Amendment to the Northeast Water Quality Management Plan

Total Maximum Daily Load for Phosphorus To Address Greenwood Lake in the Northeast Water Region

Watershed Management Area 3

Proposed:	June 7, 2004
Established:	September 10, 2004
Approved:	September 29, 2004
Adopted:	

New Jersey Department of Environmental Protection
Division of Watershed Management
P.O. Box 418
Trenton, New Jersey 08625-0418

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1.0 Executive Summary

The State of New Jersey's *Integrated List of Waterbodies* in 2002 and 2004 identified Greenwood Lake in the Northeast Water Region as being eutrophic/impaired for phosphorus. This report establishes one total maximum daily load (TMDL) for total phosphorus (TP) to address eutrophication of Greenwood Lake.

This TMDL sets the foundation on which a restoration plan will be developed to restore the lake and thereby attain applicable surface water quality standards. A TMDL is developed to identify all the contributors to surface water quality impacts and establish load reductions for pollutants of concern as necessary to meet Surface Water Quality Standards (SWQS). The pollutant of concern for this TMDL is phosphorus; phosphorus is the nutrient responsible for overfertilization of inland lakes leading to cultural eutrophication.

In order to prevent excessive primary productivity[1] and consequent impairment of recreational, water supply and aquatic life designated uses, the SWQS define both numerical and narrative criteria that address eutrophication in lakes due to overfertilization. All possible phosphorus sources were characterized on an annual scale (kg TP/yr), including runoff from the land surface, point sources, septic tank systems and internal loading from the lake sediment. Runoff from land surfaces and internal loading from the lake sediment comprise the most significant sources of phosphorus into the lake. An empirical model was used to relate annual phosphorus load and steady-state in-lake concentration of total phosphorus. To achieve the TMDL, overall load reductions were calculated for different source categories. In coordination with the bi-state Greenwood Lake Commission, an Implementation Plan has been developed for this TMDL, which includes a Lake Characterization and Restoration project, using funds made available to the New Jersey Department of Protection (NJDEP) under the Clean Water Act Section 319(h). The project will begin in July 2004. The bathymetric survey, in-lake monitoring and tributary monitoring proposed in this project will better quantify phosphorus contributions and tailor actions to achieve needed reduction as well as to identify any in-lake measures needed to supplement the nutrient reductions required by the TMDL. Stormwater runoff "hot spots" that would benefit from best management practices (BMPs) will be identified and prioritized. The efficiency of implemented BMPs will be monitored after installation. Other implementation measures include education projects that teach BMPs on lawn care, municipal ordinances to deal with phosphorus, remediation of septic systems, upgrading wastewater treatment facilities as needed, and projects to reduce the internal loading from the sediment. The Department believes that these steps will result in attainment of New Jersey's SWQS for phosphorus.

This TMDL Report is consistent with EPA's May 20, 2002 guidance document entitled: "Guidelines for Reviewing TMDLs under Existing Regulations issued in 1992," (Sutfin, 2002) which describes the statutory and regulatory requirements for approvable TMDLs.

2.0 Introduction

Sublist 5 of the State of New Jersey's *2002 Integrated List of Waterbodies* (also known traditionally as the 303(d) List) identified Greenwood lake as being eutrophic, as evidenced by elevated total phosphorus (TP), elevated chlorophyll-*a,* and/or macrophyte density that impairs recreational use (a qualitative assessment). Total phosphorus was used as the pollutant of concern, since this

[1] Primary productivity refers to the growth rate of primary producers, namely algae and aquatic plants, which form the base of the food web.

"independent" causal pollutant results in "dependent "responses in chlorophyll-*a* concentrations and/or macrophyte density. This report establishes one TMDL for TP load to Greenwood Lake and the management approaches and restoration plan needed to attain applicable surface water quality standards.

3.0 Background

3.1 305(b) Report and 303(d) List

In accordance with Section 305(b) of the Federal Clean Water Act (CWA) (33 U.S.C. 1315(B)), the State of New Jersey is required biennially to prepare and submit to the United States Environmental Protection Agency (USEPA) a report addressing the overall water quality of the State's waters. This report is commonly referred to as the 305(b) Report or the Water Quality Inventory Report.

In accordance with Section 303(d) of the CWA, the State is also required biennially to prepare and submit to USEPA a report that identifies waters that do not meet or are not expected to meet surface water quality standards (SWQS) after implementation of technology-based effluent limitations or other required controls. This report is commonly referred to as the 303(d) List. The listed waterbodies are considered water quality-limited and require total maximum daily load (TMDLs) evaluations.

In November 2001, USEPA issued guidance that encouraged states to integrate the 305(b) Report and the 303(d) List into one report. This integrated report assigns waterbodies to one of five categories. Sublist 5 constitutes the traditional 303(d) List for waters impaired or threatened by a pollutant for which one or more TMDL evaluations are needed.

Following USEPA's guidance, the Department chose to develop an Integrated Report for New Jersey. New Jersey's *Integrated List of Waterbodies* in 2002 and 2004are based upon these five categories and identifies water quality limited surface waters in accordance with N.J.A.C. 7:15-6 and Section 303(d) of the CWA. This TMDL addresses the eutrophic Greenwood Lake, as listed on Sublist 5 of the State of New Jersey's *Integrated List of Waterbodies* in 2002 and 2004.

3.2 Total Maximum Daily Loads (TMDLs)

A TMDL represents the assimilative or carrying capacity of a waterbody, taking into consideration point and nonpoint source of pollutants of concern, natural background and surface water withdrawals. A TMDL quantifies the amount of a pollutant a water body can assimilate without violating a state's water quality standards and allocates that load capacity to known point sources in the form of wasteload allocations (WLAs), nonpoint sources in the form of load allocations (LAs), and a margin of safety (MOS). A TMDL is developed to identify all the contributors to surface water quality impacts and set load reductions for pollutants of concern needed to meet SWQS.

Recent EPA guidance (Sutfin, 2002) describes the statutory and regulatory requirements for approvable TMDLs, as well as additional information generally needed for USEPA to determine if a submitted TMDL fulfills the legal requirements for approval under Section 303(d) and EPA regulations. The Department believes that this TMDL report addresses the following items in the May 20, 2002 guideline document:

1. Identification of waterbody, pollutant of concern, pollutant sources and priority ranking.
2. Description of applicable water quality standards and numeric water quality target(s).

3. Loading capacity – linking water quality and pollutant sources.
4. Load allocations.
5. Wasteload allocations.
6. Margin of safety.
7. Seasonal variation.
8. Reasonable assurances.
9. Monitoring plan to track TMDL effectiveness.
10. Implementation (USEPA is not required to and does not approve TMDL implementation plans).
11. Public Participation.

The State of New Jersey will be removing Greenwood Lake from the 303(d) List for phosphorus, once this TMDL is approved by USEPA.

4.0 Pollutant of Concern and Area of Interest

Greenwood Lake was designated as eutrophic on Sublist 5 of the *2002 Integrated List of Waterbodies* as a result of evaluations performed through the State's Clean Lakes Program. Indicators used to determine trophic status included elevated total phosphorus (TP), elevated chlorophyll-*a,* and/or macrophyte density. The pollutant of concern for this TMDL is total phosphorus. The mechanism by which phosphorus can cause use impairment is via excessive primary productivity. Phosphorus is an essential nutrient for plants and algae, but is considered a pollutant because it can stimulate excessive growth (primary production). Phosphorus is most often the major nutrient in shortest supply relative to the nutritional requirements of primary producers in freshwater lakes; consequently, phosphorus is frequently a prime determinant of the total biomass in a lake. Eutrophication has been described as the acceleration of the natural aging process of surface waters. It is characterized by excessive loading of silt, organic matter, and nutrients, causing high biological production and decreased basin volume (Cooke et al, 1993). Symptoms of eutrophication (primary impacts) include oxygen super-saturation during the day, oxygen depletion during night, and high sedimentation (filling in) rate. Algae and aquatic plants are the catalysts for these processes. Secondary biological impacts can include loss of biodiversity and structural changes to communities.

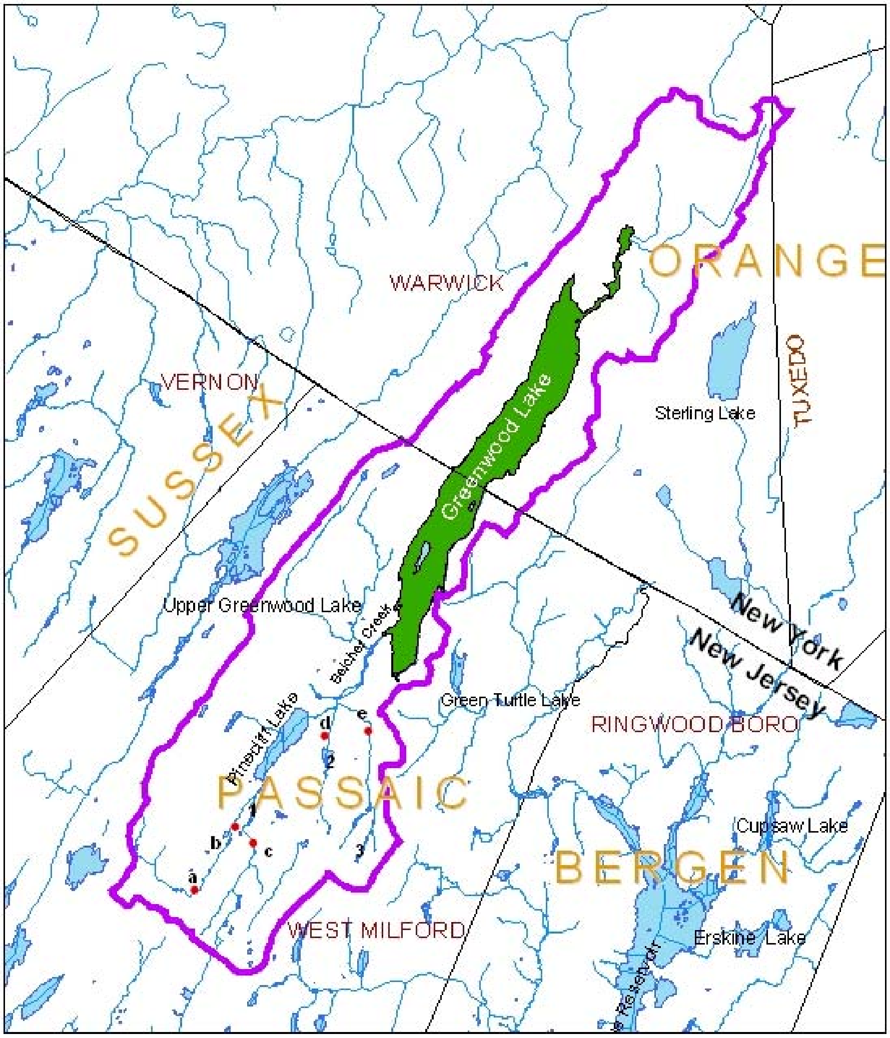
As reported in the *2002 Integrated List of Waterbodies*, the Department identified the Greenwood Lake as being eutrophic. The proposed *2004 Integrated List of Waterbodies* specifies the impairment in terms of the pollutants phosphorus, dissolved oxygen and sedimentation. This TMDL will address the phosphorus impairment and will cover 824 acres of the lake area located in New Jersey and 1060 acres of the lake area located in New York, corresponding to a total of 16,036 acres of land within the watershed. Eutrophic lake impairment is ranked as a Low Priority in the *2002 Integrated List of Waterbodies,* because it is not directly related to human health issues; however, eutrophication is an environmentally important issue. It is likely that the dissolved oxygen and sedimentation impairments are caused by primary productivity; this will be further evaluated as part of the implementation plan for this TMDL.

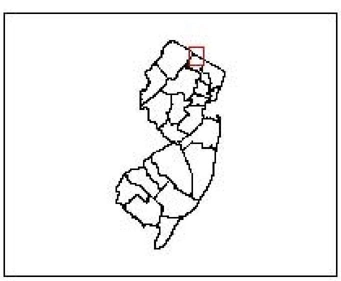
Table 1 Characteristics of Greenwood Lake

Lake Area (acre)	Lakeshed Area (acre)	Outflow[a] (m^3/yr)	Volume[a] (m^3)	Average Depth[a] (m)	Maximum Depth[a] (m)
1,884	16,036	3.45E+07	4.04E+07	5.2	17.4

a: taken from Phase 1 Study of Greenwood Lake (PAS, 1983)

Figure 1 Locations of Greenwood Lake and Its Watershed





LEGEND

ORANGE County
WARWICK Municipality
Greenwood Lake
Greenwood Lake Watershed
Stream
Lake
1 Reflection Lake 2 Westmilford Lake
3 Capri Lake

NJPDES Permitted Discharges within Lakeshed
a West Milford Twp MUA - Crescent Park STP
b Reflection Lake Garden Park
c West Milford Twp MUA - Olde Milford
d West Milford Shopping Center
e West Milford Twp MUA - Birchill

N W E S

1:133,000

As shown in Figure 1, Greenwood Lake is located on the border of New Jersey and New York. Greenwood Lake extends northward to the Town of Warwick, Orange County, New York and south to the Township of West Milford, Passaic County, New Jersey. The north and south basins are very different in terms of depth and bottom contours. The northern or New York section of the lake is characteristically deep, with a maximum depth of 18 meters and steeply sloped banks. In contrast, the southern or New Jersey section is shallow, with a maximum depth of 3 meters, gradually sloping banks. The lake's average depth is 5.2 meters, its surface area is 1884 acres and its volume is 4.04 x 10^7 m^3 (Table 1).

