may not yield the expected results. Therefore, continued monitoring should be conducted following implementation in order to gauge the relative success of the plan. These data will identify the need for changes to the plan. This adaptive management approach will enable the lake community to re-prioritize or tailor management plan elements. Recognizing this reality, the community must be patient. Improvements in lake quality or the correction of lake problems is often a slow process. A well-designed plan will recognize this prospect and will accommodate the needed flexibility without compromising the overall goals and objectives of the plan.

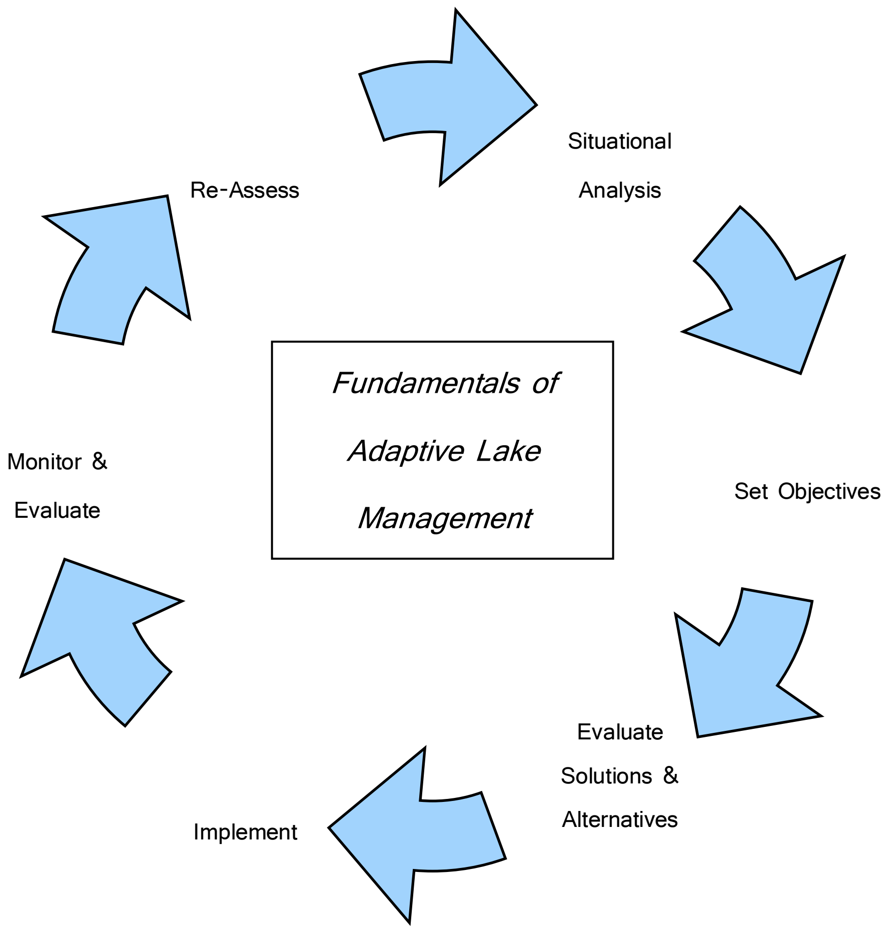
8. **Reassess and Modify/Update Plan** – Reassessment is an integral element of the adaptive management approach and serves to measure achievement of the plan's short-term goals. Continual assessment of implemented lake management activities, their effects on the lake, and ever-changing lake conditions is critical. As the lake's problems are addressed, mitigated or minimized, reassessment will serve to direct where future management efforts should be focused.

3.2 Adaptive Lake Management

Adaptive Management is a common technique used in management and restoration of natural resources. Adaptive Management acknowledges the complexity of ecological systems and sets out an approach that anticipates changing parameters and allows for contingency decisions.

Adaptive Lake Management deals with lakes as complex living systems and provides a flexible framework within which to set and then redefine management goals. The lake ecosystem is characterized by interactions among its physical, biological, chemical and hydrologic attributes. Modification of one lake attribute may trigger a change in another lake attribute. Adaptive Lake Management incorporates this dynamic nature and produces an adaptable management plan. The framework of an Adaptive Lake Management Plan will be discussed in greater detail in Chapter 4, but can be summarized by the following illustration.

Figure 1 – Adaptive Lake Management



The process begins with an assessment of existing conditions (Situational Analysis) and the identification of goals and objectives. Data are collected, alternative solutions are evaluated, and the recommended plan is implemented. Upon Monitoring and Evaluation, the effectiveness of the implemented restoration and management is measured and the management plan is modified as needed. Thus, as improvements are achieved in the water quality, aesthetic, and recreational attributes of the lake, a new Situational Analysis is conducted and Goals and Objectives are revised, leading to continued improvements. Ultimately, the goal of Adaptive Lake Management is a sustainable, ecologically balanced lake ecosystem.

This Lake Management Plan guidance document is designed to assist lake communities, whether private or public, in preparing a lake management plan that is grounded in the Adaptive Lake Management process. The goal is to provide stakeholders and those charged with the management and restoration of a lake, pond or reservoir with a road map leading to sustainable improvements.

Chapter 4 provides the framework for a detailed Situational Analysis. The Situational Analysis is the key to understanding your lake and is the fundamental first step in the lake management plan process. Chapter 5 provides specific technical guidance in collecting the data needed to properly investigate your lake. Finally, Chapter 6 provides an overview of some of the more commonly implemented lake management and restoration techniques.

Chapter 4 — Getting to Know Your Lake

4.1 Getting Started

As noted in the Highlands Regional Master Plan (RMP), the "Highlands Region lakes offer recreation opportunities, and are the defining features of many distinct communities." The RMP also notes that the quality of many of the Region's lakes has declined due to "overbuilt, damaged and poorly managed shoreland areas," the influx of pollutants and loss of the ecological values associated with a well-functioning lake ecosystem. Reversing these impacts requires a well-designed and properly orchestrated lake and watershed management plan.

4.2 Moving Forward

The success of a lake management plan begins with properly identifying the root cause of the lake's problem(s). This requires the collection of data and the preparation of a dataset robust enough to properly evaluate and ultimately rank those factors responsible for the root cause of the lake's problems. Despite the complexity of a detailed lake study, a systematic lake management plan provides the direction and the focus that will allow for the successful attainment of both short and long-term management goals. This chapter presents:

- The framework of a technically sound lake study,
- How lake study data are used to develop the lake management plan, and
- How to engage the lake user community and other stakeholders in support of plan implementation.

4.3 Lakes and Ponds are Defined by Physical, Chemical, Hydrologic, and Biological Interactions

The science of lake eutrophication involves studying and understanding the interactions that affect the overall ecological quality or "health" of a lake. It also involves investigating and understanding the linkages between a lake and its watershed. There are four basic categories of interactions that define a lake: physical, chemical, hydrologic, and biological.

> **Physical** interactions are defined by the surface area, average (mean) depth, maximum depth and volume of the waterbody. These attributes of a lake or pond are relatively static and easy to measure. However, they are critically important, as they affect the other attributes of a waterbody. These are also "must know" attributes used in the design and implementation of some of the most basic lake restoration/management techniques such as aeration and algae treatments.
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> **Chemical** interactions are defined by the makeup of the water; that is the concentration of various minerals, nutrients and other dissolved and suspended constituents present in the water column. It is important to note that the chemical makeup of the water will change

seasonally and annually. As a result, this attribute is best defined by a robust dataset rather than collection of unlinked, sampling events.

Hydrologic interactions of lakes and ponds are among the most difficult to measure and are often either overlooked or inadequately studied. Although hydrologic interactions can be simplified to an understanding of the amount of water entering and the amount of water leaving a lake or pond over time, its quantification can be difficult. The hydrology of a lake or pond can be viewed as a conveyor belt bringing in nutrients, sediments and pollutants from the surrounding watershed and in turn flushing out the lake or pond. As with the chemical properties of a lake or pond, the hydrologic properties vary substantially from month-to-month and year-to-year.

While the **Biology** of a lake may appear somewhat straightforward, there are numerous linkages and interactions that necessitate studying the intricacies of the waterbody's food-web. There are interactions that exist between phytoplankton and zooplankton, fish and zooplankton, as well as plants and algae that affect the water quality and appearance of a lake or pond, and greatly define the recreational and aesthetic qualities of the waterbody.

A clear understanding of these fundamental interactions is the foundation of an adaptive lake management plan. An adaptive lake management plan is the key to successful and sustainable lake restoration and management. The common thread connecting the case study examples provided in Appendix A is that each involved a study period that led to an analysis of the collected data that in turn led to the development of a comprehensive, multidimensional lake management plan. The ability to successfully improve the quality and sustain the condition of a lake is intimately linked to the fact that time was taken to understand the fundamental interactions defining the waterbody. The success of these projects is also a result of implementing a proactive approach that focuses on correcting the root cause of the waterbody's eutrophication as opposed to simply reacting to the symptoms of eutrophication. The sustainability of the improvements is a function of the continued monitoring and re-evaluation of lake conditions, and the modification or re-prioritization of lake management efforts based on the data.

4.4 How Much Data?

The proper study of a lake requires data, as does the preparation of a comprehensive management plan. It is imperative that the database developed during the Situational Analysis phase of an adaptive lake management study provides enough critical information to examine and understand the various physical, chemical, hydrologic and biological interactions that define a lake or pond ecosystem. These data must also correctly establish the linkages between a lake and its watershed. Chapter 5 provides details concerning the sampling protocols, data collection techniques, desktop models, and various analytical tools used to assess the status of a lake or pond.

Prior to initiating data collection, any existing data should be reviewed. The information should be sorted into the four main categories of data collection needs: physical, chemical, hydrologic and biological. The quality of any existing data should also be assessed. For example: were the data collected following proper protocols or standard operating procedures? When examining laboratory results, confirm that the analyses were conducted by a NJDEP certified laboratory or university and that the detection limits (lowest measurable concentration) for key parameters are appropriate. It is common that detection limits for total phosphorus tests conducted by wastewater certified laboratories are too high (typically > 0.1 mg/L) making the resulting data of limited value. However, even if existing available or historic data do not meet quality standards for use in the preparation of the Lake Management Plan, these data can provide some insight into the lake's overall conditions or help better define the severity of the lake's problems. A source of data or information commonly falling into this category is algae and weed treatment daily or annual reports. At a minimum, these reports provide a good overview of the types of problem algae or aquatic plants present in the lake and the successes of the measures implemented to control this growth. However, because these reports tend to be more informative as opposed to technically based, they are not always a reliable data source for use in the preparation of the Lake Management Plan.

In terms of data minimums, the following is recommended:

- The area, maximum depth, mean depth and volume of lake
- Annual volume of water entering or leaving the lake
- Water quality data, consisting of the following, collected at least in April, May, June, July, August, October and November
    - For lakes deeper than 6 feet dissolved oxygen (DO), pH, temperature, conductivity, and total alkalinity data collected in profile from surface to bottom at 1 meter (3 feet) increments
    - Total phosphorus and nitrogen concentrations measured at surface and bottom
    - Secchi clarity (Please note: because Secchi transparency is the simplest and easiest measurement, this should be measured weekly.)
- Accurate identification of the types of zooplankton, phytoplankton and macroalgae present in the lake in May, July and August
- Accurate identification of aquatic plants present in lake, including assessment of each plant's density and distribution as measured in May, July and August

4.5 Goal Setting

The Adaptive Lake Management approach requires stakeholders to set reasonable management or restoration goals and objectives. Because most of the problems affecting the lakes of the Highlands Region are a function of too much algae/phytoplankton growth, too much aquatic plant (weed) growth, or poor clarity, most lake management plans must include actions designed to reduce or control these impairments in a sustainable manner. For example, a reasonable goal for most of the lakes in the Highlands Region is the maintenance of a mid-summer Secchi transparency depth of 1 meter (approximately 3 feet). A reasonable project objective linked to this goal would be to reduce the lake's phosphorus load by, for example, 30%. Another related objective would be to control algae bloom development, for example by closely monitoring algal assemblages, implementing algal control strategies before peak bloom conditions, but doing so while limiting the use of algaecides (i.e., using algaecides in low concentrations, if at all).

In the case of goal setting, it is important to balance the previously referenced short-term user need solutions with the long-term water quality or ecological needs. While the ultimate goal of any lake management plan is to improve the overall quality of the subject lake by correcting the cause(s) of eutrophication, the symptoms of eutrophication must also be mitigated. Algae blooms, excessive weed growth, poor clarity, and sedimentation all directly affect the recreational use and aesthetics of a lake. Mitigation of these problems is therefore of critical importance to the lake users and stakeholders. Lake management efforts must be sensitive to the perspective of lake users and other stakeholders, addressing those circumstances that affect their view of the lake and its public benefits. As such, goal setting needs to focus on achieving sustainable, ecologically-based lake quality improvements, while improving the aesthetic condition of the lake for the benefit of lake users. An overview of the more commonly implemented in-lake and watershed based restoration and management measures are provided at the end of Chapter 5.

4.6 Gaining Public Support

The success of a lake management plan is weighted heavily by the ability to attain broad public support. Gaining public support requires outreach and engagement of lake stakeholders. The credibility of the lake management plan, and ultimately its success, is dependent upon endorsement from the various stakeholders. An effective lake management plan should provide assurances to lake users and stakeholders that the lake restoration recommendations and guidance will ultimately yield positive results.

Implementation of a lake management plan will occur in phases. The Solutions and Alternatives Evaluation component of the adaptive management approach will provide guidance concerning how to prioritize recommended management techniques. This step will also provide guidance concerning how to integrate and balance short-term and long-term restoration measures.

Sharing this information with stakeholders may ensure continuing public support. By keeping the user community and stakeholders informed and engaged, expectations are managed and the plan is allowed to evolve. This is also where balancing short-term and long-term restoration measures comes into play. By taking steps to control algae blooms, while at the same time implementing phosphorus reduction strategies, the immediate concerns of the lake users are satisfied, while still moving toward the attainment of the overall goal of the plan. Each of the examples provided in Appendix A had a strong public education and outreach element.

Chapter 5 — Preparation of an Adaptive Lake Management Plan

5.1 Database Development

The development of a successful lake management or restoration plan is predicated on the fact that each lake is unique. Each lake and its associated watershed should be viewed as an integral component of a biotic community of which humans are a part. A management plan should be designed to function holistically to help preserve the integrity, stability and beauty of the biotic community. All stakeholders in lake management, from lakefront homeowners and marina proprietors to drinking water users and future generations, should be considered when identifying problems and clarifying goals in the genesis of a lake management plan. A distillation of this process simply reflects the inclusion of all stakeholder opinions in the development of a management plan, as the success of lake restoration is not possible without the collective effort of the community. The community, in concert with guidance from a lake management professional, should come together to accurately define the specific problems the lake is facing and set up a plan that will:

- Collect the data necessary to identify the causes of eutrophication and other damage to lake functions,
- Utilize the data to assess and prioritize projects that will slow the rate of eutrophication and other lake impairments, and
- Implement these projects and assess water quality progress through monitoring.

Understanding the origin of the target lake, defining its current trophic state, and projecting water quality changes due to in-lake or watershed management efforts are key components in managing a waterbody and are the backbone of a proper lake management plan. This information can only be obtained through a proper diagnostic study which is comprised of a data collection phase, which serves to accurately characterize pertinent biological, chemical and physical components of a lake and its associated watershed.

The data collected from the diagnostic phase of a lake management or restoration plan are subsequently used as the empirical basis for the implementation of watershed and in-lake management efforts that will slow the rate of eutrophication and correct anthropogenic perturbations affecting the lakes or watersheds. Restoration/management efforts will ultimately address water quality problems identified in the initial phases of the plan and serve as the scientific means for slowing the rate of eutrophication and either restoring a waterbody to its original condition or improving water quality conditions so that the designated uses of the lake may be attained.

Lake management/restoration does not terminate once in-lake or watershed implementation projects have completed. These projects must be evaluated through post monitoring to gauge their effectiveness. Also, as previously mentioned, lakes are dynamic systems in a state of continual flux.

Any changes in nutrient loading, trophic dynamics, hydrology, watershed land use, or a myriad of other environmental conditions will ultimately result in a change within the lake ecosystem. While the goal of lake management/restoration is to implement changes that create positive environmental feedback, it is impossible to know the full implications of any lake management technique. As such, continued monitoring is necessary to collect the limnological data necessary to protect the biotic integrity of the lake.

The following sections of this document discuss several data collection components critical to the development of the diagnostic component of a lake management plan. Specifically, these components include defining a lake's water quality, biota, morphometry, hydrologic and pollutant budgets, and trophic state. Each section will explain the applicability and utilization of the different data collection phases.

5.2 Limnological Data Collection and Analysis

5.2.1 Primary Components

This section provides a discussion of the applicability, utilization and methods for conducting a basic lake diagnostic study of lake systems greater than 50 acres in size. Simplified versions of these methods may be used for smaller lakes (i.e. < 50 acres) to gain similar information while using less refined techniques. As previously mentioned, lakes are dynamic systems and additional monitoring may be needed based on specific water quality issues or designated usages.