Several streams flow into the lake, and of these, Belcher Creek is the major tributary. Discharge from the lake is to the Wanaque River, a tributary of the Passaic River. Annual tributary inflow to the lake totals 1.8 x 10^7 m^3yr^{-1}, while total outflow is 4.04 x 10^7 m^3 (including evaporation). Greenwood Lake's watershed encompasses a total area of approximately 16,036 acres, exclusive of the lake's surface area (See Figure 1). The eastern and western boundaries of the watershed are defined by steep mountain ridges that parallel the lake's shoreline. Several small lakes are located within the watershed, including Pinecliff Lake, Reflection Lake, West Milford Lake, and Capri Lake. As shown in Figure 1, these small lakes serve as headwaters to Belcher Creek.

4.1 Geographic Information System (GIS) Coverage

In order to describe the lake and lakeshed (watershed of the lake), the Department's Geographic Information System (GIS), as well as GIS coverages from USGS and New York State, were used in this study, given the bi-state geographical location of Greenwood Lake. The coverages used in this study are specified below.

- Greenwood Lake Hydrology coverage (7.5 minute Quad Sheet) downloaded from Cornell University Geospatial Data Information Repository (CUGIR) was used to derive the entire lake boundary coverage. Hydrography (Census 2000) shapefiles were downloaded from CUGIR to describe the streams and lakes located in NY-side.
  http://cugir.mannlib.cornell.edu/browse_map/browse_map.html
- NJDEP Countywide Lakes and Streams (Shapefile) with Name Attributes for Passaic County, Sussex County and Bergen County to describe the lakes and streams located in NJ side.
  http://www.nj.gov/dep/gis/lakesshp.html and http://www.nj.gov/dep/gis/strmshp.html
- Lakesheds were delineated based on 14-digit hydrologic unit code coverage (HUC-14) and elevation contours.
  - NJDEP 14 Digit Hydrologic Unit Code delineations (DEPHUC14), published 4/5/2000 by New Jersey Geological Survey,
    http://www.state.nj.us/dep/gis/digidownload/zips/statewide/dephuc14.zip
  - Statewide Elevation Contours (10 Foot Intervals), unpublished, auto-generated from: 7.5 minute Digital Elevation Models, published 7/1/1979 by U.S. Geological Survey.
  - NJDEP Statewide Elevation Contours (20 Foot Intervals), published 1987 by Bureau of Geographic Information and Analysis (BGIA),
    http://www.state.nj.us/dep/gis/digidownload/zips/statewide/stcon.zip.
  - CUGIR's Elevation Data in the format of ASCII DEM
- National Land Cover Data (NLCD) for New York, last updated in July 2000, and for New Jersey, last updated in March 2000. The data was produced under the direction of the USGS as part of the Multi-Resolution Land Characterization (MRLC) Regional Land Cover Characterization Project. The data used the NLCD Land Cover Classification Systems to categorize land use. http://edcsgs9.cr.usgs.gov/pub/data/landcover/states/

- NJPDES Surface Water Discharges in New Jersey, (1:12,000), published 02/02/2002 by Division of Water Quality (DWQ), Bureau of Point Source Permitting - Region 1 (PSP-R1).
- NJDEP's 2000 Census Block Shapefile and Orange County, NY 2000 Census Block Shapefile from CUGIR
- NJDEP's 2002 Orthophotography Image.
- High Resolution Digital Orthoimagery 2000-2001 for Hudson Valley/Catskill Region in New York State, downloaded from New York Sate GIS Clearinghouse. http://www.nysgis.state.ny.us/gateway/mg/high_res.htm

4.2 Greenwood Lake Commission and New York State

A bi-state Greenwood Lake Commission has been formed to address the environmental issues in Greenwood Lake. New Jersey adopted the bill to create the Greenwood Lake Commission (S1788(1R); P.L. 1999 c.402) in January of 2000. The companion bill (A00294 S416-A) was adopted by New York State in January of 2001. The 11 voting members include representatives from: Passaic County, NJ; 2 representatives from the Township of West Milford, New Jersey; the Commissioner of the New Jersey Department of Protection (NJDEP) or designee; Orange County, New York; the Village of Greenwood Lake, New York; the Town of Warwick, New York; the Commissioner of the New York Department of Environmental Conservation (NYDEC) or a designee thereof; the Greenwood Lake Watershed Management District, a citizen advisory committee that has been active for more than 20 years; and from each state, an appointed representative from the public sector with related expertise. This TMDL has been developed in coordination with Greenwood Lake Commission.

New York has also listed Greenwood Lake as impaired, based on qualitative nutrient standards applicable to the lake in that state. At this time, New York is not establishing a TMDL for the portion of Greenwood Lake under its authority, but proposes to do so, based on the calculations in this TMDL in fiscal year 2005. New York has indicated that this TMDL will be adequate to meet the New York narrative water quality requirements and supports adoption of this TMDL.

5.0 Applicable Surface Water Quality Standards

In order to prevent excessive primary productivity and consequent impairment of recreational, water supply and aquatic life designated uses, the Surface Water Quality Standards (SWQS, N.J.A.C. 7:9B) define both numerical and narrative criteria that address eutrophication in lakes due to overfertilization. The total phosphorous (TP) criterion for freshwater lakes at N.J.A.C. 7:9B – 1.14(c)5 reads as follows:

> For freshwater 2 classified lakes, Phosphorus as total phosphorus shall not exceed 0.05 mg/l in any lake, pond or reservoir or in a tributary at the point where it enters such bodies of water, except where site-specific criteria are developed to satisfy N.J.A.C. 7:9B-1.5(g)3.

N.J.A.C. 7:9B-1.5(g)3 states:

> "The Department may establish site-specific water quality criteria for nutrients in lakes, ponds, reservoirs or stream, in addition to or in place of the criteria in N.J.A.C. 7:9B-1.14, when necessary to protect existing or designated uses. Such criteria shall become part of the SWQS.

Presently, no site-specific criteria apply to Greenwood Lake.

Also at N.J.A.C. 7:9B-1.5(g)2, the following is discussed:

> "Except as due to natural conditions, nutrients shall not be allowed in concentrations that cause objectionable algal densities, nuisance aquatic vegetation, or otherwise render the waters unsuitable for the designated uses."

This TMDL is designed to meet both numeric and narrative criteria of the SWQS.

All of the waterbodies covered under this TMDL have a FW2 classification. The designated uses, both existing and potential, that have been established by the Department for waters of the State classified as such are as stated below:

In all FW2 waters, the designated uses are (N.J.A.C. 7:9B-1.12):
1. Maintenance, migration and propagation of the natural and established aquatic biota;
2. Primary and secondary contact recreation;
3. Industrial and agricultural water supply;
4. Public potable water supply after conventional filtration treatment (a series of processes including filtration, flocculation, coagulation and sedimentation, resulting in substantial particulate removal but no consistent removal of chemical constituents) and disinfection; and
5. Any other reasonable uses.

6.0 Source Assessment

As part of the 1983 Phase I Diagnostic-Feasibility Study of Greenwood Lake, New Jersey and New York (PAS, 1983), the potential sources of phosphorus in the lake were evaluated and the annual influx of phosphorus from different sources was quantified. The annual TP load was estimated to be 5936.4 kilograms. The majority of the estimated phosphorus load originated from runoff from the land surface and the internal loading. However, septic tank and sewage treatment plant effluent are responsible for a sizable portion of the annual nutrient load as well. The Phase I Study was conducted over 20 years ago, so the contributions to the lake's annual phosphorus load were updated using the most recent data from these four major sources.

Phosphorus loads were characterized on an annual scale (kg TP/yr). Long-term pollutant loads are typically more critical to overall lake water quality than the load at any particular short-term time period (e.g. day). Storage and recycling mechanisms in the lake, such as luxury uptake and sediments dynamics, allow phosphorus to be used as needed regardless of the rate of delivery to the system. Also, empirical lake models use annual loads rather than daily or monthly loads to estimate in-lake concentrations.

6.1 Assessment of Point Sources other than Stormwater

The Department's GIS on New Jersey Pollution Discharge Elimination System (NJPDES) Surface Water Discharge was used to identify the point sources that could potentially contain phosphorus located within the New Jersey portion of the lakeshed. Appendix E contains a table and map of all NJPDES permitted facilities in the affected area. Five of them are active dischargers of phosphorus and monitoring and effluent requirements are included in their current permits, see Table 2. According to EPA's Envirofact Warehouse (http://oaspub.epa.gov/enviro/ef_home2.water), there are no facilities with National Pollutant Discharge Elimination System (NPDES) permits located within New York portion of the lakeshed.

The monthly average flow and TP concentration from Discharge Monitoring Reports (DMR) 2001 through 2003 were used to calculate the existing loads for each discharger. The monthly loads for years 2001 through 2003 were calculated, summed and averaged to give the representative value for the TP influx discharged from the identified facilities, which is also the WLA for each facility. As shown in Figure 1, three facilities (i.e., W Milford Twp MUA - Crescent Park STP, Reflection Lake Garden Apartments and West Milford Twp MUA- Olde Milford) discharge to Belcher Creek upstream of Pinecliff Lake. Considering the retention effects of Pinecliff Lake on phosphorus, the retention factor (0.56) used in the Phase 1 study (PAS, 1983) is applied to the calculated load from these three facilities. The sum of the adjusted load from these three facilities plus the calculated loads from the other two facilities comprise the point-source load of TP entering Greenwood Lake, which is about 70 kg/yr. The average of all flow data for the period and the average of all concentration data for the period are also presented in Table 2 for illustrative purposes.

Table 2 NJPDES Discharges within Greenwood Lake Watershed

NJPDES ID	Facility Name	Type	Receiving Water	Permitted Flow, mgd	Data in DMRs from 1/01to12/03		
					Average Flow, mgd	Average Conc. mg/L	WLA-Actual Load[1], kg/yr
NJ0024414.001A	W Milford Shopping Center	MMI	Belchers Creek via unnamed tributary	0.02	0.0062	0.54	4.6
NJ0028541.001A	West Milford Twp MUA - Birchill	MMI	Morestown Brook (Belchers Creek)	0.02	0.013	0.65	11.9
NJ0026174.001A	W Milford Twp MUA - Crescent Park STP	MMI	Belchers Creek	0.064	0.032	0.70	30.0
NJ0027201.001A	Reflection Lake Garden Apts	MMI	Belchers Creek via unnamed trib & ditch	0.005	0.0014	0.65	1.2
NJ0027677.001A	West Milford Twp MUA- Olde Milford	MMI	Belcher Creek via unnamed tributary	0.172	0.11	0.66	90.4

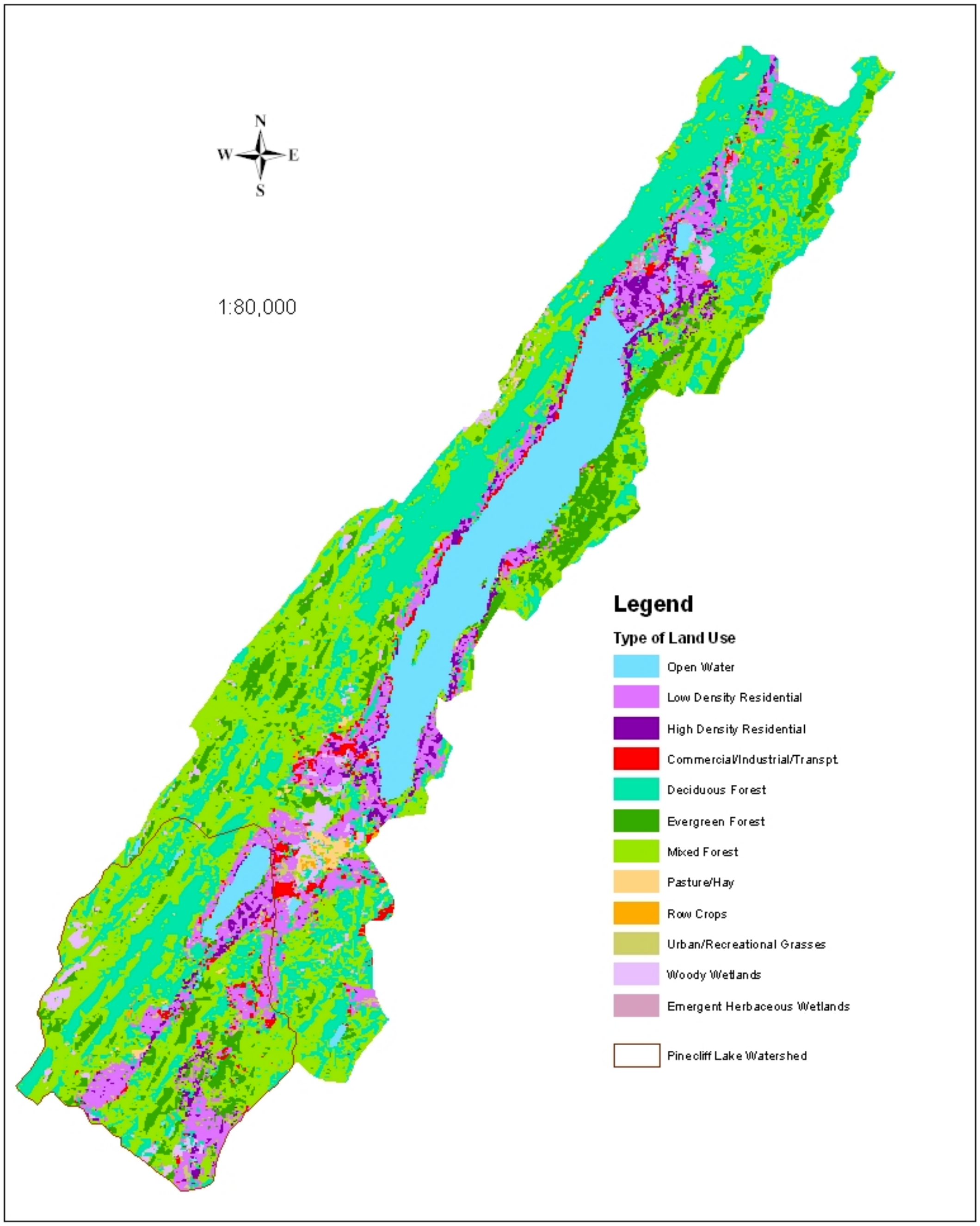
1 Based on existing flow and concentration. To estimate the loads entering Greenwood Lake, loads from the three discharges located upstream of Pinecliff Lake were multiplied by 0.44 to account for the retention effect of Pinecliff Lake on phosphorus. This is reflected in the allocation of wasteloads and loads in Table 9.

6.2 Assessment of Load from Land Surfaces Runoff

Runoff from land surfaces comprises most of the nonpoint and stormwater point sources of phosphorus into the lake. In the Phase I Study, the load from the surface runoff was calculated in two ways, the Unit Areal Load (UAL) methodology and the normalized flow-concentration methodology based on the tributary monitoring results. The tributary load suggested a much higher surface runoff load than the UAL method did. The normalized flow-concentration data were selected to represent the TP budget of the lake as they were computed from measured concentrations and precipitation adjusted flows.

Tributary monitoring has not been conducted in recent years. Therefore, the surface runoff load was updated using the UAL methodology, which applies pollutant export coefficients obtained from literature sources to the land use patterns within the watershed, as described in USEPA's Clean Lakes Program guidance manual (Reckhow, 1979b). In order to apply a uniform coverage for the entire watershed, land use was determined using the USGS 2000 National Land Cover Data (NLCD) for both New York and New Jersey (Figure 2). As part of the Department's TMDL development for previous phosphorus impairments, an extensive database (Appendix B) was reviewed for phosphorus export coefficients and the Department selected the most representative values for different land use categories defined in the Department's Land Use coverage. The NLCD classification of land use types is different from the Department's classification. Adjustments were made to assign an appropriate TP Export Coefficient for each type of NLCD land use. (Table 3).

Figure 2 Land Use Type in Greenwood Lake Watershed



A UAL of 0.07 kg TP/ha/yr was used to estimate air deposition of phosphorus directly onto the lake surface. This value was developed from statewide mean concentrations of total phosphorus from the New Jersey Air Deposition Network (Eisenreich and Reinfelder, 2001).

Land uses and calculated loading rates for the Pinecliff and Greenwood Lakes are shown in Table 4. Since Pinecliff Lake is located within the Greenwood Lake watershed, the entire Greenwood Lake watershed was divided into two parts, Pinecliff Lake watershed and the remainder of the watershed. According to the Phase 1 Study, Pinecliff Lake has a detention effect on the phosphorus entering into it and the detention factor is estimated to be 0.56. Therefore, to account for TP retention in Pinecliff Lake, it is assumed that only 44% of the load contributed by the lands within the Pinecliff Lake watershed reach Greenwood Lake. This load added to the load that originates from the lands outside of the Pinecliff Lake watershed constitutes the load from surface runoff.

Table 3 Phosphorus export coefficients (Unit Areal Loads)

Landuse description	Gridcode	EC (kg TP/ha/yr)
Open Water	11	0.07
Low Intensity Residential	21	0.7
High Intensity Residential	22	1.6
Commercial/Industrial/Transportation	23	2.4
Deciduous Forest	41	0.1
Evergreen Forest	42	0.1
Mixed Forest	43	0.1
Pasture/Hay	81	1.5
Row Crops	82	1.5
Urban/Recreational Grasses	85	1
Woody Wetlands	91	0.1
Emergent Herbaceous Wetlands	92	0.1

Units: 1 hectare (ha) = 2.47 acres
1 kilogram (kg) = 2.2 pounds (lbs)
1 kg/ha/yr = 0.89 lbs/acre/yr

Table 4 Surface Runoff Source of Phosphorus Load

Land Use description	Pinecliff watershed		Greenwood Lake Watershed beyond Pinecliff watershed		Entire Greenwood Lake Watershed
	Area (acre)	TP load (kg/yr)	Area (acre)	TP load (kg/yr)	TP load (kg/yr)
Low Intensity Residential	612	173.3	1,199	339.7	415.9
High Intensity Residential	110	71.4	405	262.2	293.6
Commercial/Industrial/Transportation	75	73.2	284	275.5	307.7
Pasture/Hay	13	7.7	86	52.3	55.7
Row Crops	12	7.4	39	23.9	27.2
Urban/Recreational Grasses	32	13.0	51	20.5	26.3
Deciduous Forest	1,127	45.6	3,960	160.3	180.3
Evergreen Forest	371	15.0	1,021	41.3	47.9
Mixed Forest	1,941	78.6	4,148	167.8	202.4
Woody Wetlands	116	4.7	271	11.0	13.0

Emergent Herbaceous Wetlands	2	0.1	26	1.0	1.1
Open Water	157	6.4	102	4.1	6.9
Air deposition	-	-	1,884	53.4	53.4
Total		**496**		**1,413**	**1,631.6**

Note: Load from the entire Greenwood Lake watershed = load from the Greenwood Lake watershed beyond Pinecliff Lake watershed + (1-0.56) * load from the Pinecliff Lake watershed.

6.3 Assessment of Load from Septic Tank System

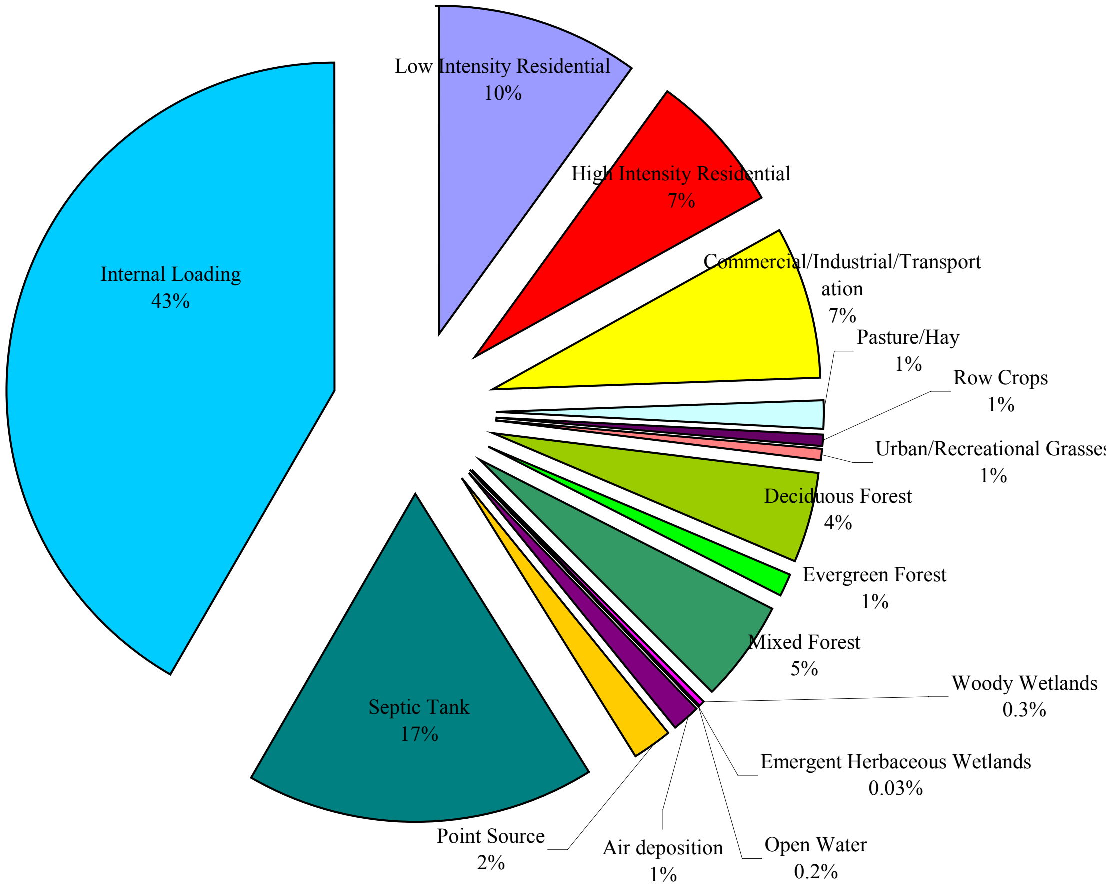
The TP load contributed to the lake as a result of onsite septic tank system use was quantified using the same methodology documented in the Phase 1 Study (PAS, 1983). The number of houses within 200 m of the lake's shoreline was determined from 2000 census data in conjunction with most recent aerial photos. A total of 2075 units that rely on septic tank systems were found within 200 meters of the lake's perimeter. 2000 census data indicated that the average size of these dwellings is 3 persons/dwelling. The loading coefficient used in the Phase 1 Study, 0.114 kg TP/capita/yr, was utilized to compute the annual load from septic tank systems. The resulting load is 710 kg TP/yr contributed to the lake via septic systems.

6.4 Internal Loading

In the Phase I Study, internal loading was quantified to be 1738.8 kg/yr, which accounted for 29.3% of the total annual load. There is no new data to update the current internal loading. Therefore, in this TMDL, it is assumed that the internal loading is still 1738.8 kg/yr.

The current phosphorus load distribution for Greenwood Lake is shown in Figure 4 below.

Figure 3 Current distribution of phosphorus load for Greenwood Lake



7.0 Water Quality Analysis

In addition to the Phase I Study, in-lake monitoring was conducted for several growing seasons between 1992 and 2001 by Princeton Hydro. Samples were collected from three stations, one at the northern, New York end, one mid-lake station and one at the southern, shallow New Jersey end (Figure 4). Of a total of 120 samples, 16 (13 percent) had TP concentrations exceeding the standard (0.05 mg/L). Overall, the concentrations at the southern station were slightly higher than the concentrations at the other two stations and the exceedance frequency at the southern station was 23%, higher than the exceedance at other two stations.

The Department has chosen an empirical model as the most appropriate means, given data available, to relate annual phosphorus load and steady-state in-lake concentration of total phosphorus. The Department surveyed the commonly used models in Table 5. These empirical models consist of equations derived from simplified mass balances that have been fitted to large datasets of actual lake measurements. The resulting regressions can be applied to lakes that fit within the range of hydrology, morphology and loading of the lakes in the model database. Reckhow (1979a) model was selected because the hydrologic, morphological and loading characteristics of Greenwood Lake fit best within the assumptions of the model and because it appeared to give the best predictive results for phosphorus concentration.