In-Lake Data Collection - Water Quality Monitoring

A central tenet to developing a successful lake management or restoration plan lies in identifying water quality impairments and taking corrective actions to mitigate the processes that are leading to degraded water quality. Water quality impairments are often experienced by lake users through aesthetic or recreational impacts such as unsightly or foul-smelling algal blooms or excessive densities of aquatic macrophytes, which impede boating, fishing or swimming. While observations are important in identifying water quality impacts, and are often the impetus for the development of a management plan, such information is highly subjective and is generally influenced by a person's use of the lake and the water quality conditions that support such use. For instance, fishermen would generally prefer greater aquatic weed biomass as this would provide an ample base for a robust trophic web thereby leading to large game fish. Conversely, many boaters or swimmers may find the level of algal and weed growth a hindrance to their recreational enjoyment of the lake. Given the inherent variability in subjective measures of water quality, it is necessary to develop an empirical, scientifically based water quality monitoring program for each lake.

A properly designed lake monitoring program should serve to monitor key biological, physical and chemical parameters of a lake system and accurately account for the natural temporal and spatial variability which exists in all lakes. Development of a water quality monitoring program need not be overly complex in order to develop a useful dataset that can be used to identify water quality impairments while helping filter out natural ecological variability or extreme conditions due to climatic or hydrologic conditions.

Foremost to the development of a proper lake management plan is the inclusion of all interested stakeholders such as lakefront residents, recreational users, waterfront businesses, municipal and county public works (where public roads are a major potential issue), municipal and county parks (where significant active recreational facilities are near the lake), or members of a lake association. The inclusion of those who have the greatest vested interest in the lake and are in the closest spatial proximity to the waterbody will provide incentive for both accurate and consistent data, two characteristics that are paramount to water quality monitoring. A water quality monitoring plan may be developed by volunteers or laypeople, but should include input from a qualified lake professional in order to monitor for those parameters that are most pertinent to lake systems while avoiding common pitfalls associated with collecting unnecessary data or frequent collection of parameters which generally exhibit little spatial or temporal variability. In addition, water quality monitoring can be carried out by lake professionals or volunteers, but only by the latter after they have received proper training. Once the personnel who are going to develop the monitoring plan are selected, some common questions and concerns need to be addressed.

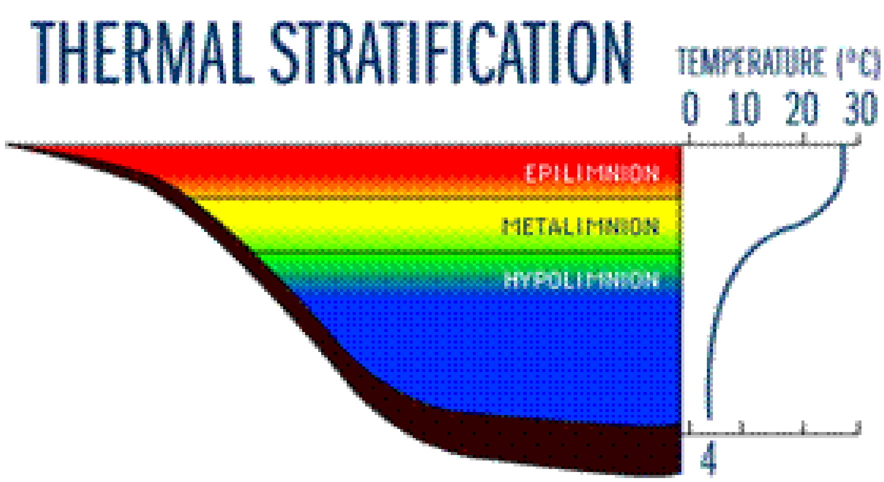
Given that lakes are dynamic systems, exhibiting variability in space and time due to both natural and anthropogenic factors, a water quality monitoring plan must account for this variability. At a minimum, most water quality monitoring plans are conducted monthly, from May through September, as this period represents the "growing season" for lakes in the Highlands Region. The growing season is the critical time during the year when the symptoms of eutrophication and excessive plant and algal growth are most pronounced and are the greatest nuisance to lake users. As such, many lakes, especially large lakes (surface area > 50 acres or complex in shape), should be monitored for in-situ parameters on a bi-weekly basis while discrete and plankton parameters should be monitored, at a minimum, on a monthly basis during the growing season.

In-situ parameters (temperature, specific conductance, dissolved oxygen and pH) should be sampled throughout the water column, at 0.5 – 1.0 meter depth intervals, on a bi-weekly basis. Monitoring of in-situ parameters is generally conducted utilizing a water quality meter that contains multiple sensors to analyze the aforementioned parameters. In addition, Secchi disk transparency should be measured, at a minimum, once every two weeks. The Secchi disk is a 20 cm disk, marked with alternating black and white quadrats, which is attached to a line or rope; demarcated in meters. In order to take a Secchi disk measurement, the user should lower the disk until it is not visible, retrieve slowly until visible again, and then average those two depths for the Secchi disk depth. This depth correlates with the amount of turbidity in the water and therefore provides an easy means of estimating water clarity and impairments due to suspensions of algae or inorganic particulates. The Secchi disk depth, in meters, divided by 1.7 yields an attenuation coefficient for the available light averaged over the Secchi disk depth.

Discrete chemical sampling of nutrient parameters should occur, at a minimum, once every month during the growing season. Typical discrete parameters include total and soluble reactive phosphorus, ammonia, nitrate, total suspended solids and chlorophyll *a*. Alkalinity and hardness should also be measured once a month for the first year but only approximately every 3 years following the initial sampling as these parameters do not exhibit high temporal variability. Furthermore, the phytoplankton and zooplankton community should be sampled on a monthly basis and identified to, at a minimum, the most dominant genera.

Lake sampling stations are ultimately dictated by the morphometry (shape) of the lake. Those lakes that are round in shape, and of generally homogenous depth, may be sampled from a single, central location. Conversely, lakes with highly irregular shorelines should be sampled at a central, deep water location and throughout any significant coves as these areas may exhibit marked variations in water quality. Spatial variation in water quality in dendritic (branching) lakes may result from numerous factors including local influences from tributary inflow, shoreline residences, temperature variability, light penetration and prevailing winds.

Figure 2: Thermal Stratification



Source: http://www.lakeaccess.org/russ/temperature.htm

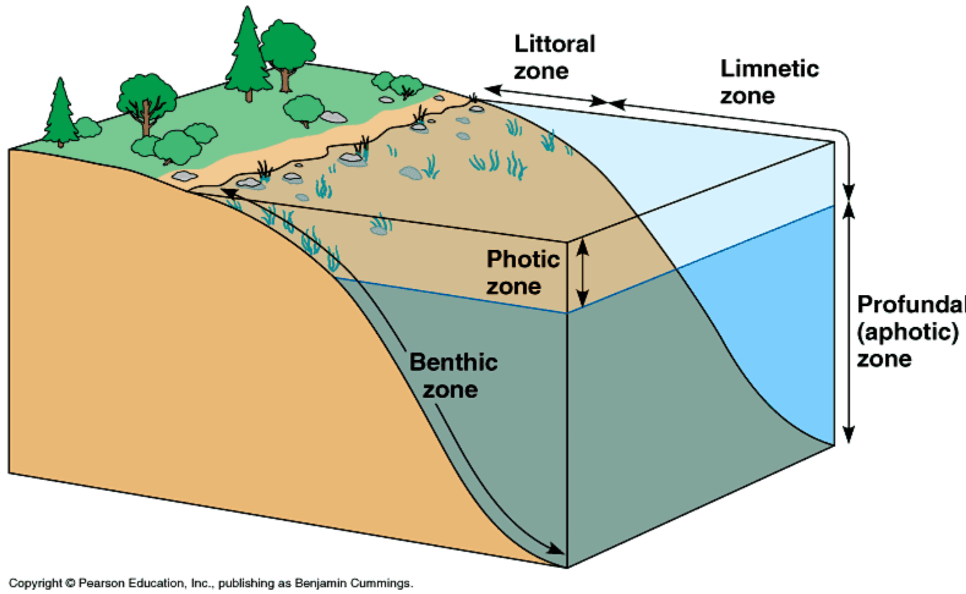
At deep sampling stations (depth, or “Z” > 20 feet) lakes may exhibit strong thermal stratification during the growing season. Summer thermal stratification results when increasing solar radiation and air temperatures, in conjunction with a few days of little wind activity, combine to heat the upper portion of the water column. Thermal stratification consists of a relatively warm upper water layer, termed the epilimnion, a transition zone, termed the metalimnion or thermocline, and a cold, deep water layer, termed the hypolimnion (Figure 2). The density differences imparted through thermal stratification serve to inhibit wind driven mixing of the water column thereby effectively sealing off the hypolimnetic layer from contact with the atmosphere. This phenomenon has important implications in that bottom waters of thermally stratified systems may become devoid of oxygen due to excessive bacterial decomposition of organic matter and a lack of atmospheric replenishment of dissolved oxygen through diffusion. Resultant conditions of hypolimnetic anoxia include internal sediment release of metals and phosphorus into the water column and reduced fish habitat. When the thermal stratification disappears (generally in the fall for most lakes), the metals and nutrients can cycle into the entire water column and cause major water quality changes. As such, water quality parameters within the epilimnetic and hypolimnetic zones are often markedly different. Therefore, in-situ measurement of temperature should be utilized to determine if the lake is thermally stratified. If stratification does exist, then discrete water quality samples should be taken approximately 0.5 m below the water's surface and approximately 1.0 m above the lake's sediment. Chlorophyll *a* should only be measured within the photic zone (approximately two times the Secchi depth) as this is the zone which receives enough sunlight for photosynthesis.

In-Lake Data Collection - Lake Morphometry/Bathymetric Surveys

Lake morphometry is defined as the physical dimensions of a lake and is determined through a combination of surface mapping and a bathymetric survey. Through bathymetric surveys, data are collected pertaining to the depths of water and unconsolidated sediments throughout a lake. Such data are commonly presented as maps which depict contour lines of water depth and depth of unconsolidated sediments. Furthermore, statistical data are calculated such as lake surface area, shoreline length and the depths and volumes of water and unconsolidated sediments. Lake morphometry, in concert with watershed characteristics, are the primary determinants of the physical, chemical and biotic characteristics of lakes. The shape of a lake basin can generally be broken down into three distinct zones which are primarily determined by lake origin but may be altered by anthropogenic activities both within the lake proper and throughout the watershed. These zones are as follows (Figure 3):

- **Littoral Zone** – The near shore region of lakes where the sediments lie within the photic zone, and where the shallow water flora is frequently dominated by macrophytes.
- **Limnetic Zone** – The open water region beyond the littoral zone. Primary productivity is dominated by phytoplankton.
- **Profundal Zone** – The deep region (hypolimnion) of stratifying lakes.

Figure 3: Diagrammatic Cross Section of Lake Zones



As previously mentioned, while many of the lakes within the Highlands Region are of glacial origin, many are man-made or have been enlarged through the impoundment of inlet tributaries. The creation of man-made lakes, or enlargement of natural lakes, is commonly associated with an increased littoral zone. As such, many of these waterbodies are characterized by excessive macrophyte growth, which harms the aesthetics and recreational and ecological functioning of these waterbodies. The littoral zone may be further expanded through watershed development, which results in increased sediment erosion and transport to the lake thereby resulting in infilling and creation of deltas, which serve as prime habitat for weed growth. Conversely, some lakes may be characterized by steep shorelines resulting in a high limnetic : littoral zone ratio. In these lakes there is little suitable habitat for macrophytes, as such, primary productivity is dominated by phytoplankton.

Lake morphometry not only dictates the type of plant growth that will occur but also has a direct impact on the flushing time, which in turn affects nutrient retention and, ultimately, eutrophication. Many lake trophic models therefore utilize morphometric statistics in various forms to account for hydraulic retention and particle settling, which ultimately relate watershed based hydrologic and pollutant loading to in-lake nutrient concentrations and, ultimately, algal growth.

Given the importance of morphometric data in evaluating lake systems, it is critical that an up-to-date bathymetric survey is conducted on the target lake for the development of a proper lake management plan. Bathymetric surveys may be conducted in the field via one of two common methods dependent upon lake size and depth. For the purpose of this document, lake sizes are broken down into two classes, those lakes between 10-50 acres in size and those lakes greater than 50 acres.

Echo sounding methods are commonly used to conduct bathymetric surveys in larger waterbodies where standard surveying methods are unfeasible due to time limitations or water depth restraints. Echo sounding methodology is the most advanced form of bathymetric survey methodology and is conducted through the utilization of a dual frequency sounder tied into a Global Positioning System (GPS) that continuously monitors vertical and horizontal datum along a series of pre-determined transects. The field data are commonly collected using specialized survey software and then imported into GIS for post-processing. Resultant information includes plan and cross-sectional maps that depict the depth of water and unconsolidated sediments of the lake. In addition, vital morphometric statistics such as maximum and mean depth, volume and lake surface area are calculated during post-processing.

Watershed Related Data Collection - Hydrology

Determining the hydrology of any lake is a fundamental step in gaining the full understanding of the overall chemical, physical and even biological dynamics of the system. A lake's hydrology plays a significant role in governing the rate, amount and sources of pollutant loading to the lake. It also factors into the effectiveness or efficiency of primary producers in the assimilation of nutrients or in the rate of sediment deposition and accumulation. As such, the accurate quantification of a lake's hydrologic properties is considered a critical element of any well-designed lake management plan.

Hydraulic retention time indicates how long a single drop of water, on average, is expected to be retained in a waterbody. Flushing rate is the opposite of retention time and is related to how many times the water in a lake is exchanged over a specified period of time. Flushing rate is derived by simply dividing the volume of all water inputs by the lake volume, while the retention time is simply the inverse of this metric. Both metrics (flushing rate and hydraulic retention time) have classically been computed on an annual scale. This may be acceptable in most cases, but numerous studies, including investigations of lakes in the Highlands Region, have shown that these properties change seasonally as a result of seasonal differences in rainfall, soil moisture content and vegetative evapotranspiration. As a result, there is greater utility and better representativeness of the data when these metrics are computed on a monthly basis. As would be expected, when calculated on a monthly or seasonal scale, flushing tends to be quicker in the spring and slower in the summer. These temporal variations in flushing and retention are of utmost importance in assessing lake trophic state due to the aforementioned direct relationships between hydrology and nutrient loading, nutrient assimilation and phytoplankton, algae and even macrophyte growth. Additionally, large individual flushing events may physically disrupt the formation of nuisance phytoplankton blooms. Therefore, having a good understanding of a lake's flushing rate and hydraulic retention time is a very important element of any lake study.

Generally speaking, watershed size and lake volume are the primary components that dictate flushing time (or hydraulic retention time). Small lakes (volume and/or surface area) with large watersheds, typical of most impounded systems, tend to have quick flushing rates (< 180 days). Conversely, when the watershed area is small in relation to lake volume, the flushing rate tends to be slow.

Hydrologic loading can change over time as a result of watershed development. These types of changes are usually more dramatic for small watersheds as opposed to large watersheds. Regardless, as vegetated land is converted to impervious areas or areas of compacted soil, the rate and volume of stormwater runoff is increased. This change in land cover has an acute impact on both storm specific hydrologic and pollutant loading, as well as a cumulative impact on the overall flushing and retention properties of the lake.

There are various means by which to measure the hydrologic properties of a lake. These techniques span the continuum of detailed in-field studies involving the measurement of surface water, groundwater, and direct precipitation loading to models that use various algorithms to simulate or predict hydrologic loading. As will be discussed below, although there are advantages and disadvantages to each approach, the combined application of field data collection and modeling tends to generate results of suitable detail and accuracy for use in lake management plans.

Watershed Related Data Collection - Pollutant Loading

As noted above with respect to hydrology, the interconnectivity between lakes and their watersheds is a central tenet in lake management. This also holds true with respect to the assessment and quantification of pollutant loading. First, it must be emphasized that when dealing with lake systems from the perspective of trophic state analysis, the pollutants of concern are total phosphorus, total nitrogen, and sediment.

Watershed size, along with land use/land cover, soil types, topography and geology, all influence the quantity of water, its temporal distribution and the pollutant load associated with inflows to a lake. As discussed in the Introduction, a direct correlation exists between watershed disturbance and increased lake eutrophication. The conversion of forests to residential, commercial and industrial lands brings about an increase in impervious surface, which serves to alter the hydrologic cycle through increasing surface water runoff while decreasing groundwater infiltration. Associated with increased surface water runoff is increasing amounts of phosphorus, nitrogen and sediments. These pollutants stimulate excessive algal and weed growth within the receiving lake. Most of these pollutants originate from diffuse, ubiquitous sources and enter the lake on a landscape scale. The input of pollutants in this manner from diffuse sources is referred to as non-point source (NPS) loading. The recognition of the effects of non-point source pollution on lake water quality has increased over the past three decades. The USEPA reports that over 70% of all the existing water quality impairments affecting lakes is the result of NPS loading (USEPA, 1999). As such, lake scientists have continued to examine a multitude of methodologies that may be utilized to measure or estimate the nutrient and sediment flux from a watershed to a receiving lake, and to relate these loads to in-lake nutrient concentrations and, ultimately, algal and weed growth.