Figure 4 Historic In-lake Monitoring Results for Greenwood Lake

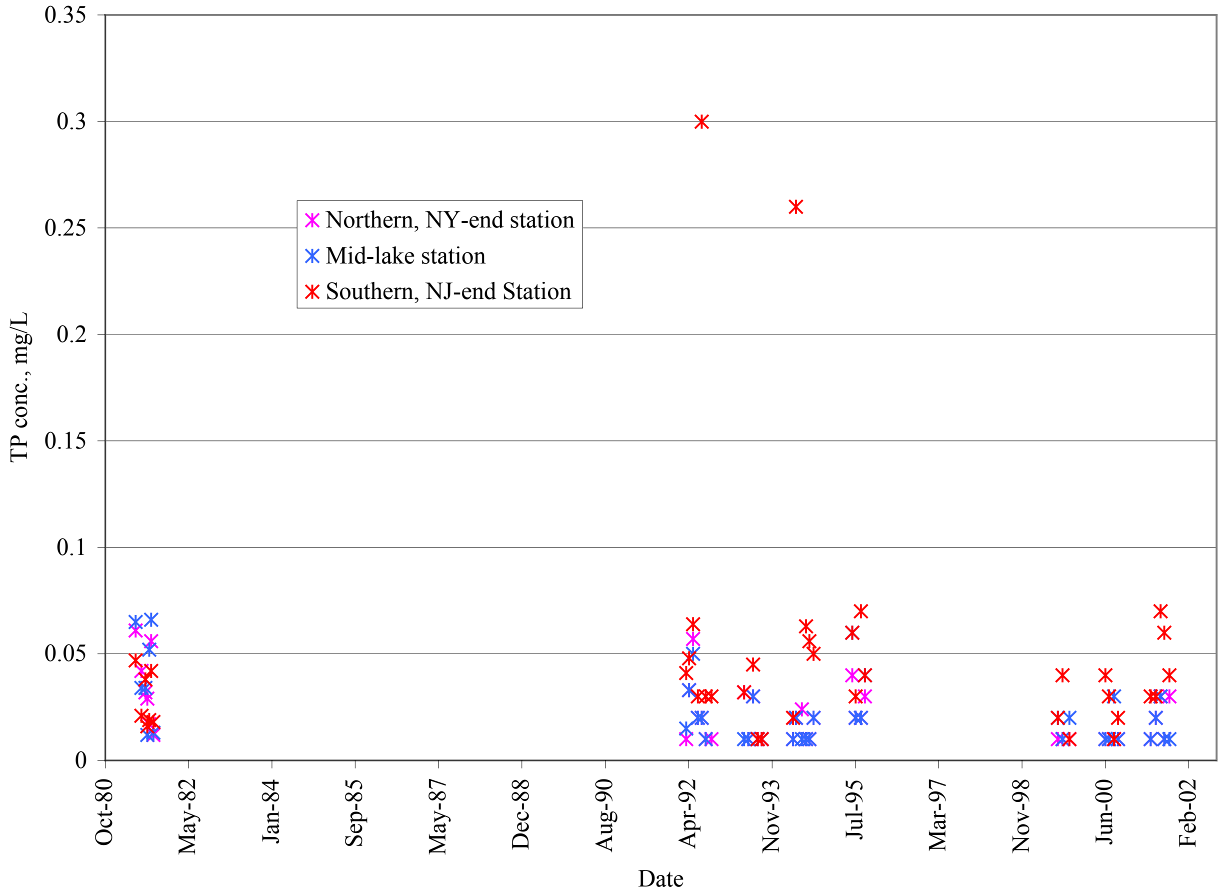


Table 5 Empirical models considered by the Department

reference	steady-state TP concentration in lake (mg/l)	Secondary term	Application
Rast, Jones and Lee, 1983	$1.81 \times NPL^{0.81}$	$NPL = \left(\frac{P_a \times DT / D_m}{1 + \sqrt{DT}} \right)$	expanded database of mostly large lakes
Vollenweider and Kerekes, 1982	$1.22 \times NPL^{0.87}$	$NPL = \left(\frac{P_a \times DT / D_m}{1 + \sqrt{DT}} \right)$	mostly large natural lakes
Reckhow, 1980	$\frac{P_a}{13.2}$	none	Upper bound for closed lake
Reckhow, 1979a	$\frac{P_a}{(11.6 + 1.2 \times Q_a)}$	$Q_a = \frac{Q_i}{A_l}$	General north temperate lakes, wide range of loading concentration, areal loading, and water load

reference	steady-state TP concentration in lake (mg/l)	Secondary term	Application
Walker, 1977	$\frac{P_a \times DT/D_m}{\left(1+0.824\times DT^{0.454}\right)}$	none	oxic lakes with $D_m/DT < 50$ m/yr
Jones and Bachmann, 1976	$\frac{0.84\times P_a}{\left(D_m \times \left(0.65 + DT^{-1}\right)\right)}$	none	may overestimate P in shallow lakes with high D_m/DT
Vollenweider, 1975	$\frac{P_a}{\left(D_m \times \left(DT^{-1} + S\right)\right)}$	$S = 10/D_m$	Overestimate P lakes with high D_m/DT
Dillon-Kirchner, 1975	$\frac{P_a}{\left(13.2 + D_m/DT\right)}$	none	low loading concentration range
Dillon-Rigler, 1974	$P_a \times DT/D_m \times (1-R)$	R = phosphorus retention coefficient	general form
Ostrofksy, 1978	Dillon-Rigler, 1974	$R = 0.201\times e^{(-0.0425\times Q_a)} + 0.5743\times e^{-0.00949*Q_a}$	lakes that flush infrequently
Kirchner-Dillon, 1975	Dillon-Rigler, 1974	$R = 0.426\times e^{\left(-0.271\times D_m/DT\right)} + 0.5743\times e^{-0.00949* D_m/DT}$	general application
Larsen-Mercier, 1975	Dillon-Rigler, 1974	$R = \frac{1}{1+\sqrt{1/DT}}$	Unparameterized form

where:
NPL = normalized phosphorus loading
P_a = areal phosphorus loading (g/m²/yr)
DT = detention time (yr)
D_m = mean depth (m)
Q_a = areal water load (m/yr)
Q_i = total inflow (m³/yr)
A_l = area of lake (m²)
S = settling rate (per year)

The Reckhow (1979a) model is described in USEPA Clean Lakes guidance documents: Quantitative Techniques for the Assessment of Lake Quality (Reckhow, 1979b) and Modeling Phosphorus Loading and Lake Response Under Uncertainty (Reckhow *et al*, 1980). The derivation of the model is summarized in Appendix C. The model relates TP load to steady state TP concentration, and is generally applicable to north temperate lakes.

As summarized in Table 6, Greenwood Lake has all the characteristics of the lakes upon which Reckhow based his analyses. Mean in-lake phosphorus concentrations at all sampling locations are within the range of 0.004 and 0.135, as in Reckhow's data set. The estimated areal phosphorous load is 0.55, again within the range of Reckhow's data set. The average influent phosphorus concentration is calculated to be 0.12, which meets the limitation of Reckhow model. Greenwood Lake's areal water load of 4.53 is also within Reckhow's range of 0.75 and 187. For the target condition (discussed in detail in Section 7), every parameter falls within the range suitable for the Reckhow model. Thus, the Reckhow model is applicable to Greenwood Lake under both the current condition and the target condition.

Table 6 Hydrologic and loading characteristics of lakes

Parameters	Ranges of Characteristics Reckhow Model can fit		Greenwood Lake	
	Min	Max	Current condition	Target Condition[3]
TP Conc. (mg/L)	0.004	0.135	0.032[1]	0.03
Avg. Influent TP Conc. (mg/L)[2]		0.298	0.12	0.11
Q_a, Areal Water Load (m/yr)	0.75	187	4.53	N/A
P_a, Areal TP Load ($g/m^2/yr$)	0.07	31.4	0.55	0.51

Note:

1. Predicted in-lake annual average concentration using Reckhow model (see section below).
2. Calculated using Pa*DT/Dm.
3. As explained below, the target concentration is 0.03 mg/L when considering the seasonal variability. The other parameters under target condition were all calculated based on the target concentration.

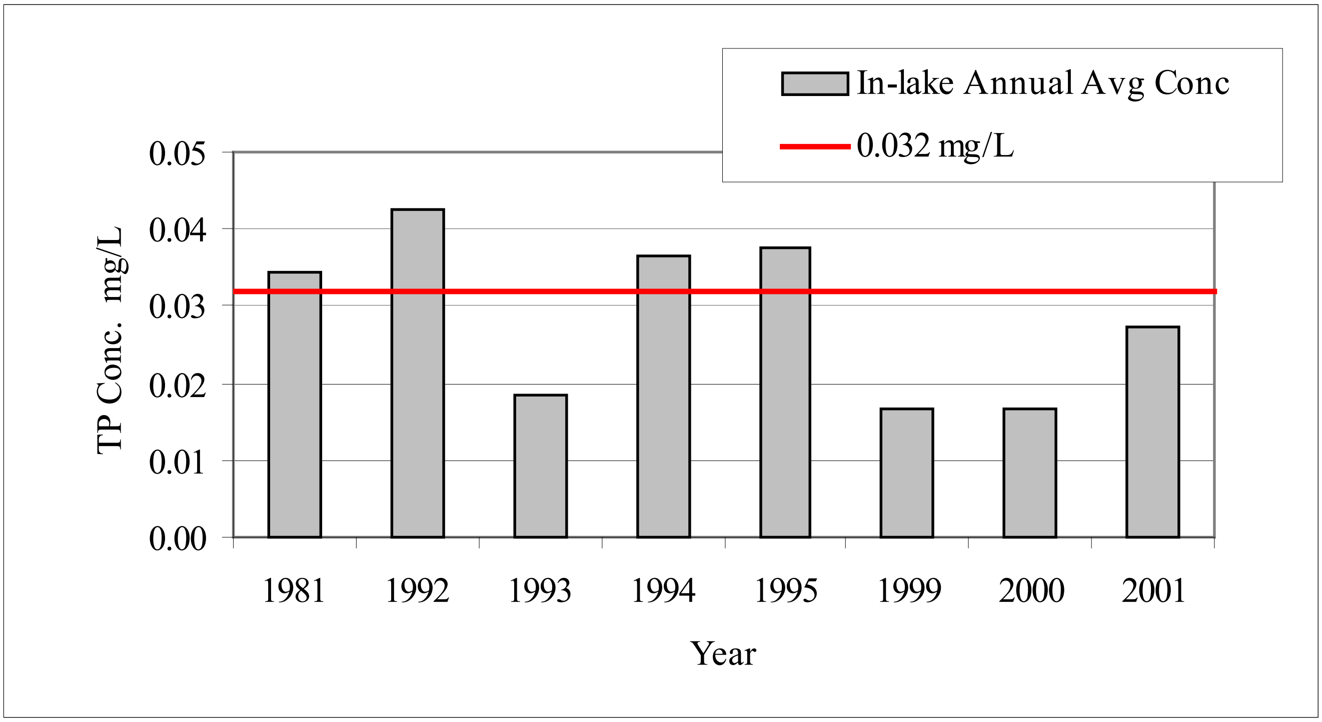
7.1 Current Condition

Using these physical parameters and estimated external loads, the predicted steady-state phosphorus concentration of the lake was calculated using the Reckhow (1979a) formulation to be 0.032 mg/L (listed in Table 7). Figure 5 presents the actual annual average total phosphorus concentration for the years when in-lake monitoring samples were collected. The annual average concentration varied year by year; the average of eight years' annual average concentrations is computed to be 0.031 mg/L. This value compares well to the concentration predicted by Reckhow model.

7.2 Reference Condition

A reference condition for Greenwood Lake was estimated by calculating external loads as if the land use throughout the lakeshed were completely forest and wetlands and the loads from point sources, septic tank systems and internal recycling were assumed to be zero. Estimates of air deposition loads were included to calculate the reference condition. Using the same physical parameters and external loads from forest, wetlands and air deposition, a reference steady-state phosphorus concentration was calculated for Greenwood Lake using the Reckhow (1979a) formulation and listed in Table 7. The reference condition was developed to estimate what the TP concentration would be under pristine conditions and assure that the target concentration will not be lower than the one possible under pristine conditions. For Greenwood Lake, the target steady state concentration is 0.03 mg/l while the steady state concentration under the reference condition is only 0.005 mg/l. Therefore, the reference condition is not used for the TMDL calculations.

Figure 5 **Annual Average In-lake TP Concentration for Greenwood Lake**



7.3 Seasonal Variation/Critical Conditions

The peak (based on the 90th percentile) to mean ratio was examined for each station using 8-years in-lake monitoring data. As a result, 1.8 is obtained as the average of three stations' ratios. Using 1.8 as the site-specific peak-to-mean ratio would result in the target phosphorus concentration of 0.028 mg/L. In previous lake TP TMDLs established by the Department, a critical condition of 0.03 mg/L was chosen based on the peak-to-mean ratios of 1.56 and 1.48 observed from Strawbridge Lake and Sylvan Lake, respectively ((Strawbridge Lake, NJDEP 2000a; Sylvan Lake, NJDEP 2000b). It was assumed that this condition is representative of lakes, in general, in New Jersey. These peak to mean ratios result in target phosphorus concentrations of 0.032 and 0.0324 mg TP/l and was rounded to 0.03 mg TP/l. This compares well with the value of 0.028 mg/l for Greenwood Lake. Therefore, the Department determined that a target phosphorus concentration of 0.03 mg TP/l is appropriate for use in the this TMDL. Since it is the annual pollutant load rather than the load at any particular time that determines overall lake water quality (section 6), the target phosphorus concentration of 0.03 mg TP/l accounts for critical conditions.

7.4 Margin of Safety

A Margin of Safety (MOS) is provided to account for "lack of knowledge concerning the relationship between effluent limitations and water quality." (40 CFR 130.7(c)). A MOS is required in order to account for uncertainty in the loading estimates, physical parameters and the model itself. The margin of safety, as described in USEPA guidance (Sutfin, 2002), can be either explicit or implicit (i.e., addressed through conservative assumptions used in establishing the TMDL). For this TMDL calculation, an implicit as well as an explicit MOS are provided.

This TMDL contains an implicit margin of safety by using conservative critical conditions and total phosphorus as the basis for reductions. Critical conditions are accounted for by comparing peak concentrations to mean concentrations and adjusting the target concentration accordingly (0.03 mg TP/l instead of 0.05 mg TP/l). In addition, the use of total phosphorus, as both the endpoint for the standard and in the loading estimates, is a conservative assumption. Use of total phosphorous does not distinguish readily between dissolved orthophosphorus, which is available for algal growth, and unavailable forms of phosphorus (e.g. particulate). While many forms of phosphorus are converted into orthophosphorus in the lake, many are captured in the sediment, for instance, and never made available for algal uptake.

In addition to the conservative assumptions built in to the calculation, an additional explicit MOS was included to account for the uncertainty in the model itself. As described in Reckhow *et al* (1980), the Reckhow (1979a) model has an associated standard error of 0.128, calculated on log-transformed predictions of phosphorus concentrations. Transforming the terms in the model error analysis from Reckhow *et al* (1980) yields the following (Appendix D):

$$MoS_p = \sqrt{1/\left((1-\rho)*4.5\right)} \times \left(10^{0.128} - 1\right),$$

where: MoS_p = margin of safety as a percentage over the predicted phosphorus concentration;
ρ = the probability that the real phosphorus concentration is less than or equal to the predicted phosphorus concentration plus the margin of safety as a concentration.

Setting the probability to 90% yields a MOS of 51% when expressed as a percentage over predicted phosphorus concentration or estimated external load. The external load for each lake was therefore multiplied by 1.51 to calculate an "upper bound" estimate of steady-state phosphorus concentration. An additional explicit MOS was included in the analyses by setting the upper bound calculations equal to the target phosphorus concentration of 0.3 mg TP/l, as described in the next section and shown in Table 7. Note that the explicit MOS is equal to 51% when expressed as a percentage over the predicted phosphorus concentration; when expressed as a percentage of total loading capacity, the MOS is equal to 33.3%:

$$\left(MoS_{lc} = \frac{MoS_p \times P}{P + \left(MoS_p \times P\right)} = \frac{MoS_p}{1 + MoS_p} = \frac{0.51}{1.51} = 0.333 \right),$$

where: MoS_p = margin of safety expressed as a percentage over the predicted phosphorus concentration or external load;
MoS_{lc} = margin of safety as a percentage of total loading capacity;
P = predicted phosphorus concentration (or external load).

7.5 Target Condition

As discussed above, when considering the seasonal variation, the steady state concentration of phosphorus in the lake must be equal to or less than 0.03 mg/L to avoid exceeding the 0.05 mg/L phosphorus criterion. Using Reckhow (1979a), any predicted concentration has a MOS of 51% when expressed as a percentage over the predicted phosphorus concentration. To assure compliance with the 0.03 mg/L target, the predicted concentration can not be higher than 0.02 mg/L (0.02 + 0.02*51% =

0.03 mg/L) considering the effect of the MOS. Therefore, 0.02 mg/L is chosen as the target concentration to attain the standard while 0.03 mg/L is defined as the upper bound target condition. The load corresponding to a 0.03 mg/L in-lake concentration is defined as the allowable loading capacity of the lake. The overall reduction to attain the standard level in Greenwood Lake was calculated by comparing the current concentration (calculated using Reckhow Model) to 0.02 mg/L, the target concentration (Table 7).

Table 7 Current condition, reference condition, target condition and overall percent reduction for Greenwood Lake

Current condition [TP] (mg/l)	Reference Condition [TP] (mg/L)	Upper Bound Target Condition [TP] (mg/L)	Target Condition [TP] (mg/l)	Overall TP load Reduction (%)
0.032	0.005	0.03	0.02	37%

8.0 TMDL Calculations

8.1 Loading Capacity

The Reckhow (1979a) model was used to solve for loading rate given the upper bound target concentration of 0.03 mg/l. This loading rate is used as the loading capacity for the lake and 33.3% of it accounts for the MOS as determined by the uncertainty associated with Reckhow Model. The acceptable loading capacity for Greenwood Lake is provided in Table 9.

8.2 Reserve Capacity

Reserve capacity is an optional means of reserving a portion of the loading capacity to allow for future growth. The primary means by which future growth could increase phosphorus load is through the development of forest land within the lakeshed. The implementation plan includes the development of a Lake Restoration Plan that will require the collection of more detailed information about the lakeshed. If the development of forest within the watershed is planned, the issue of reserve capacity to account for the additional runoff load of phosphorus may be revisited. Currently, the loading capacities and accompanying WLAs and LAs must be attained in consideration of any new sources that may accompany future development.

8.3 Allocations

USEPA regulations at 40 CFR § 130.2(i), state that "pollutant loadings may be expressed in terms of either mass per time, toxicity, or other appropriate measure." For lake nutrient TMDLs, it is appropriate to express the TMDL on a yearly basis. Long-term average pollutant loadings are typically more critical to overall lake water quality due to the storage and recycling mechanisms in the lake. Also, most available empirical lake models, such as the Reckhow model used in this analysis, use annual loads rather than daily loads to estimate in-lake concentrations.

The TMDLs for total phosphorus are therefore calculated as follows (Table 9):

TMDL = loading capacity

= Sum of the wasteload allocations (WLAs) + load allocations (LAs) + margin of safety + reserve capacity.

WLAs are hereby established for all NJPDES-regulated point sources within each source category, while LAs are established for stormwater sources that are not subject to NJPDES regulation and for all other nonpoint sources. This distribution of loading capacity between WLAs and LAs is consistent with recent EPA guidance that clarifies existing regulatory requirements for establishing WLAs for stormwater discharges (Wayland, November 2002). Stormwater discharges are captured within the runoff sources quantified according to land use, as depicted in Table 8. Distinguishing between regulated and unregulated stormwater is necessary in order to express WLAs and LAs numerically; however, "EPA recognizes that these allocations might be fairly rudimentary because of data limitations and variability within the system." (Wayland, November 2002, p.1) While the Department does not have the data to actually delineate lakesheds according to stormwater drainage areas subject to NJPDES regulation, the land use runoff categories previously defined can be used to estimate between the WLA and LA. Therefore allocations are established according to source categories as shown in Table 8. This demarcation between WLAs and LAs based on land use source categories is not perfect, but it represents the best estimate defined as narrowly as data allow. The Department acknowledges that there may be stormwater sources in the residential, commercial, industrial and mixed urban runoff source categories that are not NJPDES-regulated. Nothing in these TMDLs, including Table 8, shall be construed to require the Department to regulate a stormwater source under NJPDES that would not already be regulated as such, nor shall anything in these TMDLs be construed to prevent the Department from regulating a stormwater source under NJPDES. The WLAs and LAs in Table 9 are not themselves "Additional Measures" under N.J.A.C. 7:14A-25.6 or 25.8.

Table 8 Distribution of WLAs and LAs among source categories

Source category	TMDL allocation
Point Sources other than Stormwater	WLA
Internal Loading	LA
Septic Tank System	LA
Nonpoint and Stormwater Sources	
medium / high density residential	WLA
low density / rural residential	WLA
commercial	WLA
industrial	WLA
Mixed urban / other urban	WLA
agricultural	LA
forest, wetland, water	LA
barren land	LA
air deposition onto lake surface	LA

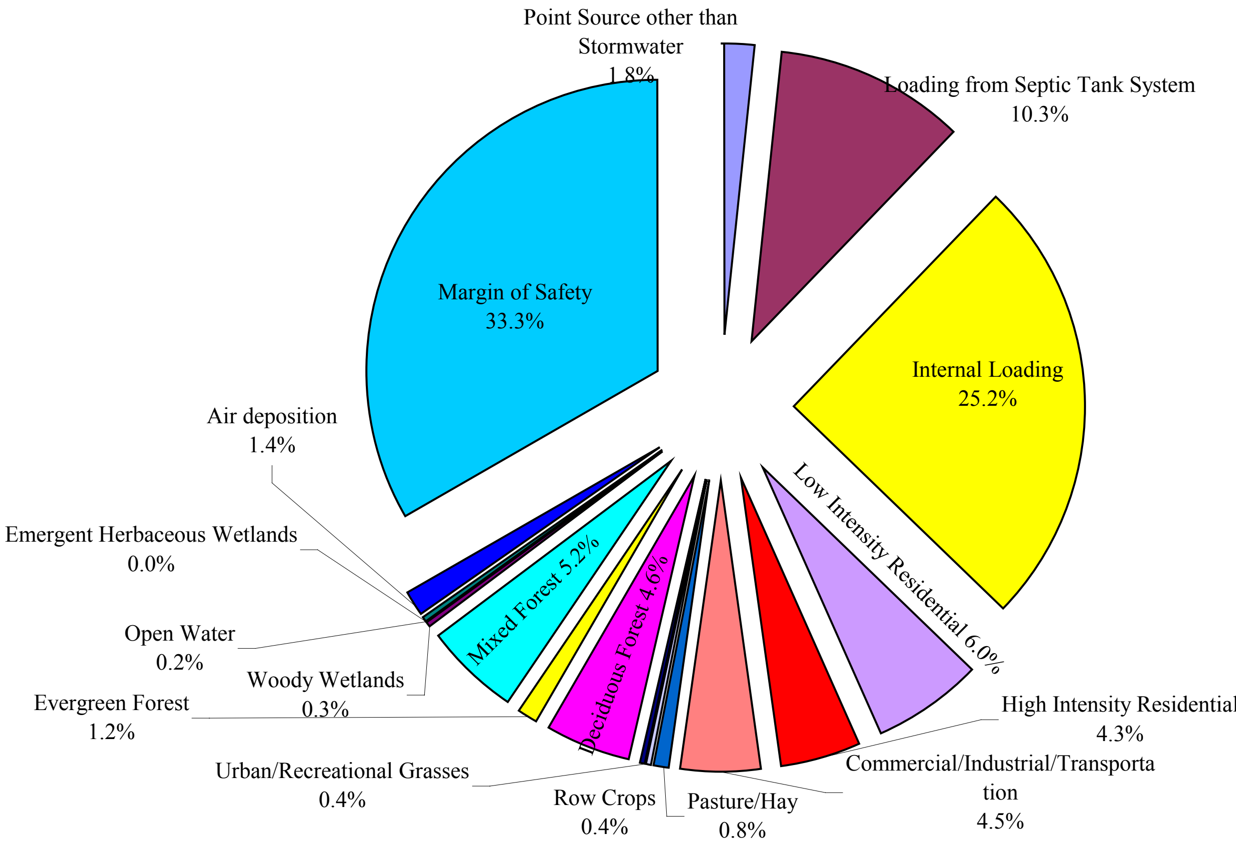
In order to attain the TMDL, the overall load reduction shown in Table 7 must be achieved. Since loading rates have been defined for multiple source categories, countless combinations of source reductions could be used to achieve the overall reduction target. The selected scenario calls for holding the load constant from wastewater treatment facilities (existing effluent quality) and achieving reductions from land use sources that can be affected by BMP implementation or NJPDES stormwater regulation, requiring equal percent reductions from each in order to achieve the necessary overall load reduction. Note that no reduction is required for the discharges from the wastewater point sources. Therefore, the WLAs for the facilities is the existing loading specified in Table 2. The flow data reported in the DMRs indicate that the wastewater treatment facilities are not at full capacity relative to the maximum allowable flow in the permits. If the facilities were to discharge at their full capacities assuming the current average effluent quality (around 0.6 mg/l), the load from this source would increase. At the maximum allowable flow under their current permits, in order to maintain the current loading of 70 kg/yr, the average concentration must be maintained at 0.35 mg/l. The wastewater treatment plants in question are relatively small and already have phosphorus treatment through chemical addition by either adding Alum or FeCl3. Therefore, the means to achieve the overall WLA for this source category may be most efficiently achieved by means other than having each treatment facility upgrade treatment capability to achieve 0.35 mg/l as a TP concentration limit. Options include: water quality trading among both point and nonpoint sources or revising permits to specify an allowable load equal to existing flow and effluent quality. The resulting TMDL, rounded to two significant digits, are shown in Table 9 and illustrated in Figure 5. The Lake Restoration and Characterization Plan developed for Greenwood Lake as part of the TMDL implementation (Section 10) will revisit the distribution of reductions among the various sources in order to reflect the outcome of the plan, implementation projects and the option(s) selected by wastewater treatment plant sources.

Table 9 TMDL calculations for Greenwood Lake (annual loads and percent reductions[a])

	Kg TP/yr	% of LC	Reduction %
Loading Capacity (LC)	3,895	100%	n/a
Point Source other than Stormwater	70	1.8%	0%
Loading from Septic Tank System	401	10%	43%
Internal Loading	983	25%	43%
Land Use Surface Runoff			
Low Intensity Residential	235	6.0%	43%
High Intensity Residential	166	4.3%	43%
Commercial/Industrial/Transportation	174	4.5%	43%
Pasture/Hay	32	0.8%	43%
Row Crops	15	0.4%	43%
Urban/Recreational Grasses	15	0.4%	43%
Deciduous Forest	180	5%	0%
Evergreen Forest	48	1.2%	0%
Mixed Forest	202	5%	0%
Woody Wetlands	13	0.3%	0%
Emergent Herbaceous Wetlands	1	0.03%	0%
Open Water	7	0.2%	0%
Air deposition	53	1.4%	0%
Other Allocation			
Margin of Safety	1,298	33%	n/a
Reserve Capacity	0	0%	n/a

a. Percent reductions shown for individual sources are necessary to achieve overall reductions in Table 7.

Figure 6 **Phosphorus allocations for Greenwood Lake TMDL**



9.0 Follow-up Monitoring

A Lake Characterization and Restoration project using funds made available to the Department under the Clean Water Act Section 319(h) will begin in July 2004. This project will provide in-lake water quality monitoring data, monitoring data for eight tributary stations within the watershed, and a bathymetric survey for New Jersey portion of the lake to provide site-specific information and data for the Lake Characterization and Restoration Plan.

In order to evaluate the current water quality conditions and to assess the seasonal variation of the water quality conditions, one spring, two summer (June/July and August) and one fall (September) water quality monitoring events are scheduled to be conducted in 2004 and 2005 for the above project. A total of five sampling stations will be identified for the monitoring program. The northern and mid-lake sampling stations will be located on the New York side of the lake. The remaining three will be located on the New Jersey side of the lake. *In-situ* water quality monitoring will be conducted at the five sampling stations for water column profiles of temperature, dissolved oxygen, pH and conductivity at 0.5 to 1.0 meter intervals from surface to bottom. Water clarity will be measured with a Secchi disk. In addition to the *in-situ* monitoring, discrete water samples will be collected and analyzed for Total Phosphorus, Soluble Reactive Phosphorus (SRP), organic-P, Nitrate and Nitrite (NO_3-N+NO_2-N), Ammonia (NH_4-N), Total Kjeldahl Nitrogen (TKN), TSS, alkalinity, and hardness during each sampling event. Limited samples will be collected for chlorophyll *a*, phytoplankton and zooplankton analyses. For summer sampling events, chemical sampling within specific vertical zones of the lake is taken into consideration.