As is the case with quantifying a lake's hydrologic properties, calculating the pollutant budget of a lake can range in complexity, cost, and time. The calculation of the pollutant budget may entail intensive and exhaustive measurement of nutrient and sediment inputs and broader approaches that estimate pollutant loading using simple export coefficients. A balance can be achieved through the use of field and modeled data in computing pollutant loadings.

The following summaries highlight some of the more commonly used techniques for developing lake hydrology and pollutant loading data.

Detailed Field Measurements

Directly quantifying hydrologic, nutrient and sediment loads to a lake by collecting hydrologic and pollutant load data from feeder tributaries, groundwater and the atmosphere is highly accurate but extremely costly and time and consuming. Furthermore, such data cannot be easily applied to another lake as they are extremely site specific. Such studies also must encompass all four seasons and in some cases be conducted over a number of years due to the intra- and inter-annual differences in meteorological and hydrological conditions that affect water and pollutant loading. Some pollutants exhibit marked seasonality based on their application to the watershed lands (e.g., fertilizers). Additionally, such studies require sampling under both base-flow and storm event conditions. As a result, these types of investigations are expensive and take time to fully implement. While field measurements and related sampling must be part of any lake study, relying only on field data is not the most cost-effective means of characterizing lake/watershed interactions or developing a trophic state database.

Modeling Based Efforts

Modeling the hydrologic and pollutant budget utilizing runoff curve numbers and pollutant export coefficients is much less accurate and detailed, but can be more cost effective and applicable for large spatial areas. The problem with modeling techniques is that care must be taken to ensure that the correct model is being used, the model is being properly applied, and an adequate amount of accurate data is used as the model input parameters. As noted with respect to detailed field assessments, reliance solely on modeling based efforts to characterize lake/watershed interactions to define trophic state is not recommended, in part, because a model developed without site-specific data cannot be easily modified to reflect changes in pollutant reduction measures. Rather, a balance using both field and modeling techniques is the best approach.

In terms of modeling efforts, the use of geographic information systems (GIS) technology has greatly improved the accuracy, ease and utility of modeling techniques used in lake management. Such technology provides the means for compiling, organizing, manipulating, analyzing and presenting spatially-referenced model input and output data to rapidly compute watershed based loading of water and nutrients.

With respect to hydrology, the Modified Rational Method is often used to arrive at the monthly hydrologic load to a lake. While this may provide a somewhat useful assessment of runoff-related loading, it needs to be augmented with direct precipitation data and then corrected for evaporation losses from the lake itself and evapotranspiration and soil attenuation losses from the surrounding watershed. Data from stream flow gauges may also be used where available.

With respect to pollutant loading, relatively accurate estimates can be generated using simple Unit Areal Loading techniques. These "models" essentially involve the application of a loading coefficient representative of the nitrogen, phosphorus and sediment load generated on a per acre or hectare basis from the surrounding watershed. The coefficients differ by land use type. The accuracy of these analyses is directly dependent on the correct input of the land use data and the selected loading coefficients. With respect to the loading coefficients, care must be taken that the selected coefficients are reflective of regional conditions and were not developed from data derived from studies conducted in other parts of the country. Given that the coefficients are representative, not site-specific, modeling can use a reasonable range of coefficients for each land use to determine the model's sensitivity to changes in the loading coefficients.

Recently, GIS has been used to integrate watershed simulation models to increase computational efficiency and accuracy of complex hydrologic and pollutant transport calculations. One such example has been the integration by Dr. Barry Evans of the Generalized Watershed Loading Function (GWLF) model developed by Haith and Shoemaker (1987) with ArcView. The resultant model package, AVGWLF (Generalized Watershed Loading Function with an ArcView (AV) geographic information systems (GIS) interface), has been endorsed by the U.S. EPA as a "mid-level" model that contains algorithms for simulating most of the key mechanisms controlling hydrologic and nutrient fluxes within a watershed (USEPA, 1999). As such, this modeling technique tends to work quite well for most lake studies.

AVGWLF was originally developed for Pennsylvania and is formatted to utilize GIS based data files from this state. Nevertheless, this model has been successfully calibrated and utilized to compute the hydrologic and nutrient budgets for lakes and streams by the New England Interstate Water Pollution Control Commission (NEIWPCC, 2007). The

AVGWLF model has also been used in New Jersey to evaluate the hydrologic and pollutant loads to Manalapan Lake and the Whippany River (Princeton Hydro, 2009).

The GWLF model provides the ability to simulate runoff, sediment, nitrogen and phosphorus loads from a watershed given variable size-source areas. It also has algorithms for calculating septic system loads and allows for the inclusion of point source nutrient loading. GWLF is a continuous simulation model that utilizes daily time steps for weather data and water balance calculations. Monthly calculations are made for nutrient and sediment loads based on the daily water balance accumulated monthly values. GWLF is considered to be a combined distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows for the inclusion of multiple land use scenarios but each area is assumed to be homogenous in regard to various attributes considered by the model. In addition, the model does not spatially route watershed transport of sediments and nutrients but simply aggregates loads from each source area. For sub-surface loading, GWLF acts as a lumped parameter model using a water balance approach. No distinct areas are considered for sub-surface flow contributions. Daily water balances are computed for an unsaturated zone as well as a saturated sub-surface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration (Evans, 2008).

Hydrologic loading is simulated through the GWLF model utilizing the Soil Conservation Service (now, Natural Resources Conservation Service) Curve Number (SCS-CN) approach with daily weather (temperature and precipitation) as inputs. Erosion and sediment yields are estimated utilizing monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of the KLSCP (K = soil erodibility factor, LS = slope length factor, C = crop management factor, P = support practice factor) values for each Land Use/Land Cover (LU/LC) combination. A sediment delivery ratio based on watershed size and a transport capacity average daily runoff is then applied to the calculated erosion to determine sediment yield for each source area. Surface nutrient losses are determined by applying dissolved nitrogen and phosphorus coefficients to surface runoff and a sediment coefficient to the yield portion for each agricultural land use source area. Point sources, fertilized fields, and septic systems are also integrated into nutrient loading calculations as the latter two sources may provide a significant nutrient source in more rural areas. Urban nutrient inputs are assumed to be solid-phase and are modeled utilizing an exponential accumulation and wash-off function. Sub-surface losses are calculated using dissolved nitrogen and phosphorus coefficients for shallow groundwater contributions to stream nutrient loads while the sub-surface sub-model considers a single, lumped parameter contributing area. Evapotranspiration is determined using daily weather data and a vegetative cover factor dependent upon LU/LC. Finally, a water balance is performed utilizing supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage and evapotranspiration values (Evans, 2008).

With the development of AVGWLF came some significant enhancements to the GWLF model that are particularly pertinent to the development of lake management plans in the Highlands Region. Specifically, a significant revision to the original GWLF model is the inclusion of a stream bank erosion routine which utilizes a watershed-specific lateral erosion rate. This rate is subsequently multiplied by total stream length, average stream height and the mean soil bulk density to compute stream bank erosion. Such information is particularly useful in the development of management plans for the prioritization of limited funding in order to target those areas which are contributing the greatest proportion of sediments and their associated nutrients to the lake. In addition, algorithms have been added to account for water extraction from surface water and groundwater sources which would affect these loading sources. The most recent additions to the model structure have now allowed for modeling of fecal coliform transport to the receiving waterbody. This function is particularly useful if the target lake is experiencing elevated fecal coliform concentrations which are impairing contact recreation or threatening drinking water reserves.

Output results from AVGWLF include monthly and annual water budgets in addition to sediment, nitrogen and phosphorus loads. Nutrient reduction through present and future BMPs can also be evaluated. The modeled nutrient and sediment load can be adjusted for any established BMPs through the utilization of a "scenario editor" which creates a scenario file. This file can subsequently be imported into the Pollution Reduction Impact Comparison Tool (PRedICT) to evaluate the effects of urban and rural BMP implementation on further reducing the pollutant load. The output data from AVGWLF and PRedICT can subsequently be utilized as the input in lake trophic models to evaluate changes in lake phosphorus and chlorophyll *a* concentrations as a result of watershed based management techniques.

While the GWLF model is designed for more rural watersheds, an urban land use sub-model, RUNQUAL, developed by Douglas Haith of Cornell University has been integrated into AVGWLF by Dr. Barry Evans. RUNQUAL is a continuous simulation model that simulates surface runoff and contaminant loads from the pervious and impervious surfaces from various land uses on a developed site. The resultant runoff may be subsequently modeled as untreated runoff or as being routed through BMPs that modify water quality characteristics before discharge from the site to the target waterbody (Haith, 1993).

As previously mentioned, AVGWLF was developed by Pennsylvania State University for ArcView GIS software (versions 3.2 and 3.3) and is utilized to create the necessary input data for the execution of the GWLF-E model. Within AVGWLF, ArcView compatible shape files and grids are manipulated for the derivation of numerous model input parameters. In order for the input parameters to be estimated properly, it is imperative that each of the required grid and shape files are created and formatted correctly. As such, Dr. Evans has written an AVGWLF Format Guide (Evans, 2008), which provides the formatting requirements for each dataset.

Internal Loading Assessment

In many lakes, historical watershed based nutrient loading has led to a marked increase in sediment accumulation of organic matter derived from allochthonous (external) and autochthonous (internal) sources. In many lakes, this sediment may serve as a significant contributor of phosphorus through a process termed internal loading. Internal loading occurs when anoxic conditions at the water/sediment interface cause tightly bound iron-phosphate molecular complexes to be reduced, thereby leaching phosphorus from the sediments into the overlying waters. Review of the scientific literature has shown internal phosphorus loading under anoxic conditions to occur at a rate up to an order of magnitude greater than under oxygenated conditions. Furthermore, internal loading may comprise a significant portion of the nutrient load in deep lakes that experience thermal stratification and significant periods of anoxia. Subsequent impacts of internal loading result in large pulses of phosphorus from the hypolimnion (i.e., the cold, deep water layer, as previously discussed) into the metalimnetic (i.e., transition zone) and epilimnetic (warm, upper water) layers of the lake during strong storm events, or during the autumn when the lake turns over. Such nutrient pulses may stimulate massive algae blooms.

While AVGWLF models the watershed based load of phosphorus to lakes, it does not model the load derived from internal sediment release. In-situ data of dissolved oxygen distributions throughout the water column, in concert with comparisons of epilimnetic and hypolimnetic phosphorus concentrations, can serve to offer important insight regarding whether internal loading is occurring within the waterbody. If anoxia occurs within the hypolimnion and there are significantly greater concentrations of soluble reactive and total phosphorus in the hypolimnion in comparison to the epilimnion, then internal loading is most likely occurring and should be quantified.

Like the quantification of the external based nutrient load, internal load modeling can range in complexity and cost and therefore accuracy can vary. The application of internal loading coefficients of total phosphorus, in the units of mg P/m2/day, may be used to determine a rough estimate of the internal load. Greater refinement of this load may be obtained through actual measurement of the flux of phosphorus from the sediments under anoxic and oxygenated conditions through sediment core sampling and laboratory analysis. While the latter is more costly, it is highly accurate and may be applicable in those lakes in which internal loading is thought to comprise a significant portion of the total phosphorus load.

Data Assimilation and Analysis - Trophic State Modeling

The purpose of trophic state modeling is to use all of the primary component field-collected data and modeled results, together with perhaps some of the secondary component data, to define the current level of a lake's productivity. The focus on controlling phosphorus concentrations in lakes has been a central tenant of lake management given the strong correlation between increasing phosphorus and chlorophyll *a* concentrations. Because of the impact of total phosphorous (TP) loading on lake ecology, numerous studies have attempted to determine the factors that exert the greatest impact on lake TP concentrations. The pillar of this research has been the Vollenweider (1969, 1975, 1976) mass balance model for lake TP loading and retention, which provides a vehicle for predicting lake water TP concentrations based, in part, on lake morphometric, hydraulic and nutrient loading data (Brett, 2007). The initial work conducted by Vollenweider ultimately served as the basis for further development of empirical phosphorus models including work conducted by Dr. Kenneth Reckhow. A simple empirical phosphorus model/uncertainty analysis procedure has been developed by Reckhow (1979d) to relate phosphorus inputs to lake water column concentrations. This model, termed the "quasi-general model," contains terms for the input, output and the settling (to the lake bottom) of phosphorus, but does not explicitly include any biological or chemical reactions. The mathematical model described herein was developed by Reckhow from 47 north temperate lakes included in the U.S. EPA National Eutrophication Survey. This model expresses phosphorus concentration (P, mg/L) as a function of phosphorus loading (L, in g/m2 –yr), areal water loading (qs, in m/yr), and apparent phosphorus settling velocity (vs, in m/yr) in the form:

$$P = L / vs + qs$$

Using least square regression, the apparent settling velocity was fitted as a weak function of qs. This resulted in the fitted mode:

$$P = L / 11.6 + 1.2qs$$

While this model is simple to use, there are some limitations that were reviewed prior to selecting this model as the standard phosphorus prediction model for the Highlands Region. Those limitations are as follows:

- Do not apply the model to lakes outside of the north temperate climate zone (though the Highlands Region is in this climate zone, so this is not a limitation for the Region),
- The model should not be applied to a lake with variable values greater than the maximum values or less than the minimum values as specified in Table 1.
- The model may be used to predict the average phosphorus concentration throughout the lake during the growing season. It cannot be used, as developed, to predict near shore or short-term concentrations.

Table 1 - Model Development Dataset

Variable	Minimum	Maximum
P (mg/L) = phosphorous concentration	0.004	0.135
L (g/m2/yr) = phosphorous loading	0.07	31.4
Qs (m/yr) = areal water loading	0.75	187.0

An important aspect of the aforementioned model is that it is a significant mathematical simplification of the real world. Thus, the prediction of phosphorus concentrations from this model is inherently uncertain. Uncertainty in this model may arise from three primary sources:

- The model
- Model parameters
- Model variables

In addition to the inclusion of a robust development dataset, the Reckhow model was chosen due to the inclusion of mathematical instruction for the analysis of prediction uncertainty, which is critical in assessing confidence in the model prediction. In this sense, prediction uncertainty may be calculated for both the model itself and also for the phosphorus load prediction and expressed in terms of confidence limits which represent the predicted in-lake average growing season phosphorus concentration plus or minus the prediction uncertainty.

The modeled phosphorus concentration derived from the quasi-general model may be utilized to assess the impacts of nutrient loading on lake water quality but most importantly may be utilized to assess the load reduction necessary to achieve a desired in-lake phosphorus concentration. This is simply done by back calculating the load necessary to achieve the desired in-lake phosphorus concentration. The phosphorus concentration threshold for New Jersey lakes is 0.05 mg/L per New Jersey Surface Water Quality Standards (NJAC 7:9b). While this threshold is state approved, it may be too high in some lakes while un-attainable in others. As such, special care should be placed on selecting a targeted in-lake phosphorus concentration that is realistically obtainable and promotes a trophic state in keeping with the lakes assimilative capacity and that promotes the upkeep of the designated usages of a specific lake.

A useful metric for evaluating lake trophic state and choosing a targeted TP threshold is the Trophic State Index (TSI) developed by Dr. Robert Carlson (1977). Carlson's TSI is a log based, single variable trophic index that uses chlorophyll *a* concentration, total phosphorus concentration, or Secchi depth to calculate an index value, from 0 to 100, to designate the productivity status of a lake. The index was calculated by Dr. Carlson through the use of regression equations on a robust dataset of North American lakes. The basic assumptions of this index are that suspended particulate matter is the primary determinant of Secchi depth and that algal particles are the sole source of this suspended matter. Given these assumptions, TSI values calculated for chlorophyll *a*, total phosphorus and Secchi disk should all be equal. Frequently they are not, and systematic differences in productivity may therefore be determined through residual analyses. The equations utilized for the calculation of lake trophic state are presented as based on chlorophyll *a*, total phosphorus and Secchi depth, below:

$$TSI(CHL) = 9.81 \ln(CHL) + 30.6$$

$$TSI(TP) = 14.42 \ln(TP) + 4.15$$

$$TSI(SD) = 60 – 14.41 \ln(SD)$$

Chlorophyll *a* and total phosphorus concentrations are entered in the units of micrograms/liter while Secchi disk is entered in meters. Table 2 lists trophic state index values for each variable and common attributes.

Table 2: Carlson's Trophic State Gradient

TSI Value	TP	Chlorophyll *a*	Secchi Disk	Attributes
<30	< 6	< 0.95	> 8	**Oligotrophic** – Clear water, oxygen throughout the year
30-40	6 - 12	0.95 - 2.6	8 – 4	Hypolimnia of shallow lakes may become anoxic
40-50	12 - 24	2.6 - 7.3	4 – 2	**Mesotrophic** – Water moderately clear; increasing probability of hypolimnetic anoxia during summer.
50-60	24 - 48	7.3 - 20	2 – 1	**Eutrophic** – Anoxic hypolimnia, macrophyte problems possible.
60-70	48 - 96	20 - 56	0.5 – 1	Blue-green algae dominate, algal scums and macrophyte problems.
70-80	96 - 192	56 - 155	0.25 – 0.5	**Hypereutrophic** – (light limited productivity). Dense algae and macrophytes.
>80	192 - 384	> 155	< 0.25	Algal scums, few macrophytes.