In order to quantify the current phosphorus loads entering Greenwood Lake on a more site specific basis, eight tributary stations (six in NJ and two in NY) will be monitored over 10 sampling events from June 2004 to May 2005. The eight stations are as follows:

1. Belcher Creek entering Greenwood Lake, NJ
2. Belcher Creek at the outlet of Pinecliff Lake, NJ
3. Green Brook at Union Valley Road, NJ
4. Cooley Brook at Union Valley Road, NJ
5. Outlet from West Milford Lake at Marshall Hill Road, NJ
6. Morsetown Brook at Marshall Hill Road, NJ
7. Unnamed creek #1 at Old Tuxedo Road, NY
8. Unnamed creek #2 at Old Tuxedo Road, NY

During each proposed sampling event, discrete water samples will be collected for total phosphorus (TP) and total suspended solids (TSS) analysis. In addition, flow (flow meter USGS type AA model 6200) will be measured at each sampling site and *in-situ* data (Hydrolab, Surveyor IV) will be collected for temperature, dissolved oxygen, pH and conductivity. The goal of the proposed tributary sampling program is to collect flow and select water quality data over the course of nearly a year to quantify loads.

In addition, a complete bathymetric survey of the New Jersey end of Greenwood Lake will be conducted to update its morphometric conditions. This information will be utilized to update the internal loading for the southern portion of the lake. Additional study will also be conducted to determine the sedimentation rate and the cause of the dissolved oxygen impairment in order to allow companion TMDLs to be developed for these impairments.

10.0 Implementation

The Department, in coordination with the Greenwood Lake Commission will address the sources of impairment, using regulatory and non-regulatory tools, through systematic source assessment, matching management strategies with sources, selecting responsible entities and aligning available resources to effect implementation. Management measures are "economically achievable measures for the control of the addition of pollutants from existing and new categories and classes of nonpoint and stormwater sources of pollution, which reflect the greatest degree of pollutant reduction achievable through the application of the best available nonpoint and stormwater source pollution control practices, technologies, processes, citing criteria, operating methods, or other alternatives" (USEPA, 1993). Greenwood Lake is a bi-state lake and will necessitate implementation measures undertaken by both New Jersey and New York. As this TMDL is an amendment to the New Jersey Northeast Water Quality Management Plan, specific implementation strategies focus on the New Jersey portion of Greenwood Lake, although, to be successful, source reduction in the New York portion of the lake and lakeshed will be necessary.

The Department recognizes that TMDL designated load reductions alone may not be sufficient to restore eutrophic lakes. The TMDL establishes the required nutrient reduction targets and provides the regulatory framework to effect those reductions. However, the nutrient load only affects the eutrophication potential of a lake. The implementation plan therefore calls for the collection of additional monitoring data, as discussed in section 9.0, and the development of a Lake Characterization and Restoration Plan. The additional monitoring proposed will provide the information needed to update the Phase I diagnostic study of Greenwood Lake, which will provide the basis for the Lake Restoration Plan. The Restoration Plan will consider in-lake measures that need to be taken to supplement the nutrient reduction measures required by the TMDL. For example, the shallow portion of the lake supports macrophytes that, at some density, are a natural part of a healthy clear-water lake ecology, but, because of density or location, interfere with boating. Phosphorus reductions alone may not address this issue and macrophyte harvesting or other measures may be a long term maintenance measure needed in certain areas to facilitate the boating use. In addition, the plan will consider the ecology of the lake and adjust the eutrophication indicator target as necessary to protect the designated uses.

Generic measures

Phosphorus is contributed to the environment from a number of sources including fertilizer application on agricultural lands, fertilizer application on lawns, discharge from treatment plants, failing or improperly functioning septic systems, lack of pump-out facilities for boats, adherence to sediment particles and the natural process of decomposition. Phosphorus from these sources can reach waterbodies directly, through overland runoff, or through sewage or stormwater conveyance facilities. Each potential source will respond to one or more management strategies designed to eliminate or reduce that source of phosphorus. Each management strategy has one or more entities that can take lead responsibility to effect the strategy. Various funding sources are available to assist in accomplishing the management strategies. Generic management strategies for various source categories and responses are summarized below:

Table 10 Generic Management Strategies

Source Category	Responses	Potential Responsible Entity	Possible Funding options
Human Sources	Low phosphorus fertilizer ordinances, NPS public education, septic tank management to address failing systems, sewering target area	Municipalities, residents, watershed stewards	319(h), State sources
Non-Human Sources	Waterfowl ordinances, pet waste ordinances, goose management programs	Municipalities, residents, watershed stewards	319(h), State sources
Agricultural practices	Install BMPs, Prioritize for conservation programs	Property owner	EQIP, CRP, CREP

Regulatory Measures

On February 2, 2004 the Department promulgated two sets of stormwater rules: The Phase II New Jersey Pollutant Discharge Elimination System (NJPDES) Stormwater Rules, N.J.A.C. 7:14A and the Stormwater Management Rules, N.J.A.C. 7:8

Phase II Stormwater Permit Rules

The Phase II NJPDES Stormwater rules require municipalities, counties, highway systems, and large public complexes to develop stormwater management programs consistent with the NJPDES permit requirements. The stormwater discharged through "municipal separate storm sewer systems" (MS4s) will be regulated under the Department's Phase II NJPDES stormwater rules. Under these rules and associated general permits, the municipalities (and various county, State, and other agencies) in the Greenwood Lake Watershed will be required to implement various control measures that should substantially reduce phosphorus loadings. These control measures include adoption and enforcement of pet waste disposal ordinances, prohibiting the feeding of unconfined wildlife on public property, cleaning catch basins, performing good housekeeping at maintenance yards, and providing related public education and employee training. The basic requirements will provide for a measure of load reduction from existing development.

As the Phase II stormwater rules were a federal mandate New York has also developed new stormwater rules providing the same basic requirements. One of the communities within the Greenwood Lake drainage basin in New York is the Village of Greenwood Lake. Within this village, an ordinance was adopted on April 2, 2001 (Ordinance # 2-2001) prohibiting the use of fertilizer containing phosphorus. In New Jersey, the contributory drainage area into Greenwood Lake is limited to West Milford Township. Adoption of a comparable ordinance will be required as an additional measure at this time for West Milford. Specifically, the additional measure is as follows:

Fertilizer Ordinance

Minimum Standard: West Milford Township shall adopt and enforce an ordinance, comparable to the ordinance adopted on April 2, 2001 by the Village of Greenwood Lake in New York State (Ordinance # 2-2001), prohibiting the use of fertilizer containing phosphorus, except as needed for establishing new vegetation after disturbance in accordance with the requirements established under the Soil Erosion and Sediment Control Act, N.J.S.A. 4:24-39 et seq. and implementing rules.

Measurable Goal: West Milford Township shall certify annually that it has met the Fertilizer Ordinance minimum standard.

Implementation: Within 6 months from adoption of the TMDL, West Milford Township shall have fully implemented the Fertilizer Ordinance minimum standard.

Follow up monitoring may determine that other additional measures are required, which would then be incorporated into Phase II permits. Additional measures that may be considered include, for example, more frequent street sweeping and inlet cleaning, or retrofit of stormwater management facilities to include nutrient removal. .

Stormwater Management Rules

The Stormwater Management Rules have been updated for the first time since their original adoption in 1983. These rules establish statewide minimum standards for stormwater management in new development, and the ability to analyze and establish region-specific performance standards targeted to the impairments and other stormwater runoff related issues within a particular drainage basin through regional stormwater management plans. The Stormwater Management rules are currently implemented through the Residential Site Improvement Standards (RSIS) and the Department's Land Use Regulation Program (LURP) in the review of permits such as freshwater wetlands, stream encroachment, CAFRA, and Waterfront Development.

The Stormwater Management Rules focus on the prevention and minimization of stormwater runoff and pollutants in the management of stormwater. The rules require every project to evaluate methods to prevent pollutants from becoming available to stormwater runoff and to design the project to minimize runoff impacts from new development through better site design, also known as low impact development. Some of the issues that are required to be assessed for the site are the maintenance of existing vegetation, minimizing and disconnecting impervious surfaces, and pollution prevention techniques. In addition, performance standards are established to address existing groundwater that contributes to baseflow and aquifers, to prevent increases to flooding and erosion, and to provide water quality treatment through stormwater management measures for TSS and nutrients.

As part of the requirement under the NJPDES Phase II program, municipalities, such as West Milford, are required to adopt and implement municipal stormwater management plans and stormwater control ordinances consistent with the requirements of the stormwater management rules. As such, in addition to changes in the design of projects regulated through the RSIS and LURP, West Milford Township will also be updating their regulatory requirements to provide the additional protections in the stormwater management rules within approximately two years of the issuance of the NJPDES General Permit Authorization.

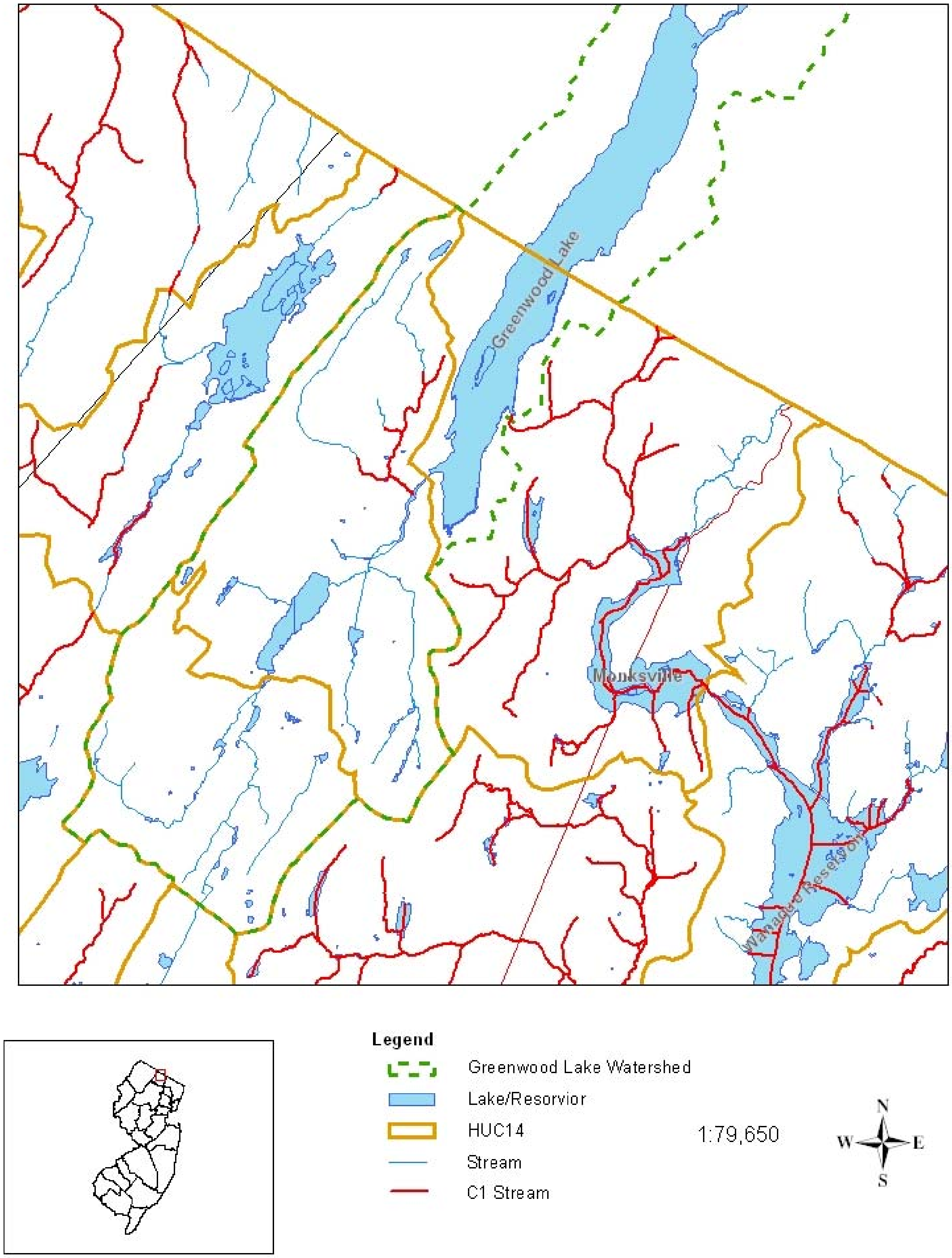
Furthermore, the New Jersey Stormwater Management rules establish a 300-foot special water resource protection area (SWRPA) around Category One (C1) waterbodies and their intermittent and perennial tributaries, within the HUC14 subwatershed. In the SWRPA, new development is typically limited to existing disturbed areas to maintain the integrity of the C1 waterbody. C1 waters receive the highest form of water quality protection in the state, which prohibits any measurable deterioration in the existing water quality. Certain segments of waterbodies tributary to Greenwood Lake as well as the Wanaque River, immediately downstream of Greenwood Lake, have been designated C1 waterbodies, and are therefore, accorded this additional protection as shown on the map in Figure 6.

These rules will provide protection with respect to new development in the lakeshed.

Short-term Management Measures

Short-term management measures include projects recently completed; underway or planned that will address sources of the phosphorus load. Some short-term management measures may provide relief during an interim period as implementation of source reductions begins to provide long-term benefits.

Figure 7 C1 Waterbodies Located Upstream and Downstream of Greenwood Lake



Greenwood Lake Characterization and Restoration Plan

The TMDL for Greenwood Lake was developed with assistance from the Greenwood Lake Commission, and stakeholders in Watershed Management Area 3, as part of the Department's ongoing watershed management efforts.

Under the funding provided in the 319(h) grant discussed in section 9.0 the Department has awarded $152,330 to the Township of West Milford and the Greenwood Lake Commission to complete a Lake Characterization and Restoration Plan. Stormwater related tasks that are funded under the New Jersey grant include: identification of stormwater/surface runoff "hot spots" in need of restoration and/or protection; development of the stormwater component of the Lake Characterization and Restoration Plan; installation of a series of BMPs and retrofits in West Milford; and Best Management Practices (BMP) monitoring in order to objectively assess the relative success of the BMP installation/retrofit projects that will be conducted as part of this project. The BMP monitoring will analyze total phosphorus (TP), total nitrogen (TN) and total suspended solids (TSS) prior to and after the BMP/retrofits are installed to quantify the NPS pollutant reductions associated with the various BMP/retrofit technologies that will be installed. While empirically derived percent reductions for NPS pollutants may be available within the existing literature (i.e. New Jersey BMP Manual), the collection of this BMP data will provide site specific information on the relative efficiencies of these installed BMPs and retrofits. Site specific removal efficiencies can be used to quantify the degree of load reduction that can be obtained through BMPs and retrofits. A similar proposal for the New York portion of the Greenwood Lake watershed was submitted to the New York State Department of Environmental Conservation (NYSDEC) under the Statewide Nonpoint Source Abatement and Control Program (EPF/PPG). The status of that grant application is not known at the time of the writing of this document.

Greenwood Lake has ecological differences within the lake itself along with the geographic/political boundaries. The New Jersey portion of the lake is shallow, having a maximum depth of 3 meters, meaning that at this end, most of the lake volume is within the photic zone and therefore more able to support aquatic plant growth (Holdren *et al*, 2001) while the New York portion of the lake has a greater mean and maximum depth. Addressing the ecological nuances of shallow and deep portion of the lake separately will potentially be the most valuable outcome of the Lake Characterization and Restoration Plan. Shallow lakes are generally characterized by either abundant submerged macrophytes and clear water or by abundant phytoplankton and turbid water. From an aquatic life and biodiversity perspective, it is desirable for shallow lakes to be dominated by aquatic plants rather than algae, especially phytoplankton. While lower nutrient concentrations favor the clear/plant state, either state can persist over a wide range of nutrient concentrations. Shallow lakes have ecological stabilizing mechanisms that tend to resist switches from clear/plant state to turbid/algae state, and vice-versa. The clear/plant state is more stable at lower nutrient concentrations and irreversible at very low nutrient concentrations; the turbid/algae state is more stable at higher nutrient concentrations. Although a macrophyte-dominated lake may be preferable, excessive growth of aquatic plants can, and does in Greenwood Lake, lead to impairment and the loss of designated uses. Aquatic growth in Greenwood Lake includes *Lyngbya latissima, Potamogeton robbinsii, Myriophyllum spicatum, Cabomba caroliniana* and *Potamogeton amplifolius*, which are invasive species (PAS, 1983).

The Lake Characterization and Restoration Plan developed for the lake may revisit the distributions of reductions required among the various sources. It will be on the basis of refined source estimates and reduction efficiencies that more specific or revised strategies for reduction of nonpoint sources will be developed. Issues such as cost and feasibility will be considered when specifying the refined reduction targets for any source or source type. If needed, other additional measures to be applied to stormwater point sources through NJPDES permits will be adopted by the Department as amendments to the applicable areawide Water Quality Management Plan.

The Township of West Milford has already initiated stormwater management activities. They have completed GIS mapping of all stormwater outfalls under funding from a separate grant. Passaic County has also provided mapping of all stormwater outfalls on County roads. Information from both of these projects will provide important information for the development of the stormwater plan under the planned 319(h) project. Under an earlier 319(h) project, the Township of West Milford received $90,000 for nonpoint source pollution control through the installation of 19 catch basins in the Belcher's Creek subwatershed. Removal of sediment from these catch basins as part of the maintenance program will remove an estimated 2,452 ft^3 of sediment annually.

The Village of Greenwood Lake, New York conducts weed-harvesting on several occasions during the summer months. The Greenwood Lake Commission is working with the Township of West Milford to conduct select harvesting events beginning in the summer of 2004. Harvesting can provide some limited reduction in nutrient concentrations by removal of organic material from the lake compared to allowing settling of organic material within the sediments as a potential phosphorus reservoir.

Dredging is another short-term measure to reduce the internal load of phosphorus and increase the distance between the photic zone and the sediments, impeding growth of rooted aquatic plants. Without addressing all sources of sedimentation and phosphorus loading this measure provides limited, short-term relief. A Bill has been introduced to the New Jersey Legislature (Assembly Bill No. 1369) on January 13, 2004 and was referred to the Assembly Environmental and Solid Waste Committee. The bill is for dredging of Greenwood Lake and associated activities. The Greenwood Lake Commission is also investigating the possibility of dredging under a proposal with the Army Corps of Engineers as a component of a stump removal project. The Village of Greenwood Lake, New York has just completed a $250,000 dredging project on the New York portion of the lake under a federal grant.

Drawdown, or lowering of water levels to expose bottom sediments, of a lake can be an effective tool for controlling some aquatic weed species. A Drawdown/Water Level Management Plan was adopted for Greenwood Lake in 1997. Ownership of the dam impounding the waters of Greenwood Lake and the sluice gates lies within the authority and responsibility of the New Jersey Department of Environmental Protection, Division of Parks and Forestry. The goal of this plan is to provide a means for aquatic weed control and enhancement of water quality while maintaining the required minimum passing flow of 3 million gallons per day (MGD) below the dam. The Greenwood Lake Watershed Management District, Inc. is the unit requesting the drawdown and coordinating the activities. A drawdown of five feet is scheduled for 2005. The GLMDI will also submit a report to the Division of Parks and Forestry evaluating the effect of the drawdown, including the extent and type of vegetation control achieved, the percentage of vegetation remaining in the littoral zone, the changes in species composition noted, the effects on the density and species composition of the macroinvertebrate community and any other factors which may affect the need for continued drawdowns. Drawdowns are on a scheduled 5-year basis.

Long-term Management measures

Long-term management measures are strategies that will effect a measurable reduction in pollutant loads by addressing the source and remediating the problem. The stormwater implementation plan will provide a list of activities that may not be economically feasible during the current year but would provide for a significant reduction in phosphorus as they are implemented over time. The stormwater implementation projects that will be installed under the pending project will begin immediately to provide source reduction, and are considered a long-term solution to phosphorus loading.

On-site wastewater systems

Septic management measures will be an important component of the implementation plan. As a component of this TMDL the septic loading has been updated from the Phase I diagnostic study. As septic loads are a significant source of phosphorus, long-term management measures to address septic problems on both the New York and the New Jersey portion of the lake are a necessary component. Failing or improperly functioning septic system can be a source of phosphorus, and the extent of the load is significantly determined by geologic and soil constraints. On Greenwood Lake's northern New York side there are apparent severe restrictions to the proper operation of septic systems based on lack of depth to bedrock and steep slopes. An aggressive septic management plan, possibly including alternative treatment measures, will be necessary. Towards this end, the Village of Greenwood Lake adopted an ordinance on April 2, 2001, which requires proof of proper functioning systems and pump-out every three years as an on-going requirement. Alternative treatment may still be needed due to the environmental constraints in the area. The New Jersey portion of Greenwood Lake also has septic management concerns, although the geology and slopes are less severe. There are documented instances of septic failure. The Department is working with the Greenwood Lake Commission to address these issues. As this is a local issue, the Department has submitted a request to verify a failure and provide a written report within 30 days of the incident. The Department will continue to actively pursue issues of septic problems within its purview. The Department is planning a partnership with the United States Department of Agriculture and the Natural Resource Conservation Service newly formed section, the Liberty RC&D (which covers Hudson, Essex, Passaic and Bergen counties) to provide a septic management workshop for the fall of 2004. This workshop will be provided to the Greenwood Lake Commission, municipal and county officials and other interested private and public stakeholders.

An in-depth investigation of septic issues will be required to complete the Lake Characterization and Restoration Plan. Issues to be covered include detailed information on the number of septic systems which potentially impact the lake, the percentage of failing or improperly functioning systems, the ability of standard systems to function given specific geologic and soil restrictions, the area required for a properly functioning leach field given the environmental constraints, other options and a cost analysis.

Agricultural Activities

Agricultural activities are another example of potential sources of phosphorus. Implementation of conservation management plans and best management practices are the best means of controlling agricultural sources of phosphorus. Several programs are available to assist farmers in the development and implementation of conservation management plans and best management practices. The Natural Resource Conservation Service is the primary source of assistance for landowners in the development of resource management pertaining to soil conservation, water quality improvement, wildlife habitat enhancement, and irrigation water management. The USDA Farm Services Agency is the lead on most of the funding assistance. All agricultural technical assistance is coordinated through the locally led Soil Conservation Districts. Agricultural sources within the watershed provide greater than 25 kg/yr from runoff and should be addressed through Best Management Practices. The available funding programs in New Jersey include:

- **The Environmental Quality Incentive Program (EQIP)** is designed to provide technical, financial, and educational assistance to farmers/producers for conservation practices that address natural resource concerns, such as water quality. Practices under this program include integrated crop management, grazing land management, well sealing, erosion control systems, agri-chemical handling facilities, vegetative filter strips/riparian buffers, animal waste management facilities and irrigation systems.

- **The Conservation Reserve Program (CRP)** is designed to provide technical and financial assistance to farmers/producers to address the agricultural impacts on water quality and to maintain and improve wildlife habitat. CRP practices include the establishment of filter strips, riparian buffers and permanent wildlife habitats. This program provides the basis for the Conservation Reserve Enhancement Program (CREP).

- **Conservation Reserve Enhancement Program (CREP)** The New Jersey Departments of Environmental Protection and Agriculture, in partnership with the Farm Service Agency and Natural Resources Conservation Service, signed a $100 million CREP agreement earlier this year. This program matches $23 million of State money with $77 million from the Commodity Credit Corp. within USDA. Through CREP, financial incentives are offered for agricultural landowners to voluntarily implement conservation practices on agricultural lands. NJ CREP will be part of the USDA's Conservation Reserve Program (CRP). There will be a ten-year enrollment period, with CREP leases ranging between 10-15 years. The State intends to augment this program to make these leases permanent easements. The enrollment of farmland into CREP in New Jersey is expected to improve stream health through the installation of water quality conservation practices on New Jersey farmland.

Many similar programs would also be available in New York under similar federal programs.

Reasonable Assurance

With the implementation of follow-up monitoring, source identification and source reduction as described, the Department has reasonable assurance that the New Jersey and New York Surface Water Quality Standards will be attained for phosphorus in Greenwood Lake.

The phosphorus reductions proposed in this TMDL require that the existing NJPDES permitted facilities containing phosphorus will receive effluent limits commensurate with holding the load from this source, subject to the options, such as water quality trading, as described. Stormwater point sources will be controlled by requirements of the Phase II stormwater permitting program and additional measures. Nonpoint source controls are also planned, as described.

The Department's ambient monitoring network will be the means to determine if the strategies identified have been effective. Ambient monitoring will be evaluated to determine if additional strategies for source reduction are needed.

11.0 Public Participation

The Water Quality Management Planning Rules NJAC 7:15-7.2 encourage the Department to initiate a public process prior to the development of each TMDL and to allow public input to the Department on policy issues affecting the development of the TMDL. An informal presentation of the findings and results of this TMDL was provided at the May 19, 2004 Greenwood Lake Commission meeting.

Additional public participation and input was received through the New Jersey EcoComplex. The Department contracted with Rutgers NJEC in July 2001. The role of NJEC is to provide comments on the Department's management strategies, including those related to the development of TMDL values. NJEC consists of a review panel of New Jersey University professors who provide a review of the technical approaches developed by the Department. The New Jersey Statewide Protocol for Developing Eutrophic Lakes TMDLs was presented to NJEC on September 27, 2002 and was subsequently reviewed. Feedback received from NJEC was incorporated into the TMDLs to address lake eutrophication. New Jersey's Statewide Protocol for Developing Lake and Fecal TMDLs was also presented at the SETAC Fall Workshop on September 13, 2002.

In accordance with N.J.A.C. 7:15–7.2(g), this TMDL was proposed by the Department as an amendment to the Northeast Water Quality Management Plan. Notice of this TMDL was published June 7, 2004 in the New Jersey Register and the Star Ledger in order to provide the public an opportunity to review the TMDL and submit comments. Additional public participation was provided at the Public Hearing for the Greenwood Lake TMDL held July 7, 2004 at 6:30 PM at the Long Pond Iron Works Museum of Ringwood State Park. Following approval of this TMDL by the EPA, the TMDL will be adopted as an amendment to the Northeast WQMP.