(Source) - http://www.secchidipin.org/tsi.htm

5.2.2 Secondary Components

While the previous section reviewed diagnostic components that are essential to the proper assessment of lake eutrophication and therefore considered fundamental elements of any lake management planning initiative, there are additional diagnostic assessments that may be called for depending on the nature or scope of the lake management plan.

This section will review the applicability and methodology of secondary diagnostic components.

Fishery Assessment

Because the fishery is often one of the primary recreational resources of lake systems, attention is often placed on understanding this resource from the recreational fishing perspective only. In such cases, emphasis is placed on understanding how best to sustain or enhance the fishery for recreational enjoyment. However, a lake's fishery may also have the unique function of actually defining lake ecosystem properties that go well beyond recreational enjoyment. Fish primarily occupy the uppermost strata of a lake's trophic web. Feeding pressure exerted by certain fish species, or on certain fish species, can have marked impacts on overall lake conditions. Thus fish can be very important components in driving water quality and structuring the lake's overall biota. Because the fishery occupies these dual roles it is important to effectively manage the fishery from the perspectives of both recreational enjoyment and water quality/lake ecology. It is not unusual for these different management perspectives to have divergent consequences on lake water quality. Conversely, by understanding in full the dynamics of a lake's fishery it is possible for these management perspectives to be complementary. Understanding the composition, distribution, and makeup of a lake's fishery makes it is possible to employ uniform strategies capable of managing the fishery for both recreation and water quality enhancement.

Any lake program may benefit from a fishery survey but funding and available resources sometimes do not make this possible. At a minimum, lakes larger than 50 acres should have a fishery survey conducted once every five years. Such a survey should consist of utilizing electrofishing, gill nets and trap nets to sample the littoral, pelagic and profundal zones of the lake. Data analysis should consist of basic fishery population and community metrics. Such data can be utilized to assess the fishery from water quality and recreational perspectives and should serve to find a balance between these two objectives. Lakes between 10 – 50 acres may also benefit from a fishery survey if the primary components are addressed and resources are available.

Macrophyte Survey

Many eutrophic, shallow lakes are characterized by an expansive littoral zone which supports appropriate habitat for dense macrophyte communities. In these lakes, primary productivity may be dominated by macrophytes and have relatively low phytoplankton growth. As such, chlorophyll *a* concentrations measured in these lakes would not represent the dominant type of primary productivity and lead to a false assessment of lake trophic state. Such conditions may be further exacerbated through the colonization of invasive macrophyte species, such as Curly leaf pondweed (*Potamogeton crispus*), Eurasian watermilfoil (*Myriophyllum spicatum*) and Water Chestnut

(*Trapa natans*). These species may rapidly take over a lake thereby leading to exponential increases in plant biomass.

Macrophyte surveys should be conducted in those lakes that exhibit excessive growth of macrophytes, which impede recreational, ecological or aesthetic conditions. Such conditions are likely to occur in smaller lakes, within the 10 – 50 acre size but may also occur in larger lakes characterized by numerous shallow coves. Information derived from the bathymetric survey may therefore be utilized in the assessment of the area of the lake that may support macrophyte growth. If this area comprises a significant portion of the total lake surface area, then a macrophyte survey may be warranted. In addition, any lake that is known to have any invasive macrophyte species should be surveyed.

Macrophyte surveys should be conducted following the line intercept sampling methodology (Madsen, 1999). Such methodology consists of establishing sampling transects throughout the lake surface area in a sufficient number to account for spatial variation in macrophyte community composition and biomass. At each transect information should be collected related to species composition, relative abundance and biomass at multiple depths along each transect line.

Threatened and Endangered Species Assessments

An aspect of Highlands Region lakes that makes them unique in many cases is that they serve as habitat for threatened and endangered species. This includes reptiles (e.g., wood turtle), birds (e.g., osprey and bald eagle), aquatic plants (e.g., water marigold and green sedge) and certain species of mussels (e.g., dwarf wedgemussel), to name a few groups. Additionally the lands immediately adjacent to some of Highlands Region lakes also support and provide habitat for threatened and endangered species. In many cases the quality of this terrestrial or riparian habitat and its ability to support threatened and endangered species are directly linked to the quality of the lake. As such, threatened and endangered species assessments and surveys may often be an essential element of a lake survey with the resulting data playing an important role in the overall lake management plan.

5.3 Incorporation of Limnological Data into Management Plan

Following the collection of detailed limnological data it will be necessary to set objectives, evaluate solutions and alternatives and implement watershed and in-lake management measures which serve to correct water quality issues as determined from the data and information gathered during the Situational Analysis phase. The aforementioned data should ultimately be utilized to rank or prioritize manageable watershed based pollutant loading and identify possible pollutant load reduction measures or strategies. Finally, in-lake restoration measures may be utilized to curb internal nutrient loading sources or alleviate nuisance phytoplankton blooms or excessive macrophyte growth.

Chapter 6 — Synopsis of Commonly Implemented Lake and Watershed Management and Restoration Techniques and Strategies

6.1 Watershed Management Strategies

When formulating recommendations for the long-term management of lakes within the Highlands Region, emphasis must be given to proper watershed management. This is in fact the key to realizing sustainable water quality and lake ecology improvements. Watershed control measures are designed to reduce non-point source (NPS) pollution. NPS pollution is very diffuse and generated over a relatively large area and produced by a wide variety of sources. This can include such over-looked sources as lawn and garden fertilizers, waste generated from pets and waterfowl, surface runoff from paved surfaces, and even dust and fine particulate material that falls from the atmosphere. Septic systems are another often important contributor to NPS pollution. Unfortunately, NPS pollutants can often be more difficult and expensive to control than point source pollutants. Nevertheless, when NPS pollutants account for all or a large fraction of the total pollutant load, it must be effectively reduced and controlled if long-term water quality improvements are to be realized. For most ponds and lakes, the focus of the watershed management strategies contained in a lake management plan will involve the control and management of stormwater runoff.

6.1.1 Public Education and Outreach

The following are examples of measures that can be promoted through a well-designed Public Education and Outreach effort. Basically, these measures are largely voluntary and to be successful must be embraced by the community. However, if rigorously implemented, these measures can have pronounced positive effects on water quality and even help control a lake's eutrophic state. This is because they aim to reduce pollutant loading before it occurs.

Minimize Shoreline Disturbance and Utilize Alternative Landscaping

This is an important measure for the lots fronting the lake shoreline. These are preventative pollutant load management techniques that can be easily implemented by any homeowner. In already developed areas of the watershed, especially the residential areas immediately adjacent to a lake, homeowners should be encouraged to allow nature to take its course along that portion of the property that abuts the lake. 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 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

Steep slopes, shallow soils, and shallow depth to groundwater are all environmental conditions that facilitate the transport of nutrients and pesticides into a lake, especially from those lots located along the lake's shoreline. Integrated pest management (IPM) is a common sense approach that includes technically well-structured techniques for addressing the use of fertilizers and pesticides. Central to the success of IPM as a strategy to control phosphorus loading to the lake, is the employment of environmentally friendly methods to maintain a lawn. Unfortunately, a considerable amount of over application of pesticides and fertilizers occurs during the routine care of residential lawns. By law, as of November 2012, all over-the-counter lawn fertilizers sold in New Jersey contain no phosphorus and have a slow-release nitrogen component. These rules also limit the time period during which lawn fertilizers can be applied. 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. A key element of IPM is therefore the proper 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. The effectiveness of fertilizer management is dependent upon cumulative effects within the watershed, and requires commitment on an area-wide basis. Thus, homeowners and lawn care services must be educated regarding proper lawn maintenance.

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 County Soil Conservation Districts and Rutgers Agricultural Extension offer general soil assessments, and many lawn care services will conduct such testing and adjust the soil pH accordingly in advance of fertilizer applications. 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. Lawns can also become compacted over time decreasing the ability of precipitation from infiltrating into the soils. This increases the amount of runoff and increases the likelihood for fertilizers and pesticides to becomes mobilized and carried into the lake. 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 a lake 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.

IPM and fertilizer management ordinances, especially those that pertain to private, residential lawns, tend to be highly contested, and subject to extensive public opposition, and also are difficult to police and enforce. The public's voluntary participation is therefore needed if IPM and fertilizer management are to be successful. Again, this is where a well-designed public education program is of value.

6.1.2 Canada Geese Control

Canada geese can be a major contributor of phosphorus, especially for some of the smaller lakes and ponds of the region. When the geese defecate in a lake, phosphorus is released into the water. In addition, there is a significant amount of runoff of geese feces from lake lawns and open recreational lands (where the geese prefer to reside) that are typically located adjacent to a lake's shoreline. There are many methods that can be used to decrease Canada geese densities. These methods range from very simple and inexpensive to very costly and complicated. At best, most are only moderately successful and there is no one option best suited for any pond or lake. New Jersey, through the US Fish and Wildlife Service, allows for special permits that let the applicants addle the eggs of nesting geese. Addling the eggs involves coating the egg with a mineral oil. Although this kills the egg, the geese will continue to sit on the eggs and not produce another clutch. However, this will not eliminate the entire goose population, but rather keep the population from increasing.

6.1.3 Septic Management

Most of the lake communities within the Highlands Region are serviced by septic systems (individual subsurface sewage disposal systems). Septic management should therefore be an integral element of the management plan developed for most of the region's lakes and ponds. Successful septic management involves the integration of public education, product design 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 especially environmentally sensitive areas. It must be emphasized that even a properly operating septic system will generate a phosphorus load that can affect a lake's eutrophication if that system is located within 300 feet of the lake or its tributaries. As such, the impact of septic systems on lake eutrophication is not limited only to failing or sub-standard systems.

Product modification refers to the use of non-phosphorus or low phosphorus wash 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 leftover household chemicals and cleaning products in septic systems. There are a wide variety of public information fact sheets on septic management available through the Highlands Council, NJDEP and the EPA's Small Flows Clearing House. This educational material can prove beneficial in educating residents about the need for septic management and the serious impacts to septic systems arising from improperly disposed household chemicals and degreasing agents.

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, it has been demonstrated in a nationwide septic management study, that routine inspections help decrease the occurrence of large scale failures by early on identifying the more easily corrected, less costly problems. Similarly, routine pump outs decrease the buildup 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.

In summary, a correctly implemented septic system management program will decrease nutrient (nitrogen and phosphorus) loading and pathogen loading to a lake. For established lake communities, given their age and history, the actual functionality and treatment capabilities of existing septic systems may be lacking and far from that needed to protect the lake from pathogen and nutrient loading. For these communities (as well as growing communities), reductions in septic related pollution problems are directly linked to proper septic system maintenance. At a minimum, this should entail routine inspection and pump out of systems; typically on a three-year cycle. In those communities where the condition, design or functional status of septic systems are in question, the lake management plan's long-term management goal should also include measures that ensure systems are brought up to current code requirements or, where appropriate, eliminated.

6.1.4 Shoreline and Stream Bank Stabilization

Eroding and unstable shorelines present a number of problems to lakes. They increase turbidity problems, can be a source of nutrient loading and can impact the fishery due to loss of spawning and nursery habitat. Depending on site-specific conditions, standard structural (i.e. riprap, gabions) and/or bioengineering (i.e. biologs, installation of vegetation) techniques may be used to stabilize eroded shorelines or stream banks. The preferred way is to utilize naturalized and bioengineered solutions. Regardless of which technique is implemented, there will be the need to obtain NJDEP permits in advance of conducting shoreline stabilization activities.

6.1.5 Stormwater Management

For most of the lakes of the Highlands Region, stormwater runoff will usually be the major source of sediment and nutrient loading. Stormwater management must include both source control and delivery control techniques. Source control techniques reduce or prevent the generation of runoff and associated pollutants. Such controls are typically implemented by ordinances and regulations, land preservation and the maintenance of buffers. Delivery control techniques intercept runoff and treat or control it in a manner that reduces the overall volume of runoff and associated influx of pollutants. These techniques are best exemplified by structural best management practices (BMPs) such as bioretention and infiltration basins, but also encompass non-structural stormwater management measures and even land development and re-development techniques.

Because most of the land directly adjacent to the lakes located within the Highlands Region is extensively developed, there is little opportunity to construct large regional stormwater management facilities. As such, most of the delivery control stormwater management that can be implemented will be in the form of upgrades or retrofits of the existing stormwater collection and conveyance system. Stormwater retrofits are essentially modifications or enhancements of an existing stormwater conveyance system to improve the system's NPS pollutant reduction capacity. The advantages to such retrofits are that they require substantially smaller amounts of space for installation than do the construction of surface basins. They are also typically less expensive to construct. Below is a list of typical stormwater retrofits that would applicable for many of the Highlands Region's lakes. The installation of each retrofit is dependent upon site specific conditions.

- **Water Quality Inlets** - Essentially catch basins with a baffle system or sumped bottom. These structures slow down the flow of the incoming stormwater forcing sediment to settle. The sumped basins are intended to infiltrate the retained stormwater into the ground, thus consideration needs to be given to depth to groundwater or bedrock. These easy to implement and relatively inexpensive retrofits can effectively reduce particulate pollutants and the pollutants (i.e. phosphorus) adsorbed on sediment particles. Typical cost including installation: $1,500 to $3,000.

- **Manufactured Treatment Devices (MTDs)** - Available through a variety of manufacturers (e.g., Stormceptor, BaySaver, SunTree, Vortechs, etc.) MTDs are commonly used to retrofit existing stormwater collection systems. These larger and more sophisticated treatment devices use various types of hydraulic techniques to separate sediments and particulate material from the stormwater stream. These devices tend to have at least 50% TSS removal capability and some can decrease nutrient loads as well. Due to their higher pollutant removal efficiencies, these devices need routine maintenance. Typical cost including installation: $60,000 - $90,000.

- **StormFilter** - A filtering system that treats both dissolved and particulate pollutants in stormwater. These treatment devices tend to be relatively large, expensive and require much more maintenance than do the manufactured treatment devices listed above. Typical cost including installation: $100,000.

Prior to implementing any stormwater retrofit projects, it will be necessary to better map and detail the existing stormwater conveyance system. This information is critical in properly sizing and even in selecting the appropriate BMP.

All BMPs, even the "simple" retrofit techniques, will require maintenance to optimize their long-term operation and effectiveness. The frequency of maintenance for retrofits is greater than needed for larger BMPs. This is a function of their limited size. The need for maintenance increases during particularly wet years when loading increases.

Correctly implemented stormwater management will:

- Decrease the erosional forces that scour and destabilize tributaries,
- Decrease the mobilization and transport of sediments that fill the lakes,
- Decrease the amount of nutrient loading responsible for the eutrophication of the lakes,
- Decrease pathogen inputs that limit swimming and contact recreation,
- Increase the recharge of groundwater, and
- Decrease the influx of pesticides, petroleum hydrocarbons, heavy metals and other contaminates that impair the biota of lakes.

6.1.6 Preservation of Existing Land

For lakes with watersheds that are largely undeveloped or undisturbed, the preservation of existing lands can play a significant role in the long-term management of a lake. Forested and undeveloped lands generate the lowest per unit area surface runoff pollutant loads. Additionally, wetlands assimilate nutrients and other pollutants. Therefore, actions supporting measures that limit watershed disturbance and loss of forested lands should be part of the management plan for any lake or pond in the Highlands Region.

6.2 In-Lake Management Techniques

Even if it was possible to put in place all the necessary watershed management measures needed to reduce existing impacts to the region's lakes and prevent their further deterioration, action would still be needed for the majority of these waterbodies to rectify past impacts and restore these lakes to their full ecological, water quality and recreational potential. As such, a comprehensive lake management plan must include the implementation of in-lake restoration measures. These are the actions that result in the removal of accumulated silt, management of dense algae blooms, control of aquatic weed growth and the improvement and restoration of aquatic habitats and aquatic communities. In many cases, to achieve the desired improvement in lake quality, restoration measures must also be implemented in the lakes' feeder streams and tributaries. For many of the Region's lakes, their tributaries have succumbed to the same aforementioned impacts attributable to watershed development, such as degraded water quality, severely eroded stream channels and minimal base-flow. Contributing to the streams' loss of ecological services and functions are the alteration of the floodplains, filling of wetlands and reduction of riparian areas.

6.2.1 Drawdown

Drawdown involves the temporary, partial lowering of a lake, typically for the purpose of weed control. Most lake drawdowns are conducted in the winter, to capitalize on exposure, freezing and desiccation to kill plant seeds or destroy roots and rhizomes. At best, it is marginally successful. Milfoil (*Myriophylum sp.*) and lilies (*Nuphar sp.* and *Nymphaea sp.*) tend to be affected, but pond weed (*Potamogeton sp.*) may actually exploit such conditions and expand its coverage after a drawdown. The cost is usually minimal.

6.2.2 Aeration

There are a variety of artificial circulation or aeration techniques, each of which has a particular application for which it is best suited. Fountain type aeration systems are largely cosmetic or aesthetic and have no real application in the management of waterbodies greater than 5 – 10 acres in size. Surface and subsurface destratification aerators are the most commonly used technique. Such systems are usually used in shallow lakes (< 25 feet) to prevent the onset of thermal stratification, improve or increase dissolved oxygen (DO) concentrations and control the formation of algal scums on the surface of the lake or pond. The objective of a typical destratification aeration system is not to introduce or inject oxygen into the lake. Instead, the objective is to circulate anoxic (oxygen poor) water to the surface where it is re-oxygenated by being exposed to the atmosphere. This type of aeration can also help control and significantly reduce internal phosphorus loading. Essentially, keeping the lake well mixed and destratified prevents the onset of anoxic conditions in the bottom waters of the lake. By keeping the bottom waters oxygenated, phosphorus associated with the bottom sediments remains bound to iron and largely sequestered in the sediments. This reduces the magnitude of the internal phosphorus load. For some lakes, this will reduce the occurrence of algal blooms that are fueled by the internal recycling of sedimentary phosphorus. Most of the aeration systems for deeper lakes (>25 feet) are not designed to destratify and completely mix the water column. Referred to as hypolimnetic aerators, these aeration systems maintain distinct thermal layers in the lake and focus on increasing dissolved oxygen concentrations in a lake's intermediate and/or deeper layers. Such aerators are particularly well suited for lakes and reservoirs that need to maintain a well oxygenated but cool deep layers to support a cold water fishery. As with the destratification systems, hypolimnetic systems also reduce the magnitude of the internal phosphorus load. Some of the other common benefits associated with hypolimnetic aeration systems in addition to restoring or expanding fish habitat are preventing the formation of stagnant zones at select water column depths, providing refuge habitat for zooplankton and reducing the magnitude of mid-depth water column algal blooms.

6.2.3 Dredging

Lakes that have become extensively silted can be deepened to their original depth or proportions by dredging. Dredging is a very effective means of decreasing the organic load and will eliminate weed growth. However, dredging is very expensive and requires a substantial amount of planning. Dredging is also a highly regulated activity meaning that it will be necessary to obtain permits from the NJDEP in advance of conducting the work. Before a lake association considers dredging, it is imperative that all engineering and environmental details be properly addressed. Dredging can be accomplished using hydraulic equipment or conventional construction equipment (bulldozer, excavator, etc.). Conventional equipment techniques are typically quicker, cheaper and more manageable than hydraulic techniques.

6.2.4 Macrophyte Harvesting

In some cases, invasive aquatic weed growth can be controlled by mechanically cutting and removing the weeds from the lake. The physical removal of weed mass from a lake is an alternative to using herbicides and is viewed as a more environmentally safe technique. No NJDEP permits are needed for weed harvesting. When correctly conducted, weed harvesting will not only provide relief from excessive weed growth that hampers recreational usage, but it can actually result in the removal of significant amounts of organic material and nutrients.

Some of these same types of machines can be used to harvest mat algae blooms. These machines are typically smaller than the ones used to harvest weeds, but operate in a similar manner. By physically removing the mat algae from the lake the use of algaecides can be avoided or reduced.

6.2.5 Algaecides

The chemicals used to treat and control algae blooms are referred to as algaecides. When conducted properly algaecide applications can have a definite, positive affect. Therefore, there is room for their use in lake restoration efforts. However, algaecides should be used cautiously and conservatively. Additionally, as stressed throughout this guidance document, algaecides should not be relied on as the primary restoration tool nor should all of the lake community's management efforts be focused on algae control. Algaecide treatments require a permit from the NJDEP. Additionally, these treatments can only be conducted by NJDEP licensed Category V applicators.

One of the most obvious and frequently used means of controlling excessive algal growth is the application of the algaecide copper sulfate (CuSO4). Copper sulfate is extremely effective in killing a large portion of the resident algal community; however, this response is brief. Additionally it only controls the symptom of the problem as opposed to rectifying the cause. Several undesirable environmental impacts are known to be associated with high-dose reactive copper sulfate treatments. Negative impacts include fish and zooplankton toxicity, the depletion of dissolved oxygen, copper accumulation in the sediments, increased internal nutrient recycling and increased tolerance to copper by some nuisance Cyanophyta algae. Zooplankton, the organisms which feed on phytoplankton and serve as a natural means of controlling excessive algal growth are more sensitive to copper than the algae. In addition, the generation times of zooplankton are substantially longer than algae, meaning these organisms require a longer amount of time to recover from a copper treatment than do algae. The result can be a perturbation of the lake's food web. While the phytoplankton community can recover from a copper treatment within 1-2 weeks, recovery of zooplankton can take several weeks. Thus, the phytoplankton rebound quicker than do their natural predators from copper treatments.

One of the most convincing reasons for minimizing the frequency and magnitude of large-scale copper sulfate treatments is the fact that several studies have demonstrated that many of the nuisance Cyanophytes, such as *Anabaena* and *Coelospaerium*, may develop a tolerance to long-term applications of copper sulfate. Indeed, studies have shown that Cyanophyte tolerance to the liberal application of copper sulfate can increase to the point that the treatments are no longer economically feasible.

If algaecide treatments are conducted early enough in the development of an algal bloom, the occurrence of undesirable ecosystem perturbation can be severely minimized. Such a strategy is in sharp contrast to waiting for an algal bloom to attain extremely high concentrations and then attempting to improve water quality conditions by quickly killing off the bloom with large quantities of CuSO4.

6.2.6 Herbicides

Herbicides are chemicals used to control excessive macrophyte (weed) growth. As with the use of algaecides, herbicide treatments are among the more commonly employed lake restoration tools used by lake communities. However, herbicides should be used cautiously and conservatively. Additionally, as stressed throughout this guidance document, herbicides should not be relied on as the primary restoration tool nor should all of the lake community's management efforts be focused on weed control. Herbicide treatments require a permit from the NJDEP. Additionally, these treatments can only be conducted by NJDEP licensed Category V applicators.

There are a wide array of herbicides, however they all fall into one of two categories; contact or systemic. Contact herbicides will kill weeds quickly as their function is to destroy the cell wall of the plants. Systemic herbicides work slower as they function by altering the biochemical processes of the plants. Each class of herbicides has positive and negative attributes. Also, not all plants are affected the same by all herbicides. It is thus imperative to properly identify the targeted pest macrophyte and select the proper herbicide for its control.

As is the case with algaecides, herbicides can have negative side effects, especially if improperly applied. Additionally, some of these products have temporary use restrictions which limit the post-treatment use of the lake, including swimming, fishing and the use of lake water for irrigation purposes.

6.2.7 Fishery Biomanipulation

Biomanipulation typically involves the specific stocking or removal of fish species from a lake to facilitate certain biological interactions. This technique is most often used to increase zooplankton densities for the purpose of reducing algal biomass. In effect, biomanipulation is the re-structuring of the aquatic food web. Classically that has been accomplished by decreasing the densities of the fish that feed on zooplankton, by increasing the densities of large piscivorous (fish eating) fish. An increase in the number of large, game fish increases the grazing pressure placed on the zooplankton eating fish. As the numbers of zooplankton-feeding fish decrease, an increase in herbivorous zooplankton biomass is experienced, and this in turn leads to more grazing pressure on the phytoplankton.

In order to determine the feasibility or impact of any type of biomanipulation operation for any lake, it will be necessary to first conduct a detailed fishery survey. While the overall lack of zooplankton, particularly herbivorous zooplankton, indicates that an imbalance is present, the cause of this imbalance may not be entirely fishery related. If a fishery survey shows an imbalance in the piscivorous and predator fish population, the stocking of some large bodied predator species could be an effective means of decreasing grazing pressure exerted by "bait" fish on the zooplankton community. It should be stressed that biomanipulation is an advanced lake management technique. Until a lake's external (and potentially internal) phosphorus loads are controlled, the benefits of any form of biomanipulation technique is unlikely to generate any positive, measurable effects. It should also be noted that typically a permit is required from the NJDEP for the stocking of fish in a lake or pond.

6.2.8 Nutrient Inactivation

Nutrient inactivation typically involves the application of a product (most commonly alum) to bond and sequester the dissolved phosphorus present in the water column. By reducing the amount of dissolved phosphorus available for algal assimilation a decrease in algal densities should be realized. Nutrient inactivation is a highly specialized lake management tool. As some of the products used to sequester the dissolved phosphorus can have negative impacts on the biota of a lake, an extensive amount of data and knowledge of the lake's water chemistry is needed before implementing this technique. Additionally, NJDEP permits/approvals may be required.

Chapter 7 — Data Summary

7.1 Data Compilation and Reporting

As discussed in the introduction, the purpose of this document is to provide the reader with guidance in the preparation of a lake management plan. It can be viewed as a "cook book" or "blueprint" that identifies the "what" and "how" of preparing a successful plan and then implementing that plan using an adaptive management approach. A good lake management plan is thus organic and by design meant to aid the community in meeting existing lake management challenges while at the same time serving as the framework for ongoing management needs.

The document template provided by Highlands Council staff (see Appendix C) may be used during report preparation. The report should provide background regarding the subject lake and should identify (and include contact information for) primary project proponents and their partners, technical advisory individuals or agencies, the project manager and workers who prepared the plan. Mapping and digital data standards provided by the Highlands Council may be used during report preparation (see Appendix B).

7.2 Quality Assurance/Quality Control

The report shall address quality assurance and quality control issues that may compromise the validity of the final conclusions. A QA/QC log must be included that documents (i) sources of data, (ii) presumed accuracy of supporting information and secondary analyses, (iii) identify information gaps or unmet data needs, and (iv) any steps or portions of the protocol that may have been modified or abridged.

Glossary of Commonly Used 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). 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).

Anthropogenic activities – Affected 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 and other organisms which contain chlorophyll and live floating or suspended in water. Algae may also form dense colonies and mats. Algae also may be attached to structures, rocks, or other submerged surfaces. It serves as 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 during the night or after die-off. See also phytoplankton.

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. A key nutrient.

Anoxic – Devoid of oxygen or dissolved oxygen. DO concentrations less than 1.0 mg/L are generally treated as anoxic.

Autotroph – Autotrophs are primary producers that sustain their energy from photosynthesis. Phytoplankton and macrophytes are autotrophs.

Bathymetry - 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

Conductivity or Conductance – See Specific Conductivity.

Cyanobacteria – This group of algae is also known as blue-green algae or cyanophytes. This taxon consists of algae that are prone to bloom formation. This is due to certain competitive advantages including the ability to fix atmospheric nitrogen and to utilize organic forms of phosphorus, traits which no other algae share. They are also not consumed by zooplankton. As a result, they are not subject to nitrogen limitation, grazing, and can utilize other forms of phosphorus. Blooms produce foul odors and can deplete dissolved oxygen levels at night and upon senescence.

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 decomposing organic materials or from terrestrial sources like leaves.

Diel – Refers to the course of events over a day and includes both diurnal and nocturnal cycles. In limnology, diel variations are measured in a variety of parameters.

Dissolved oxygen – The concentration of the gas oxygen (O2) present in water. Dissolved oxygen (DO) can be an indicator of the ecologic function of the waterbody. Oxygen is more soluble at lower temperatures and less soluble at higher temperatures. Contributors to DO in water include atmospheric diffusion and photosynthetic processes of algae and aquatic vegetation. Percent saturation refers to maximum concentration of DO per a given temperature due to atmospheric diffusion. Supersaturated conditions occur when excessive photosynthesis contributes more DO to a system than would occur through inorganic processes alone at a given temperature.

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 with nutrients; as a consequence it becomes overgrown in algae and other aquatic plants. These autotrophs senesce or die and are decomposed by microbes. This decomposition or respiration by microbes can significantly reduce dissolved oxygen levels to the impairment of other aquatic organisms. 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, and nutrients from animal wastes and 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.

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 oligotrophy (maximum transparency, minimum chlorophyll-a, minimum phosphorus) through mesotrophy, eutrophy, to hypereutrophy water (minimum transparency, maximum chlorophyll *a*, maximum phosphorus). Also see Trophic State.

Hypolimnion - Bottom waters of a thermally stratified lake. This layer consists of colder, denser water. Temperatures may remain relatively constant year around and it may experience little or no mixing with the upper warmer layers of the water body, although almost all lakes of moderate depth (<100 feet) will periodically mix. The hypolimnion of a eutrophic lake is usually low or lacking in oxygen.

Hypoxic – low or depressed dissolved oxygen concentrations generally less than 2.0 mg/L, but may be applied to DO concentrations less than 4.0 mg/L.

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. Sometimes characterized as twice the Secchi depth or at a depth equal to 1% of incident light penetration at the surface. 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 – Large aquatic invertebrates. Generally applied to aquatic insects, mollusks, and crustaceans.

Macrophyte – Vascular (higher order) plants that grow in water. Includes different growth forms such as emergents, submerged, rooted floating-leaf, and floating. Also known as submerged aquatic vegetation or aquatic weeds. Includes waterweeds, pondweeds, water lilies, and duck weed amongst others.

Mesotrophic - Reservoirs and lakes which contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

Microbes – Bacteria, fungus, and other microscopic life forms. Generally responsible for the decomposition of organic materials.

Morphometry or Lake Morphometry – The three-dimensional shape of lake including depth. This term is generally interchangeable with bathymetry. Lake morphometry is characterized by bathymetry surveys.

Nitrate – The most common form of nitrogen nutrient in most aquatic ecosystems and the nitrogen species most often utilized by plants and algae. Nitrates are generally found in high supply relative to phosphorus and highly mobile in water.

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 with the exception of cyanobacteria or blue-green algae. 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. There are various forms of both oxidized and reduced nitrogen including Ammonia and Nitrates.

Non-point source pollution – Non-point source pollution is the enrichment of pollutants or nutrients through stormwater runoff. Natural or human-induced pollution caused by diffuse, indefinable sources that are not regulated as point sources, resulting in the alteration of the chemical, physical, and biological 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 basicity of a material, or the concentration of the positive hydrogen ion, 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 basic.

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. There are various species or forms of phosphorus including Total Phosphorus (sum of all species), Organic Phosphorus, and Dissolved Phosphorus amongst others. Soluble reactive phosphorus is a measure of soluble orthophosphates.

Photic Zone – The upper layers of lake in which photosynthesis occurs. Generally depths less than twice the Secchi depth.

Photosynthesis - The process by which plants and algae transform carbon dioxide and water into carbohydrates and other compounds, using energy from the sun captured by chlorophyll in the plant. The rate of photosynthesis depends on climate, intensity and duration of sunlight, nutrient availability, temperature, and carbon dioxide concentration.

Phytoplankton - Very tiny, often microscopic, plants and other photosynthetic or autotrophic organisms found in fresh and saltwater. Phytoplankton drift near the surface of the water where there is plenty of sunlight for growth. Phytoplankton form the base for most lake food chains.

Point-source pollution - Easily discernible source of water pollution such wastewater treatment plants and other facilities that directly discharge to waterways.

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.

Respiration – The consumption of organic materials by living organisms in a lake. All aquatic life forms, including microbes, algae, zooplankton, and fish respire organic materials. Respiration can lower pH values and for most organisms except certain bacteria requires dissolved oxygen.

Secchi disk transparency - A flat, white disc is 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 and 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 there is no mixing 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.

Thermal Stratification – A natural phenomenon in which lakes of sufficient depth are divided into distinct depth zones of varying temperatures. In the summer months the coolest and densest water is located at the lake bottom. In winter months the upper depths of a lake may be warmer than the bottom. The maximum density of freshwater occurs at 39°F. Thermal stratification prevents the mixing of the entire water column.

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.

Trophic State – Indicates the level of primary production as measured by photosynthetic activity or other metrics. Various models exist to describe trophic state. Perhaps the most widely used is Carlson's Trophic State Index (TSI) which relies on the use of summer average chlorophyll, Secchi depth, and Total Phosphorus values.

Tributary – A stream or other flowing waterbody discharging to a lake or a larger stream.

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.

Zooplankton - Tiny, sometimes microscopic, floating, aquatic animals and protozoans. Zooplankton generally feed upon phytoplankton, organic detritus, microbes, and other zooplankters.

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Figure 2.1 Lake Stratification - http://www.waterontheweb.org

Figure 2.2: Diagrammatic Cross Section of Lake Zones -
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Appendix A:
Lake Management Case Studies/Success Stories

Example Lake 1

Located in northern Sussex County, this relatively shallow (mean depth 8 feet) but fairly large (approximately 750 acres) private lake is surrounded by a watershed that has been extensively developed primarily in the form of single-family homes. The lake had a long-standing history of well documented, intense blue green algae blooms. The frequency and durations of these blooms were severe enough to greatly limit recreational use and affect the lake's overall aesthetics. The primary approach that had been used for decades was to respond to each of these blooms by applying larger and larger amounts of a copper-sulfate based algaecide. While these algaecide applications may have provided some degree of short-term relief from the negative water quality impacts of the algae blooms, the intensity and duration of the blooms actually increased over time despite the increased frequency of the algaecide treatments.