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Appendix B: Database of Phosphorus Export Coefficients

In December 2001, the Department concluded a contract with the USEPA, Region 2, and a contracting entity, TetraTech, Inc., the purpose of which was to identify export coefficients applicable to New Jersey. As part of that contract, a database of literature values was assembled that includes approximately four-thousand values accompanied by site-specific characteristics such as location, soil type, mean annual rainfall, and site percent-impervious. In conjunction with the database, the contractor reported on recommendations for selecting values for use in New Jersey. Analysis of mean annual rainfall data revealed noticeable trends, and, of the categories analyzed, was shown to have the most influence on the reported export coefficients. Incorporating this and other contractor recommendations, the Department took steps to identify appropriate export values for these TMDLs by first filtering the database to include only those studies whose reported mean annual rainfall was between 40 and 51 inches per year. From the remaining studies, total phosphorus values were selected based on best professional judgment for eight land uses categories.

The sources incorporated in the database include a variety of governmental and non-governmental documents. All values used to develop the database and the total phosphorus values in this document are included in the below reference list.

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Appendix C: Summary of Reckhow (1979a) model derivation

The following general expression for phosphorus mass balance in lake assumes the removal of phosphorus from a lake occurs through two pathways, the outlet (M_o) and the sediments (ϕ):

$$V \cdot \frac{dP}{dt} = M_i - M_o - \phi$$ **Equation 1**

where:
- V = lake volume (10^3 m³)
- P = lake phosphorus concentration (mg/l)
- M_i = annual mass influx of phosphorus (kg/yr)
- M_o = annual mass efflux of phosphorus (kg/yr)
- ϕ = annual net flux of phosphorus to the sediments (kg/yr).

The sediment removal term is a multidimensional variable (dependent on a number of variables) that has been expressed as a phosphorus retention coefficient, a sedimentation coefficient, or an effective settling velocity. All three have been shown to yield similar results; Reckhow's formulation assumes a constant effective settling velocity, which treats sedimentation as an areal sink.

Assuming the lake is completely mixed such that the outflow concentration is the same as the lake concentration, the phosphorus mass balance can be expressed as:

$$V \cdot \frac{dP}{dt} = M_i - v_s \cdot P \cdot A - P \cdot Q$$ **Equation 2**

where:
- v_s = effective settling velocity (m/yr)
- A = area of lake (10^3 m²)
- Q = annual outflow (10^3 m³/yr).

The steady-state solution of Equation 2 can be expressed as:

$$P = \frac{P_a}{v_s + z/T} = \frac{P_a}{v_s + Q_a}$$ **Equation 3**

where:
- P_a = areal phosphorus loading rate (g/m²/yr)
- z = mean depth (m)
- T = hydraulic detention time (yr)
- Q_a = Q/A = areal water load (m/yr).

Using least squares regression on a database of 47 north temperate lakes, Reckhow fit the effective settling velocity using a function of areal water load: $P = \frac{P_a}{11.6 + 1.2 \cdot Q_a}$. **Equation 4**

Appendix D: Derivation of Margin of Safety from Reckhow *et al* (1980)

As described in Reckhow *et al* (1980), the Reckhow (1979a) model has an associated standard error of 0.128, calculated on log-transformed predictions of phosphorus concentrations. The model error analysis from Reckhow *et al* (1980) defined the following confidence limits:

$$P_L = P - h \cdot \left(10^{(\log P - 0.128)} - P\right)$$
$$P_U = P + h \cdot \left(10^{(\log P + 0.128)} - P\right)$$
$$\rho \geq 1 - \frac{1}{2.25 \cdot h^2}$$

where:

P_L = lower bound phosphorus concentration (mg/l);
P_U = upper bound phosphorus concentration (mg/l);
P = predicted phosphorus concentration (mg/l);
h = prediction error multiple
ρ = the probability that the real phosphorus concentration lies within the lower and upper bound phosphorus concentrations, inclusively.

Assuming an even-tailed probability distribution, the probability (ρ_u) that the real phosphorus concentration is less than or equal to the upper bound phosphorus concentration is:

$$\rho_u = \rho + \frac{1-\rho}{2} = \rho + \frac{1}{2} - \frac{\rho}{2} = \rho \cdot \left(1 - \frac{1}{2}\right) + \frac{1}{2} = \frac{1}{2} \cdot \rho + \frac{1}{2}$$

Substituting for ρ as a function of *h*:

$$\rho_u = \frac{1}{2} \cdot \left(1 - \frac{1}{2.25 \cdot h^2}\right) + \frac{1}{2} = \frac{1}{2} - \frac{1}{4.5 \cdot h^2} + \frac{1}{2} = 1 - \frac{1}{4.5 \cdot h^2}$$

Solving for *h* as a function of the probability that the real phosphorus concentration is less than or equal to the upper bound phosphorus concentration:

$$\frac{1}{4.5 \cdot h^2} = 1 - \rho_u$$
$$h^2 = \frac{1}{4.5(1 - \rho_u)}$$
$$h = \sqrt{\frac{1}{4.5(1 - \rho_u)}}$$

Expressing Margin of Safety (MoS_p) as a percentage over the predicted phosphorus concentration yields:

$$MoS_p = \frac{P_U}{P} - 1 = \frac{P_U - P}{P}$$

Substituting the equation for P_U:

$$MoS_p = \frac{P + h\cdot\left(10^{(\log P + 0.128)} - P\right) - P}{P} = \frac{h\cdot\left(10^{(\log P+0.128)} - P\right)}{P}$$

$$P\cdot MoS_p = h\cdot\left(10^{(\log P+0.128)} - P\right)$$

$$\frac{P\cdot MoS_p}{h} = 10^{(\log P+0.128)} - P$$

$$\frac{P\cdot MoS_p}{h} + P = 10^{(\log P+0.128)}$$

Taking the log of both sides and solving for margin of safety:

$$\log\left(\frac{P\cdot MoS_p}{h} + P\right) = \log P + 0.128$$

$$\log\left(\frac{P\cdot MoS_p}{h} + P\right) - \log P = 0.128$$

$$\log\left(P\left(\frac{MoS_p}{h} + 1\right)\right) - \log P = 0.128$$

$$\log P + \log\left(\frac{MoS_p}{h} + 1\right) - \log P = 0.128$$

$$\log\left(\frac{MoS_p}{h} + 1\right) = 0.128$$

$$\frac{MoS_p}{h} + 1 = 10^{0.128}$$

$$\frac{MoS_p}{h} = 10^{0.128} - 1$$

$$MoS_p = h\left(10^{0.128} - 1\right)$$

Finally, substituting for *h* yields Margin of Safety (*MoS_p*) as a percentage over the predicted phosphorus concentration, expressed as a function of the probability (ρ_u) that the real phosphorus concentration is less than or equal to the upper bound phosphorus concentration:

$$MoS_p = \sqrt{1 / \left((1-\rho_u)*4.5\right)} \times \left(10^{0.128} - 1\right)$$

Appendix E   NJPDES Permitted Discharges

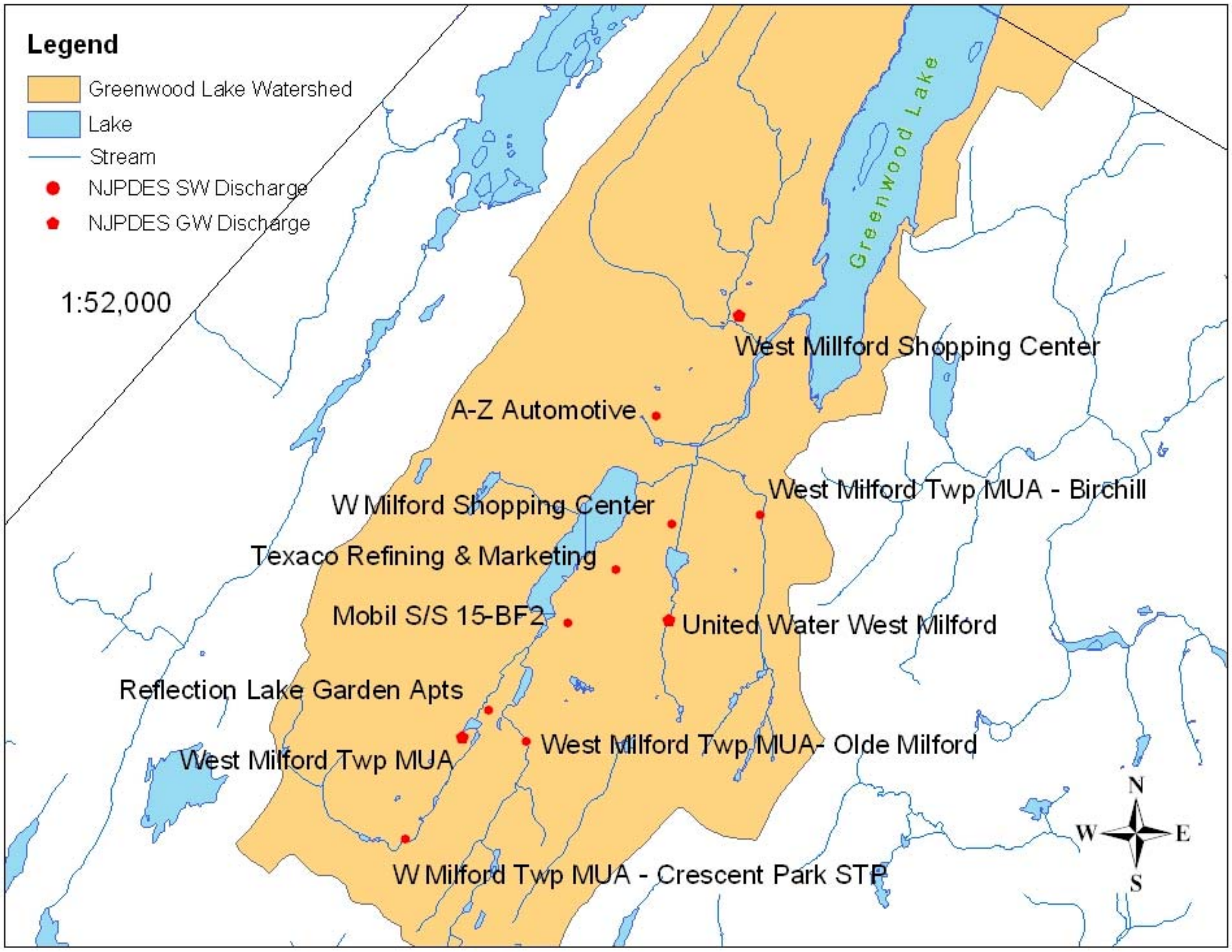
Table 1 Active NJPDES Discharges Located in the Greenwood Lake Watershed

NJPDESID	Facility Name	Discharge Type	Receiving Water	DMR Status*
NJ0024414.001 A GPS	W Milford Shopping Center	Sanitary discharge, Municipal Minor	Belchers Creek via unnamed trib and stor	I
NJ0028541.001 A GPS	West Milford Twp MUA - Birchill	Sanitary discharge, Municipal Minor	Morestown Brook (Belchers Creek)	I
NJ0026174.001 A GPS	W Milford Twp MUA - Crescent Park STP	Sanitary discharge, Municipal Minor	Belchers Creek	I
NJ0027201.001 A GPS	Reflection Lake Garden Apts	Sanitary discharge, Municipal Minor	Belchers Cr via unnmd trib and ditch	I
NJ0027677.001 A GPS	West Milford Twp MUA- Olde Milford	Sanitary discharge, Municipal Minor	Belcher Creek via unnamed trib	I
NJG0076511.001A GPS	Mobil S/S 15-BF2	Petroleum hydrocarbon remediation	Pine Cliff Lk (Belcher Cr) via strm swr	II
NJ0129488.001 A	Texaco Refining & Marketing	Petroleum hydrocarbon remediation	Belcher Creek via storm sewer	II
NJ0134660.001 A	A-Z Automotive	Petroleum hydrocarbon remediation	Belcher Creek	II
NJ0051098.T01 T GPS	West Milford Twp MUA	Underground injection sanitary, Infiltration lagoon	Infiltrtn Pond or Undrgrnd Injection	III
NJ0081914.T01 T	United Water West Milford	Underground injection sanitary, Infiltration lagoon	Infiltrtn Pond or Undrgrnd Injection	III
NJ0087530.T01 T	West Millford Shopping Center	Underground injection sanitary, Infiltration lagoon	Infiltrtn Pond or Undrgrnd Injection	III

Note:

I: Both flow and TP concentration in the discharge are reported in the DMR.
II: No DMR
III: Only TP concentration in residual is reported in the DMR.

Figure 1 Location of Active NJPDES Discharges in the Greenwood Lake Watershed


Legend
Greenwood Lake Watershed
Lake
Stream
NJPDES SW Discharge
NJPDES GW Discharge
1:52,000
Greenwood Lake
West Millford Shopping Center
A-Z Automotive
West Milford Twp MUA - Birchill
W Milford Shopping Center
Texaco Refining & Marketing
Mobil S/S 15-BF2
United Water West Milford
Reflection Lake Garden Apts
West Milford Twp MUA- Olde Milford
West Milford Twp MUA
W Milford Twp MUA - Crescent Park STP
N
W
E
S