Recognizing that the existing approach was not greatly benefitting the lake or the user community, a decision was made to conduct a comprehensive study of the lake for the purpose of developing the database needed to prepare a detailed lake management master plan. The study included measurements of existing water quality, investigation of seasonal variations in algae, plankton and macrophyte (weed) species, and most importantly, quantification of the lake's hydrology and pollutant budget. The data revealed that although the lake's septic and stormwater related nutrient (phosphorus and nitrogen) loads were significant, it was the lake's internally driven phosphorus load that appeared to be the root cause of the lake's persistent algae bloom problems. Furthermore, the lake's exceptionally long hydraulic flushing rate (approximately 1.5 years) exacerbated the impacts of the nutrient loading as it promoted the lake's thermal stratification and facilitated the algal assimilation of even relatively small amounts of available phosphorus.

A very innovative, long-term management and restoration plan was developed for the lake. The plan, developed from the combination of both actually measured as well as modeled lake data, provided a series of recommendations. While aimed at improving the lake's recreational potential, the recommendations contained in the plan focused extensively on the control and reduction of the lake's phosphorus load. With respect to phosphorus load reduction, the plan integrated measures that reduced loading from septic systems, lawn fertilizers, and stormwater runoff, but in particular emphasized the control of the lake's most significant phosphorus source, that which was recycled internally. Some of the key elements of the plan involved:

- Mandatory pump-out and inspection of all septic systems once every three years.
- Prohibition of the use of phosphorus containing fertilizers.
- Construction and installation of over 20 multi-baffled, stormwater sedimentation basins.
- Installation of a lake-wide aeration system capable of maintaining the lake in a fully destratified state and maintaining positive dissolved oxygen levels from surface to bottom.
- The surface application of alum to bind and control the lake's internal phosphorus load.
- The installation of a very unique lake-wide alum injection system to bind and control the lake's external phosphorus load and further control the lake's internal phosphorus load.

- Biomanipulation of the lake's fishery, zooplankton community and phytoplankton community.

The full implementation of this plan occurred over a 10-year period, as funding became available and measurable improvements were attained. The success of the plan was buoyed by a very aggressive education and outreach program. The program not only educated the lake community about what was affecting the quality of the lake and what needed to be done to improve it, but introduced them to the importance of their direct involvement in the lake's restoration. As a result, it was easier to elicit the support needed for the successful implementation of the septic pump-out and non-phosphorus fertilizer elements of the plan. The education of the community also changed user perceptions regarding the need for high concentration algaecide applications.

Actual documented improvements, as based on data collected over a 20-year period, include the following:

- A 60% decrease in the lake's total annual phosphorus load
- A 10-fold increase in lake clarity; mid-summer,
- A decease in the intensity, frequency and duration in blue-green algae blooms
- A decrease in the overall use of copper-based algacides
- A sizable reduction in sediment loading and the subsequent in-filling of the lake
- A resurgence of the lake's aquatic plant community
- Improvements in the quality of the lake's fishery
- More sustainable recreational use (swimming, boating, fishing and passive uses)

The success of this program was recognized by USEPA by means of an Environmental Excellence Award, by the NJDEP in the form of an Environmental Initiative Award and by the North American Lake Management Society with a Technical Merit Award. More importantly, while the lake is still a eutrophic waterbody, through the direction provided by the management plan, the lake is now more ecologically balanced and better meets the needs of the user community.

Example Lake 2

This public lake, located in western Morris County, has a surface area of approximately 375 acres. It is a multi-purpose, public recreational waterbody. While portions of the lake's watershed are undeveloped and are part of a state managed recreational area, a fair amount of the watershed is fairly densely populated with development ranging from small-lot, single-family homes to commercial and retail uses which encompass large swaths of impervious cover. The breakdown of the watershed's land use is as follows:

- Urban 34%
- Agricultural 0.7%
- Forest 36%
- Wetland 12%
- Barren 2%
- Open Water 14%

This lake and its watershed were the subject of both a NJDEP funded Watershed Protection Plan and a NJDEP implemented Total Maximum Daily Load (TMDL) study. Through both of these studies, the lake's existing pollutant load and hydrologic budgets were quantified and recommendations were developed to both decrease the lake's annual phosphorus and sediment loads and control bacteria related problems. Guidance for reduction of the phosphorus and sediment loads was provided in the Watershed Protection Plan, while guidance for the reduction of the bacteria load was provided through the TMDL. Additionally, municipal efforts were taken to control further development of the watershed, promote the use of non-phosphorus fertilizers, reduce the lake's Canada goose population, and for those sections of the watershed still relying on septic systems, promote the better care and maintenance of these systems.

Two major accomplishments related to the recreational enhancement of the lake are the partial dredging and reclamation of the southern end of the lake and the successful implementation of an ecologically guided, invasive macrophyte (weed) control program.

While the dredging effort was relatively small scale, it did result in the removal of over 6,000 cubic yards of sediment that was affecting the use of a public beach area and an adjacent marina. Prior to initiating the dredging effort, a detailed bathymetric survey was conducted to accurately quantify the volume and the expanse of the deposited sediments. Detailed engineering plans were prepared from the resulting data and used to both obtain the required NJDEP permits as well as prepare contractor bid specifications. Aspects related to the design of the lake's dam and the distribution of the accumulated sediments increased the project's logistical and environmental issues. However, the project was successfully completed with no ancillary environmental impacts.

With respect to the weed control effort, the municipality was confronted with an expanding distribution of two of the most prevalent and problematic invasive weed species in New Jersey, curly-leaf pond weed (*Potamogeton crispus*) and Eurasian water milfoil (*Myriophyllum spicatum*). The weed densities had become so great that they directly limited the overall use of the lake for boating and fishing. The environmental commission developed a comprehensive plan to control both of these species using a very environmentally friendly, systemic herbicide applied in a very controlled, well timed and limited manner. The treatment program successfully controlled the intensive growth of both targeted plants. At the same time, due to the ecologically balanced nature of the program and the selection of the correct type of herbicide, neither the lake's important native aquatic plants nor the vegetation in an adjacent high quality wetland/bog ecosystem were impacted. It should be noted that although it was necessary to conduct the weed control program for two consecutive years, the level of control achieved through the program was good enough to negate the need for the application of the herbicide for the past two years.

The municipality continues to look for opportunities, as funding becomes available, to implement the recommendations contained in both the Watershed Protection Plan and the TMDL. These measures are aimed at controlling the sources and correcting the root causes of the lake's problems. Efforts implemented by the municipality include working with local developers and the NJDOT to reduce pollutant loading to the lake through better stormwater management and stormwater system retrofits. To further their understanding of the inter-relationships of the lake and its watershed, the municipality prepared a Natural Resources Inventory. The NRI is more than a detailed catalog of the all of the municipality's important natural resources; it included a vital element detailing the ranking of presently undeveloped lands with respect to their sensitivity to development. This enabled the municipality to identify lands within the lake's watershed most susceptible to environmental perturbation if disturbed or developed. With this information, the municipality was then able to target parcels for purchase and preservation. Additionally, for those parcels slated for development, the NRI provided the data used to support the need for more aggressive erosion and sediment control measures, advanced stormwater management techniques and the protection of especially environmentally sensitive features including steep slopes, erodible soils, important habitat areas and lands immediately adjacent to streams, wetlands and the lake itself.

Example Lake 3

A relatively small (approximately 35 acres) private lake located in Morris County had a long-standing problem with excessive macrophyte (weed) growth, occasional problems with algae blooms and periodic, though infrequent, fish kills. For years, the community did what most lake communities do, react to the weed and algae problems by applying herbicides and algaecides. While these lake treatments abated some of the impacts related to excessive weed and algae growth, it did nothing to significantly improve the quality of the lake.

Over the years, there had been various discussions and debates as to what should be done to improve the lake's quality. Dredging, aeration, more aggressive herbicide or algaecide treatments, and the stocking of the lake with "weed and algae eating" fish were among some of the more commonly raised recommendations. Before doing anything else, the lake association invested in a well-designed, comprehensive lake study. The primary objective of the study was to identify the actual causes of the lake's problems, and use the data developed through the study to prepare a pragmatic approach to addressing these problems. An important element for the lake association was the prioritization of projects as this could be used by them to create a long-term capital improvement budget.

The lake study was comprised of six basic tasks:

- Bathymetric assessment to establish existing water depths, measurement of the amount of accumulated sediment and identification of areas that could potentially benefit from dredging.
- Measurements of key water quality parameters including temperature/dissolved oxygen profiles, seasonal changes in lake clarity, in-lake and tributary nutrient concentrations, the species composition of the zooplankton and phytoplankton communities and changes in their composition over time.
- The species composition and distribution of the lake's macrophyte community.
- Modeling of the lake's phosphorus, nitrogen and sediment loads.
- Modeling of the lake's hydrologic budget.
- Computation of the lake's existing trophic state and projection of the improvement in trophic state gained through the implementation of various lake restoration measures.

The plan included the prioritization of restoration measures (divided into in-lake and watershed based projects), a schedule of project implementation, and cost estimates for each of the recommended in-lake and watershed projects. The plan also identified any NJDEP permits that would likely be needed. Given the recreational use of the lake and the direct link between the quality of the lake and property values, the plan sought to balance short-term restoration actions (mostly dealing with algae and weed control) and long-term management actions (mostly dealing with nutrient and sediment management).

Two very interesting outcomes of the project pertained to the association's on-going weed control efforts and the perceived need for dredging and sediment removal. With respect to weed control, the study actually documented that the type of herbicide being used and the timing of the herbicide treatments were actually affecting the overall water quality of the lake. Specifically, because the association was relying on the application of a contact herbicide and the treatment was being conducted well after a significant volume of biomass had developed, the subsequent die-off of the plants was creating a phosphorus pulse to the lake. Given that the treatments were initiated in June and then usually repeated in late July, the lake was receiving an additional phosphorus load during the peak period of time for algae bloom development. As a result, the weed control treatments were actually setting the stage for algae blooms. The plan recommended switching to a systemic herbicide from the contact herbicide and conducting the treatment earlier in the growing season. Data collected subsequent to this change in weed control strategy has documented adequate weed control, with less secondary impacts such as algae blooms, nutrient spikes, dissolved oxygen depletion and fish kills.

With respect to dredging, the bathymetric data clearly showed that sediment accumulation was limited to a few locations, the majority being at the mouth of stormwater outfalls. Due to the limited volume of sediment present at each location, logistical problems with accessing these sites and overall costs, it was determined that there was no pressing need for dredging and if dredging was conducted, the cost-benefit of the operation was not favorable. When used in concert with the sediment modeling data, it was possible to show that the better approach would be to retrofit a few key catch basins so that they could function as sediment traps. This would not only reduce sediment loading to the lake, but also decrease some of the lake's phosphorus load.

The lake community is still in the process of implementing many of the recommendations contained in the plan, especially those involving watershed management due to the daunting costs of some of these projects. However, the data developed through the study, dismissed the value of stocking the lake with herbivorous fish (the lake is technically too large), supported the benefits of aeration, and as noted above, documented that a weed control program based on the use of a systemic herbicide was both ecologically better for the lake and better met the needs of the user community than the past program that was based on the use of contact herbicides.

Appendix B:
NJDEP GIS Mapping and Digital Data Standards

New Jersey
Department of Environmental Protection
Geographic Information System

Mapping and Digital Data

Standards

Prepared by:

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Summary

APPENDIX

RESOURCES

SUMMARY

The New Jersey Department of Environmental Protection (NJDEP) maintains a Geographic Information System (GIS) for the storage and analysis of cartographic (mapped) and related environmental scientific and regulatory information for use by the Department. A GIS is a computer mapping system used to display and analyze geographic information and spatial databases.

Many Departmental programs require the submission of mapped data to a GIS standard. The submission of mapped data by all sectors based on this standard will facilitate data input into the Department's GIS and the integration of data with the New Jersey Environmental Management System (NJEMS). Much of these data can be shared back with the regulated community and public as appropriate. Important concepts regarding the creation, capture and delivery of digital mapped information are addressed in this document.

There are three basic concepts that must be followed.

The first concept addresses the need for all mapping to meet accepted accuracy standards. All digital data must meet or reference published standards such as those defined by the Federal Geographic Data Committee or a defined survey standard, regardless of scale. Testing against base maps or photography of known accuracy determines the accuracy of data. This will ensure appropriate positional accuracy of the geographic data and, therefore, compatibility of digital information.

Secondly, digital data provided to or produced for the Department are required to be in North American Datum 1983 (NAD83) horizontal geodetic datum and in the New Jersey State Plane Coordinate system (SPC). SPC is a geographic reference system in the horizontal plane describing the position of points or features with respect to other points in New Jersey. All coordinates of the system are expressed in meters. The Department, however, prefers to receive and maintain data in U.S. survey feet. The official survey base of the State is known as the New Jersey State Plane Coordinate System whose geodetic positions have been adjusted on the NAD83 as per Chapter 218, Laws of New Jersey 1989.

Lastly, GIS data must also be documented using the Federal Geographic Data Committee (FGDC) Metadata Standard or be compliant with the FGDC Metadata Standard. Metadata is information about the digital data being provided. It is important to know not only the positional coordinates of mapped information, but also how the data was produced and the accuracy of the data being made available. The Federal Spatial Data Transfer Standard (SDTS) requires that a quality report accompany the data. This information should include a statement of the positional accuracy of the data and testing procedures used to determine positional accuracy. Geographic data must be delivered according to standard media and digital formats. Accepted formats and media currently used by the Department are presented in the body of this paper.

Programs within the Department may define additional technical mapping requirements to accommodate specific program needs.

1.0 INTRODUCTION

Geographic Information System technology has become a tool for innovative efforts to protect the natural environment and the public health of citizens, nationally and within the State of New Jersey. To adequately address these and other issues, the Department must make decisions based on sound data of known and adequate accuracy. This document provides guidance for the basic standards for creating, describing and distributing spatial data on a GIS. Basic standards will ensure consistent data quality and documentation, provide for compatibility between data sets, facilitate interactive analysis within the Department and ensure the highest quality of results derived from the GIS.

The Department endorses the Federal Geospatial Standards (FGDC, 1998) for positional accuracy as the most comprehensive and current standard. The Department continues to support National Map Accuracy Standards.

2.0 GEOSPATIAL POSITIONING ACCURACY STANDARDS AND TESTING

There are two widely accepted standards for positioning accuracy for mapped data, the Federal Geographic Data Committee (FGDC) "Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy" (1998) and National Map Accuracy Standard (1947). The Department supports both these standards and either standard can be used for mapped data. The Department recommends the more current FGDC (1998) standard.

2.1 Federal Geographic Data Committee (FGDC)

The Federal Geographic Data Committee (FGDC) in 1998 released the endorsed version of "Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy" (NSSDA) (http://www.fgdc.gov/standards/). This standard is designed for digital spatial data. In spite of the title, it prescribes a testing methodology, rather than threshold accuracy values, and is described as a Data Usability Standard.

The NSSDA requires the following test (quoted from Sections 3.2.1, 3.2.2, and Appendix 3-A):

> The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points.
>
> Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.
>
> Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher

accuracy. Vertical accuracy shall be tested by comparing the elevations in the dataset with elevations of the same points as determined from an independent source of higher accuracy.

Errors in recording or processing data, such as reversing signs or inconsistencies between the dataset and independent source of higher accuracy in coordinate reference system definition, must be corrected before computing the accuracy value.
A minimum of 20 checkpoints shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications.

Horizontal Root Mean Square Error is known as $RMSE_r$.

If error is normally distributed and independent in each the x- and y-component and error, the factor 2.4477 is used to compute horizontal accuracy at the 95% confidence level (Greenwalt and Schultz, 1968). When the preceding conditions apply, $Accuracy_r$, the accuracy value according to NSSDA, shall be computed by the formula:

$$Accuracy_r = 2.4477 * RMSE_x = 2.4477 * RMSE_y$$
$$= 2.4477 * RMSE_r /1.4142$$
$$Accuracy_r = 1.7308 * RMSE_r$$

Note that because this formula is based on statistical probabilities, the satisfaction of the underlying assumptions is important, and the formula also applies to a specific number of error measurements (20 points). The full FGDC document gives more information on what to do in cases where either of these requirements cannot be satisfied. It also gives direction on additional topics, and a worked example.

The NSSDA test described above has been embodied in the ArcView 3.x extension RMSEr2.avx, written by Gregory Herman of the New Jersey Geological Survey; the extension is available from the ESRI web site (http://arcscripts.esri.com/details.asp?dbid=10672). Note that the extension does not provide a test of the validity of the assumptions.

A data set that has been tested for horizontal accuracy per the NSSDA standard should be reported in the metadata as *"Tested _____(meters, feet) horizontal accuracy at 95% confidence level."* Tests and reporting statements for vertical accuracy are analogous, and are shown in the FGDC document.

If alternate means of evaluating accuracy are used, the data set should be reported in the metadata as *"Compiled to meet _____(meters, feet) horizontal accuracy at 95% confidence level."*

In summary, there are seven steps in applying the NSSDA (from Positional Accuracy Handbook, 1999, Minnesota Planning Land Management Information Center):

1. Determine if the test involves horizontal accuracy, vertical accuracy, or both.
2. Select a set of test points from the data set being evaluated.
3. Select an independent data set of higher accuracy that corresponds to the data set being evaluated.
4. Collect measurements from identical points from each of those two sources.
5. Calculate a positional accuracy statistic using either the horizontal or vertical accuracy statistic worksheet.
6. Prepare an accuracy statement in a standardized report form.
7. Include that report in a comprehensive description of the data set called metadata.

The Positional Accuracy Handbook provides a very clear explanation of NSSDA and excellent examples of testing methods and non-testing assessments. It can be found at (http://www.mnplan.state.mn.us/pdf/1999/lmic/nssda_o.pdf).

The NSSDA itself does not include threshold values, i.e. values of accuracy that are required for particular purposes. Sources for appropriate threshold values are discussed further below in Section 2.3.

2.2 National Map Accuracy Standard (NMAS)

The National Map Accuracy Standard, designed for paper maps, has been used since their adoption in 1941 to set accuracy requirements and to describe accuracy levels of maps. The 1947 revision is quoted in part below:

> 1. Horizontal accuracy for maps on publication scales larger than 1:20,000, not more than 10% of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50th of an inch. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as benchmarks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings); etc. In general what is well defined will also be determined by what is plottable on the scale of the map within 1/100 inch. Thus, while the intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. Examples of data in this class would be timberlines, soil boundaries, etc.
>
> 2. Vertical Accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

NMAS accuracy is described in map units (inches on the map), rather than ground units (feet or meters in the real world). Given a scale, one can translate the map units into ground units. For example, NMAS requires that a map of scale 1:12,000 shall have an accuracy of 1/30 inch; the corresponding ground unit accuracy is 33.3 ft. Although designed for paper maps, NMAS has been widely used to describe the accuracy level of digital data; for example, a digital data set is commonly described as meeting NMAS at a particular nominal scale.

As discussed above, NMAS is based on statistical testing; however the confidence level is set at 90%, in contrast to the 95% confidence level required by NSSDA. This means that the same map or data set will have a different accuracy level description (i.e. different numerical accuracy value in feet or meters) for NMAS vs. NSSDA. One can think of the horizontal accuracy as a circle of that radius around each well-defined position point: the confidence level expresses the likelihood that the actual location of the point falls within that circle. For a given "quality" of data, one needs a larger circle for a 95% confidence level than for a 90% confidence level. Appendix 3-D of the NSSDA document gives a fuller treatment of the relationship between NMAS and NSSDA.

The full text of National Map Accuracy Standards (1947) is shown in Appendix A.

2.3 Threshold Accuracy Values

The Department continues to support positioning data to meet the accuracy level of the NMAS, but using the testing methodology and reporting language of NSSDA. One approach to satisfying this requirement is to establish an appropriate nominal scale for the data/mapping in question, and use the NSSDA equivalent of NMAS values to establish threshold values for accuracy. The mathematical relationship is described in the NSSDA document (Appendix 3-D). Table 2.3.1 below shows the results of this calculation for a range of scales.

Table 2.3.1 Threshold accuracy values in ground units.

Scale	NMAS accuracy (feet)	NSSDA $Accuracy_r$ (feet)	NMAS accuracy (meters)	NSSDA $Accuracy_r$ (meters)
Large scale	1/30 inch (map)			
1:1,200	3.3	3.8	1.0	1.2
1:2,400	6.7	7.7	2.0	2.3
1:6,000	16.7	19	5.1	5.8
1:12,000	33.3	38	10.1	12
Small scale	1/50 inch (map)			
1:24,000	40	46	12.2	14
1:63,360	106	120	32.3	37
1:100,000	167	190	50.9	58
1:250,000	417	475	127	145
1:500,000	833	950	254	290

D*erived from National Map Accuracy Standards (1947).*

When the FGDC began work on the NSSDA, the subcommittee used Accuracy Standards for Large-Scale Maps (Interim, 1990) from the American Society for Photogrammetry and Remote Sensing (ASPRS) as the basis for updating NMAS. The ASPRS standards use $RMSE_x$ and $RMSE_y$ as their base statistics, and state threshold values for various scales. (Note that $RMSE_x$ and $RMSE_y$ are NOT the same as $RMSE_r$.) Discussion of these standards can be found in the NSSDA document (section 3.1.5 and Appendix 3-D). Table 2.3.2 below shows the threshold values of the ASPRS Class 1 mapping standards and their translation into $Accuracy_r$ of NSSDA (note that statistical assumptions are involved in making this calculation). As comparison of $Accuracy_r$ values between the two tables shows, the ASPRS standards are stricter than NMAS.

Should the map producer not be able to test the quality of the submitted data by either of these two tests, then the producer shall document this fact in the metadata submitted with the digital GIS data. The Department strongly recommends that when a producer of mapped information is not required to submit data to a quality standard by regulation or by contract, that an accuracy statement be submitted with the GIS data and referenced in the metadata.

Table 2.3.2 Threshold accuracy values in ground units.

Scale	Class 1 Planimetric Accuracy, limiting RMSE (feet)	Equivalent $Accuracy_r$, NSSDA (feet)	Class 1 Planimetric Accuracy, limiting RMSE (meters)	Equivalent $Accuracy_r$, NSSDA (meters)
1:60	0.05	0.12		
1:1,200	1.0	2.4		
1:2,000			0.50	1.2
1:2,400	2.0	4.9		
1:5,000			1.25	3.1
1:6,000	5.0	12.2		
1:10,000			2.50	6.1
1:12,000	10.0	24.5		
1:20,000	16.7	40.9	5.00	12.2

Derived from American Society for Photogrammetry and Remote Sensing Class 1 Horizontal Interim Accuracy Standards for Large-Scale maps (1990).

The New Jersey Society of Professional Land Surveyors (NJSPLS, http://www.njspls.org/) has also produced a set of proposed threshold $Accuracy_r$ values for several specific types of GIS data. Because these standards have not yet been adopted, they are not shown here.

3.0 NEW JERSEY DEPARTMENT ENVIROMNETAL PROTECTION GIS DATA STANDARDS

The remainder of this document describes standards adopted by the Department to facilitate data sharing and provide the basic standards for creating, describing and distributing spatial data on its GIS. The objective is to facilitate interactive analysis of data of the highest quality within the Department.

3.1 Datum and Projection

3.1.1 Horizontal and Vertical Datums

The North American Datum of 1983 (NAD83) is required for mapping in the horizontal plane .The North American Vertical Datum of 1988 (NAVD 88) should be used when possible rather than the older National Geodetic Vertical Datum of 1929 (NGVD29).

3.1.2 Projection and Coordinate System

Based on the Chapter 218, Laws of New Jersey 1989, New Jersey State Plane is required in meters (the Department prefers feet), NAD83. The State of New Jersey is entirely contained within one state plane zone (2900). Special situations may require other projection systems for small-scale maps of regional (interstate) or national interest. The Department prefers to use feet as the units of measure and serves all of its data in the following Projected Coordinate System: **NAD_1983_StatePlane_New_Jersey_FIPS_2900_Feet**

3.2 Data Capture Methodology and Procedure

GIS information comes from a variety of sources, which can produce a wide range of positional accuracy. Consequently, each source must be evaluated to determine whether redrafting is necessary to prepare the data for entry into the GIS. Heads-up digitizing, Tablet digitizing, Scanning, and Global Positioning Systems (See Section 4.0) are all viable methods to input data to a GIS. Much of the data required for a GIS can be derived directly from the photo-interpretation of aerial photos or from rectified photo basemaps**.** Whichever method is used it is important that the most accurate data source set be used whenever possible. For NJ, the February-April, 2002 digital color infrared (CIR) orthophotography 1:2400 (1"=200') are currently the preferred reference for heads up digitizing. Only differentially corrected GPS coordinates may surpass this source in accuracy.

3.2.1 Heads-Up Digitizing

Heads-Up digitizing is a technique that is useful for capturing or updating data from digital imagery on screen. High-resolution digital imagery now allows GIS users to edit and delineate features directly on the screen using desktop GIS software. The following considerations should be carefully planned out in advance.

1. The user must document procedures when using this technique.
2. Scale used for data capture should be established & documented. Recommended scales for digitizing should be between 1:1200 to 1:4000 over DOQQ. Below 1:1200 the imagery becomes extremely blurred. Above 1:4000 accuracy could be compromised.
3. Digitizing tolerances should be established and documented.
4. Users should maintain clear definitions or classifications of features that are being interpreted and delineated.
5. Ground truth (field verification) remains an important step in establishing the quality of heads-up digitizing, particularly for land cover delineation.
6. Make sure appropriate entries concerning the quality of the data are documented in the metadata files.

Detailed classification systems and resolution of imagery may require that features be captured on the screen and then photo-interpreted from aerial photography to the digital image. Photo-interpreting and heads-up digitizing at the same time can be extremely difficult even for experienced users.

All attribute coding shall be 100% correctly coded. A full description of each code should be provided as part of the metadata. The coding of features should follow an approved classification system as adopted by State and Federal agencies. These codes follow specifications of organizations responsible for deriving and maintaining the data. For example, the Department uses the Cowardin et al. (1979) system for the Classification of Wetland and Subaqueous Lands in the United States as adopted by the National Wetlands Inventory of the U.S. Fish and Wildlife Service. In addition the Department supports a modified version of Anderson et al. (1976), USGS, for classifying land use/land cover. For prototype classification schemes, clear concise documentation describing the classes is required.

3.2.2 Tablet Digitizing

Tablet digitizing is a common method of getting data into a GIS. The procedure involves tracing lines or locating points with a computer mouse on a digitizer. The manuscript's lines should be clear and complete with no gaps or shortfalls. Operators should not interpret and digitize at the same time. The digitizer should concentrate solely on capturing the exact nature of the features. All maps shall be edge matched prior to digitization to eliminate cartographic errors and reduce digital problems. Digital accuracy shall be evaluated by proof plotting the digital data to the base at the same scale as the manuscript and overlaying the data to the original map. The line work should be digitized in such a way as to create a digital copy that is within +/- one line width of the original. Edits can be flagged and corrected such that the standard is met. Coverage TICS should be identified and RMS errors documented in the metadata.

3.2.3 Scanning and Recompilation

Scanning of features from hardcopy sources or the recompilation of existing digital data, involves the redrafting of features from one source to a more accurate, planimetric source based on identifiable features. This method is commonly used to improve the quality of data that has been delineated on sources of unknown or unspecified quality or paper manuscripts. It is also commonly used to transfer data or non-rectified photography to a rectified orthophoto basemap based on a series of local fits of common photo-identifiable features, such as roads.

Other data sources without photo-images may be recompiled to planimetric sources by using other coincident features. For instance, grids on source data may be generated and plotted to planimetric basemaps and used as a guide for the redrafting of information that would otherwise not be usable in a digital form. This has been used to draft historical purveyor boundaries from old atlas sheets to the photoquads, for instance. Whatever the technique, metadata must be completed describing the recompilation techniques employed.

4.0 GLOBAL POSITIONING SYSTEM (GPS)

The NAVSTAR Global Positioning System (GPS) has become a mainstream technology for data collection for GIS. In New Jersey, state, county and municipal government agencies, academic institutions, public utilities, non-profit organizations, and private firms are using the technology to collect positions of features associated with their activities. A GPS receiver is able to determine its 3D position (latitude, longitude, and elevation) on the surface of the earth, store location information and convert the coordinates into features for use in a GIS. Users can not only capture a feature's location, but also enter descriptive attribute data that significantly adds to the final data layer's value in GIS.

GPS is most effective when the GPS receiver's antenna has an unobstructed view of the sky. Buildings in urban areas and dense tree cover can create reception problems making GPS collection work difficult in these types of environments. The GPS receiver must be able to receive relatively clear signals from at least four satellites simultaneously to determine a 3D position or fix. Depending on the design of the GPS receiver, and the data collection/data processing techniques used, the horizontal range of accuracy can be 15 meters to sub-centimeter.

Positional data collected with GPS must, at a minimum, meet within a 5 meter, 95% confidence standard. This requires all GPS data to be differentially corrected. If accuracy requirements call for higher accuracy, parameter settings have to be adjusted accordingly in order to meet the higher standard.

The Department has adopted standards for the critical settings for rover (field data) receivers that are consistent regardless of which receiver model is being used. Users should not deviate from these standards. These settings include:

Table 4.0.1 Critical and Recommended Settings for Data Collection

Standard GPS Collection Parameter Settings

Position Mode	Manual 3D is the normal setting.
Elevation Mask	15 degrees above horizon.
PDOP Mask	6
Signal to Noise Ratio Mask (SNR)	6
Minimum Positions for Point Features	200 (100 for Trimble Pro XL, 60 for Pro XR)
Logging Intervals	Intervals for point features will be 1 second or faster. Intervals for line and area features depend on the velocity at which the receiver will be traveling and the nature of the feature and the operating environment. Under normal circumstances (i.e., when the user is walking with the receiver) the interval for line and area features will be set to a 5-second interval.
Logging of DOP	Turned On.

For detailed information on recommended GPS receiver settings and collection procedures, see the Department's *Standards for Using Code-Based Global Positioning Systems (GPS) for the Development of Accurate Location Data for Use with Arc/Info and ArcView Geographic Information Systems*. (http://www.state.nj.us/dep/gis/gpsoutstand.html)

5.0 METADATA standards

Metadata is required for all digital data layers created by the Department. Metadata is supporting information that describes the digital data layer and is critical for users to understand the key components of the data. Metadata describes how the data were created, who created and maintains the data, when the data were created and/or updated, item (attribute) descriptions, transfer standards, and more. The Federal Geographic Data Committee has defined the Federal metadata standard that all Federal agencies are required to follow for each digital data layer. The Department requires that metadata be provided with each digital data layer and that the metadata be FGDC compliant. Standard FGDC compliant metadata is a critical component of information management systems (clearinghouses) on the World Wide Web (WWW) and for any interactive mapping applications provided across the WWW.

The following is a statement from the FGDC on the metadata standard:

> The objectives of the standard are to provide a common set of terminology and definitions for the documentation of digital geospatial data. The standard establishes the names of data elements and compound elements (groups of data elements) to be used for these purposes, the definitions of these compound elements and data elements, and information about the values that are to be provided for the data elements.
>
> This standard is the data documentation standard referenced in the executive order (Executive Order 12906, "Coordinating Geographic Data Acquisition and Access: the National Spatial Data Infrastructure)." The standard was developed from the perspective of defining the information required by a prospective user to determine the availability of a set of geospatial data, to determine the fitness the set of geospatial data for an intended use, to determine the means of accessing the set of geospatial data, and to successfully transfer the set of geospatial data. As such, the standard establishes the names of data elements and compound elements to be used for these purposes, the definitions of these data elements and compound elements, and information about values that are to be provided for the data elements.

For more information on metadata, go to the Department's GIS Metadata page (http://www.state.nj.us/dep/gis/metastan.htm). For examples of metadata for GIS data layers go to the New Jersey Geographic Information Network (NJGIN) and "Search" for data (https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp).

Additional information can be found at (http://www.fgdc.gov/metadata/).

6.0 DATA TRANSFER STANDARDS

In order to enhance data exchange, the following standards should be followed. Presented below are recommended exchange standards for ESRI's Arc suite of products.

6.1 SOFTWARE

Digital Exchange Standards for GIS

Table 6.1.1 details the exchange standards recommended for the exchange with the Department's GIS software. For "relate," "join" or "link" databases, dbase IV, Access and Excel are preferred over INFO look up tables.

Table 6.1.1 NJDEP GIS Compatible Configurations

PLATFORM	***UNIX Workstation***	***PC***
OPERATING SYSTEM	**UNIX**	**Windows 2000, XP**
SOFTWARE/ File Format	**ArcGIS 9.x** **Workstation** **Geodatabase** **Coverage** **Shape Files** **ArcView 3.x** **Coverage** **Shape Files** **DXF**	**ArcGIS 9.x** **Geodatabase** **Personal Geodatabase** **Coverage** **Shape Files** **ArcView 3.x shape files** **DWG (AutoCad)** **DGN (Microstation)** **DXF**
DATA TRANSFER	**Arc/Info Interchange File (*.e00)** **Shapefile** **XML**	**Arc/Info Interchange File (*.e00)** **Shapefile** **XML** **Winzip (rename to *.abc)** **(*=name of file)**
MEDIA	**CD-ROM (CD-R)** **DVD** **3 1/2" HD 1.44MB**	**CD-ROM (CD-R)** **DVD** **3 1/2" HD 1.44MB** **Zip Disk (100 or 250MB)**

6.2 DATA DISTRIBUTION

6.2.1 Digital Transfer Methods

Data are available in the following variety of formats from a variety of sources today. The formats, usually available in compressed Zip file format, should be compatible with Table 6.1. The New Jersey Geographic Information Network (NJGIN) (https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp) is the preferred centralized location and method for data distribution to users outside the Department.

6.2.2 Data Supplied by NJDEP

For data supplied by the Department the following Distribution Agreement (NJDEP) shall accompany all data transfers. The users agree to abide by the terms and conditions of the following:

I. Description of Data to be provided

The data provided herein are distributed subject to the following conditions and restrictions.

For all data contained herein, (NJDEP) makes no representations of any kind, including, but not limited to, the warranties of merchantability or fitness for a particular use, nor are any such warranties to be implied with respect to the digital data layers furnished hereunder. NJDEP assumes no responsibility to maintain them in any manner or form.

II. Terms of Agreement

1. Digital data received from the NJDEP are to be used solely for internal purposes in the conduct of daily affairs.

2. The data are provided, as is, without warranty of any kind and the user is responsible for understanding the accuracy limitations of all digital data layers provided herein, as documented in the accompanying Metadata, Data Dictionary and Readme files. Any reproduction or manipulation of the above data must ensure that the coordinate reference system remains intact.

3. Digital data received from the NJDEP may not be reproduced or redistributed for use by anyone without first obtaining written permission from the NJDEP. This clause is not intended to restrict the distribution of printed mapped information produced from the digital data.

4. Any maps, publications, reports, or other documents produced as a result of this project that utilize the Department's digital data will credit the Department's Geographic Information System (GIS) as the source of the data with the following credit/disclaimer: "This (map/publication/report) was developed using New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP and is not State-authorized."

5. Users shall require any independent contractor, hired to undertake work that will utilize digital data obtained from the Department, to agree not to use, reproduce, or redistribute NJDEP GIS data for any purpose other than the specified contractual work. All copies of the Department's GIS data utilized by an independent contractor will be required to be returned to the original user at the close of such contractual work.

Users hereby agree to abide by the use and reproduction conditions specified above and agree to hold any independent contractor to the same terms. By using data provided herein, the user acknowledges that terms and conditions have been read and that the user is bound by these criteria.

APPENDIX

Appendix A. National Map Accuracy Standard (NMAS)

NATIONAL MAP ACCURACY STANDARDS
United States National Map Accuracy Standards
U.S. Bureau of the Budget, Revised June 17, 1947

With a view to the utmost economy and expedition in producing maps, which fulfill not only the broad needs for standard or principal maps, but also the reasonable particular needs of individual agencies, standards of accuracy for published maps are defined as follows.

1. Horizontal accuracy, for maps on publication scales larger than 1:20,000, not more than 10% of the points tested shall be in error by more than 1/30 inch, measured on the publication scale; for maps on publication scales of 1:20,000 or smaller, 1/50th of an inch. These limits of accuracy shall apply in all cases to positions of well-defined points only. Well-defined points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as benchmarks, property boundary monuments; intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings); etc. In general what is well defined will also be determined by what is plotable on the scale of the map within 1/100 inch. Thus, while the intersection of two road or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would obviously not be practicable within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted, even though their positions may be scaled closely upon the map. This class would include timberlines, soil boundaries, etc.

2. Vertical Accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

3. The accuracy of any map may be tested by comparing the positions of points whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy. Tests shall be made by the producing agency, which shall also determine which of its maps are to be tested, and the extent of such testing.

4. Published maps meeting these accuracy requirements shall note this fact on their legends, as follows: "This map complies with National Map Accuracy Standards."

5. Published maps whose errors exceed that aforesaid shall omit from their legends all mention of standard accuracy.

6. When a published map is a considerable enlargement of a map drawing (manuscript) or of a published map, that fact shall be stated in the legend. For example, "This map is an enlargement of a 1:20000-scale map drawing," or "This map is an enlargement of a 1:24000-scale published map."

7. To facilitate ready interchange and use of basic information for map construction among all Federal mapmaking agencies, feasible and consistent with the uses to which the map is to be put, shall conform to latitude and longitude boundaries, being 15 minutes of latitude and longitude, or 7.5 minutes, or 3-3/4 minutes in size. (From Thompson, 1987).

Appendix B. Digital Imagery (Meets NMAS)

2002 Digital color infrared (CIR) orthophotography

Aerial photography of the entire State of New Jersey was captured during February-April, 2002. Digital color infrared (CIR) orthophotography was produced at a scale of 1:2400 (1"=200') with a 1 foot pixel resolution for New Jersey in State Plane NAD83 Coordinates, U.S. Survey Feet. Digital orthophotography combines the image characteristics of a photograph with the geometric qualities of a map. Digital orthophotography is a process, which converts aerial photography from an original photonegative to a digital product that has been positionally corrected for camera lens distortion, vertical displacement and variations in aircraft altitude and orientation. The ortho-rectification process achieved a +/-4.0 ft. horizontal accuracy at a 95% confidence level, National Standard for Spatial Data Accuracy (NSSDA).

This dataset consists of 5000' x 5000' files in MrSID format with a 15:1 compression ratio. The files, which can be selected and downloaded from the NJGIN site, were produced utilizing MrSID Geospatial Edition 1.4 and are approximately 5 MB in size.

State Resource: **NJ Geographic Information Network (NJGIN)**
(https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp)

The 2002 orthos are available for purchase in MrSID compressed format (on DVD media only) from the USGS-EROS Data Center.

A complete set of orthos for the State is available on 13 DVDs at a cost of $785.00. Note: If you are NOT purchasing a complete set of orthos on 13 DVDs, you need to include the DVD series number (i.e., DVD 1 of 13, DVD 2 of 13, etc.) with your order.

The MrSID Index with the series number for each DVD is provided as an ESRI shapefile from the NJGIN site.

Pricing Information: $60 per DVD + $5 handling fee per order (subject to change).

Payment, or obligation by way of a purchase order, must be received by the USGS-EROS Data Center before order processing may begin. All instruments of payment are to be made payable to Department of the Interior, USGS. The link for payment options is:
http://edc.usgs.gov/about/customer/modes.html

To order: Send email to custserv@usgs.gov or contact Kim Brown at 1-800-252-4547, ext. 2061. USGS-EROS Data Center Business Hours: Monday through Friday, 8:00 a.m. to 4:00 p.m., Central Time.

1995-97 Digital color infrared (CIR) orthophotography

The imagery conforms to the standards of USGS "standard product" for digital orthophoto quarterquads (DOQQs). Many organizations including the Department use these high quality images as digital base maps for mapping applications.

The 1995/97 imagery is color infrared (CIR), has 3 bands, 1 meter resolution, and is NAD83 in UTM (meters). The standard product is available through the USGS EROS Data Center. The Department has made the data available on the GIS server in SPC feet, NAD83. The imagery is available from the following resources:

Federal Resource:	http://earthexplorer.usgs.gov http://www.usgs.gov/pubprod/index.html **USGS (703) 648-5931**
State Resource:	**NJ Geographic Information Network** (https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp)

1991-92 Digital imagery

The 1991-92 digital imagery is available at 5-ft (quarter quad) resolution or 10 ft (quad) grayscale (1 band) digital files, NAD83. These images meet NMAS at the production scale (1:12000) and are the manuscript images from which the 1991-92 Mylar basemaps were made. The files are *.gis* (ERDAS) files and are 16mb each. These digital images are available only from MARKHURD.

Contractor Resource: **MARKHURD, Minneapolis, MN (1-800-MAP-HURD).**

Appendix C. New Jersey Basemaps Which Meet NMAS

The Department has created several source basemaps that are available for mapping initiatives that meet or exceed NMAS. Basemaps provide the foundation for many mapping projects and for the display of mapped information. As such, basemaps must meet uniform, rigorous standards for positional accuracy and cartographic integrity. Over the years, several series of quality basemaps that meet or exceed NMAS have been produced. Basemaps can be either hardcopy (Mylar or acetate) or digital (softcopy). A statewide synoptic set of hardcopy basemaps for New Jersey was made from aerial over-flights sponsored by the Department in 1991 and 1986. In both cases, both quadrangle (1:24000) and quarter quadrangle (1:12000) hardcopy Mylar basemaps were produced. Other basemaps cover specific areas only, such as the 1977-78 Tidelands photo basemaps. Two series of digital (softcopy) basemaps have also been produced, from the 1991 and 1995/97 over-flights. The digital images were produced at quarterquad scale (1:12000).

* Hardcopy (Mylar) Basemaps

Listed below in order of general overall quality is available New Jersey basemap series that were produced on stable base mylar and meet a definable mapping standard (NMAS). The first four series listed are photo basemaps, derived from aerial photography. The 1991/92 and the 1986 wetland series are both orthophoto basemaps compiled from a sophisticated aero-triangulation process. They should be used whenever possible to generate GIS compatible data and/or to use as a recompilation base.

All the hardcopy basemaps described herein with the exception of the 1991/92 products are referenced in NAD27. For this reason, the 1991/92 mylar basemap quads (1:24000) and quarterquads (1:12000) series, referenced in NAD83 are highly recommended by the Department over all other sources listed for mapping at these scales. Stable base site maps of large scale meeting NMAS, produced by surveying, mapping or photogrammetric firms may qualify as GIS compatible if they contain a minimum of four registration tics in the New Jersey State Plane Coordinate System, North American Datum 1983 (NAD83), the official survey base of New Jersey. The USGS topoquad series are not recommended as a delineation source because they are generally available only on paper and are not synoptic data sources. Rather, they represent variable data sources and dates.

* 1991/92 Orthophoto Basemaps (Quadrangles and Quarter quadrangles)

The most recent statewide set of hardcopy chronoflex quarterquad (1:12000) and photoquad (1:24000) photo basemaps were produced from the 1991/92 aerial overflight of the State. These basemaps meet or exceed NMAS. This series of maps is referenced in SPC feet in NAD83, but also has NAD27 tics in the margin. This series is the most current, highest quality basemaps of their scale available statewide, that are referenced in the new datum, NAD83. This basemap series is highly recommended by the Department for mapping efforts at these scales.

* 1986 Freshwater Wetlands Orthophoto Quarterquad Basemaps (1:12000)

The passage of the Freshwater Wetlands Act of 1987 required the State to produce a composite map of the freshwater wetlands (FWW) for the State. Subsequently, a set of 635 chronoflex photo quarterquads for the entire State from the March 1986 overflight was produced. The maps represent an excellent source for both photo-interpretation and recompilation at a county, municipal or site level. However, these maps are dated and are referenced in the old datum (NAD27). The 1991/92 series now supercedes these maps. There is also a set of composite hardcopy FWW maps with the delineation superimposed on the image.

*** 1986 Photoquad Basemaps (1:24000)**

A statewide overflight in March 1986 produced a complete set of stable base photoquads at 1:24000. The control for the production of these basemaps was the Mylar USGS 7.5-Minute topoquads. The photoquads have been widely used both to create data layers and to recompile other data sources from paper or non-planimetric sources. These basemaps did not follow rigorous orthophoto techniques and are referenced in the old datum. The 1991/92 basemaps supercedes these maps.

*** 1977/78 Tidelands Basemaps (1:2400)**

The tidelands maps are a series of 1:2400 base maps for the coastal zone that include all tidal areas in the State to delineate the State's claim to all tide-flowed lands. The series consists of 1628 photo basemaps. These maps are rectified products that meet NMAS below the ten-foot contour. The photo-image is late summer of 1977 and 1978. These maps cover the entire coastal zone up to the head-of-tide.

*** USGS 7.5-Minute Series Topoquad Basemaps (1:24000)**

The USGS has published an entire series of 172 topographic maps for the State at a scale of 1:24000. The base information ranged from the late 1940's to the 1980's with photo-updates into the mid 1990's. Because these maps vary in source date, and because more accurate and current basemaps (1991/92) are available, the USGS topoquads series <u>*is not recommended*</u> by the Department as a mapping base. The topoquads do represent an excellent reference source, particularly for named places and features.

Appendix D. Basemap Resources

Mylar photo basemaps from 1991, 1986 and 1977/78 and the digital imagery from 1991 may be obtained from MARKHURD, Minneapolis, MN (1-800-MAP-HURD). There are several sets of the 1986 and 1991 chronoflex (Mylar) base maps in the Department. The GIS Unit has a set of each for reference.

Paper prints of 1986 and 1991 orthophoto basemap series, as well as paper prints of USGS topoquads, may be obtained from the Department's Maps and Publications; (609) 777-1038. Paper prints from the 1977/78 series are available from the Bureau of Tidelands Management: (609) 292-2573.

Topoquads and other USGS Federal maps (and aerial photos) may be ordered from 1-800-USA-MAPS or (703) 648-5931.

* Aerial Photograph Resources

Historic aerial photography is available for inspection at the Department's Tidelands Management Program (TMP) by scheduled appointment. The 1986, 1991/92, 1995/97 and 2002 photo color infrared frames are also available for inspection at the TMP. Appointments are required. The 1991/92 and 1995/97 photos may also be purchased from the USGS EROS Data Center.

Federal Resource: http://www.usgs.gov/pubprod/index.html
USGS (703) 648-5931

Department Resource: Tidelands Management Program (609) 633-7369

Appendix E. Metadata

For examples of metadata please go to the New Jersey Geographic Information Network and search for GIS data (https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp). For additional resources go to the Department's GIS web site (http://www.state.nj.us/dep/gis/metastan.htm) for a description of metadata and additional examples.

Appendix F. Internet Resources

NJDEP, GIS: http://www.state.nj.us/dep/gis

NJ Geographic Information Network: https://njgin.state.nj.us/NJ_NJGINExplorer/index.jsp

GPS Resource: http://www.state.nj.us/dep/gis/newgps.htm

Appendix C:
Highlands Technical Documentation Template

New Jersey Highlands Water Protection and Planning Council

[Title]

Release Date: [DATE]

Abstract

[75-100 word description of document clarifying intended audience and use.]

Highlands Council New Jersey

100 North Road (Route 513) | Chester, NJ 07930-2322 | (908)879 6737 | www.highlands.state.nj.us

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Statutory Platform, Purpose and Funding

250 word max. Clarify:

1. Why this document was prepared (ACT/RMP context: cite goals and objectives that drive need for this document)
2. What this document is/does.
3. Who it is intended to be used by.
4. How it will be funded for Highlands conforming towns.

Example provided by Highlands Council:

Through the passage of the New Jersey Highlands Water Protection and Planning Act in 2004, the NJ Highlands Water Protection and Planning Council (the Highlands Council) was created and charged with developing a Regional Master Plan (RMP). Adopted in 2008, the RMP serves as the guiding document for the long-term protection and restoration of the region's critical resources. This Lake Management Plan Guidance document was developed in accordance with Objective 1L6a of the RMP. *

This is a technical document, intended to be used by planning and science professionals within a municipality to aid in the development of an Adaptive Lake Management strategy, by providing the tools to analyze lake management needs, set corresponding goals, identify appropriate solutions, implement those solutions, and establish ongoing monitoring and management tactics.

Funding to support this work within a municipality is provided through the Highlands Plan Conformance process. Municipalities with approved Plan Conformance Petitions are eligible for grant funding to cover the reasonable expenses of planning activities associated with the Conformance process and should contact their Highlands Council Municipal Liaison for additional information.

** Copies of the Highlands Regional Master Plan are available in most municipal offices and can be obtained by contacting the Highlands Council office.*

Table of Contents

Chapter 1 Title – Use style "Heading 1, Chapter Title"

This Microsoft Word template was created using styles that will allow for the automatic creation of a table of contents ONLY IF the appropriate styles are selected. A copy of the MS Word file is available by contacting the Highlands Council.

Body copy for main chapter text, and all text under heading 1, 2 and 3, should use the "Normal" style. Use a manual return between paragraphs and before the first line of text in a new chapter, but NOT after subheadings.

Please use APA style for all in-text citations and reference list at end of document. If another style is preferable, please just remain consistent throughout document and include complete reference list at end of document.

Second-level heading – Use style "Heading 2"

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Third level heading – Use style "Heading 3"

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Fifth Level Heading – Use style "Heading 5

Here again, use "Body Copy level 4 and 5 (indent).

At the end of a Chapter, insert a "Next Page" Section Break, so that the page footer can be customized with the chapter title.

Chapter 2 – Title of Chapter

Second-level heading – Use style "Heading 2"

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Third level heading – Use style "Heading 3"

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Fourth level heading – Use style "Heading 4"

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Fifth level heading – Use style "Heading 5"

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Sixth level heading – Use style "Heading 6"

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When all chapters are complete, insert divider title page before appendices, glossaries, reference notes, etc.

Appendix A:
Case Studies/Success Stories

Case Study 1

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Case Study 2

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Glossary of Commonly Used Terms

Word – Definition.

Word – Definition.

Word – Definition.

Word – Definition.

Word – Definition.

Word – Definition.

References

[Please use APA style for all in-text citations and reference list at end of document. If another style is preferable, please just remain consistent throughout document and include complete reference list at end of document.]