Amendment to the
Northeast Water Quality Management Plan
Lower Raritan-Middlesex Water Quality Management Plan
Monmouth County Water Quality Management Plan
Upper Raritan Water Quality Management Plan

Total Maximum Daily Loads for Phosphorus To Address 6 Eutrophic Lakes in the Raritan Water Region

ECHO LAKES, UNION COUNTY
DAVIDSON'S MILL LAKE, MIDDLESEX COUNTY
DEVOE LAKE, MIDDLESEX COUNTY
MANALAPAN LAKE, MIDDLESEX COUNTY
TOPANEMUS LAKE, MONMOUTH COUNTY

Proposed: January 21, 2003
Established: March 28, 2003
Approved (by EPA Region 2): September 29, 2003

ROUND VALLEY RECREATIONAL AREA, HUNTERDON COUNTY

Proposed: April 21, 2003
Established: June 27, 2003
Approved (by EPA Region 2): September 30, 2003

Adopted:

Watershed Management Area 7
(Arthur Kill Watershed)
Watershed Management Area 8
(North and South Branch Raritan Watersheds)
Watershed Management Area 9
(Lower Raritan, South River and Lawrence Watersheds)

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1.0 Executive Summary

The State of New Jersey's *2002 Integrated List of Waterbodies* identified several lakes in the Raritan Water Region as being eutrophic. This report establishes total maximum daily loads (TMDLs) for total phosphorus (TP) that address eutrophication of the lakes listed in Table 1.

Table 1 Eutrophic Lakes for which Phosphorus TMDLs are being established

TMDL Number	Lake Name	Municipality	WMA	Acres
1	Echo Lakes	Mountainside, Union County	07	17.8
2	Davidson's Mill Lake	South Brunswick, Middlesex County	09	26.1
3	Devoe Lake	Spotswood Boro, Middlesex County	09	35.1
4	Manalapan Lake	Monroe, Middlesex County	09	47.7
5	Round Valley Recreational Area	Clinton, Hunterdon County	08	31.0
6	Topanemus Lake	Freehold, Monmouth County	09	22.0

These TMDLs serve as the foundation on which restoration plans will be developed to restore eutrophic lakes and thereby attain applicable surface water quality standards. A TMDL is developed as a mechanism for identifying all the contributors to surface water quality impacts and setting goals for load reductions for pollutants of concern as necessary to meet Surface Water Quality Standards (SWQS). The pollutant of concern for these TMDLs is phosphorus, since phosphorus is generally the nutrient responsible for overfertilization of inland lakes leading to cultural eutrophication. The Department's Geographic Information System (GIS) was used extensively to describe the lakes and lakesheds (drainage basin of the lakes).

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. Phosphorus sources were characterized on an annual scale (kg TP/yr) for both point and nonpoint sources. Runoff from land surfaces comprises a substantial source of phosphorus into lakes. An empirical model was used to relate annual phosphorus load and steady-state in-lake concentration of total phosphorus. To achieve the TMDLs, overall load reductions were calculated for at least eight source categories. In order to track effectiveness of remediation measures (including TMDLs) and to develop baseline and trend information on lakes, the Department will augment its ambient monitoring program to include lakes on a rotating schedule. The implementation plan also calls for the collection of additional monitoring data and the development of a Lake Restoration Plan for each lake. These plans will consider what in-lake measures need to be taken to supplement the nutrient reduction measures required by the TMDL. Each TMDL shall be proposed and adopted by the Department as an amendment to the appropriate areawide water quality management plan(s) in accordance with N.J.A.C. 7:15-3.4(g).

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

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

2.0 Introduction

Sublist 5 (also known as List 5 or, traditionally, the 303(d) List) of the State of New Jersey's *2002 Integrated List of Waterbodies* identified several lakes in the Raritan Water Region 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 "independent" causal pollutant causes "dependent " responses in chlorophyll-*a* concentrations and/or macrophyte density. This report establishes five total maximum daily loads (TMDLs) that address total phosphorus loads to the identified lakes. These TMDLs serve as the foundation on which management approaches or restoration plans will be developed to restore eutrophic lakes and thereby attain applicable surface water quality standards. Several of the lakes are listed on Sublist 5 for impairments caused by other pollutants. These TMDLs address only the impairment of lakes due to eutrophication. Separate TMDL evaluations will be developed to address the other pollutants of concern. The waterbodies will remain on Sublist 5 until such time as TMDL evaluations for all pollutants have been completed and approved by the United States Environmental Protection Agency (USEPA).

A TMDL is considered to be "proposed" when NJDEP publishes the TMDL Report as a proposed Water Quality Management Plan Amendment in the New Jersey Register (NJR) for public review and comment. A TMDL is considered to be "established" when NJDEP finalizes the TMDL Report after considering comments received during the public comment period for the proposed plan amendment and formally submits it to EPA Region 2 for thirty (30)-day review and approval. The TMDL is considered "approved" when the NJDEP-established TMDL is approved by EPA Region 2. The TMDL is considered to be "adopted" when the EPA-approved TMDL is adopted by NJDEP as a water quality management plan amendment and the adoption notice is published in the NJR.

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 to biennially 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 to biennially 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. For waterbodies identified on the 303(d) List, there are three possible scenarios that may result in a waterbody being removed from the 303(d) List:

Scenario 1: A TMDL is established for the pollutant of concern;
Scenario 2: A determination is made that the waterbody is meeting water quality standards (no TMDL is required); or
Scenario 3: A determination is made that a TMDL is not the appropriate mechanism for achieving water quality standards and that other control actions will result in meeting standards.

Where a TMDL is required (Scenario 1), it will: 1) specify the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards**;** and 2) allocate pollutant loadings among point and nonpoint pollutant sources.

Recent EPA guidance (Suftin, 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, which includes three TMDLs, addresses the following items in the May 20, 2002 guideline document:

1. Identification of waterbody(ies), 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.
12. Submittal letter.

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. A TMDL is developed as a mechanism for identifying all the contributors to surface water quality impacts and setting goals for load reductions for pollutants of concern as necessary to meet SWQS.

Once one of the three possible delisting scenarios, noted above, is completed, states have the option to remove the waterbody and specific pollutant of concern from the 303(d) List or maintain the waterbody on the 303(d) list until SWQS are achieved. The State of New Jersey will be removing lakes from the 303(d) List for eutrophication once their TMDLS are approved by USEPA.

3.3 Integrated List of Waterbodies

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. In general, Categories 1 through 4 include a range of designated use impairments with a discussion of enforceable management strategies, whereas 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. Where more than one pollutant is associated with the impairment for a given waterbody, that waterbody will remain on Sublist 5 until one of the three possible delisting scenarios is completed. In the case of an Integrated List, however, the waterbody is not delisted but moved to one of the other categories.

Following USEPA's guidance, the Department chose to develop an Integrated Report for New Jersey. New Jersey's *2002 Integrated List of Waterbodies* is 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. These TMDLs address eutrophic lakes, as listed on Sublist 5 of the State of New Jersey's *2002 Integrated List of Waterbodies.*

4.0 Pollutant of Concern and Area of Interest

Lakes were designated as impaired due to Nutrients/Sedimentation (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 impairment was designated as "Nutrients/Sedimentation" because these are the broad causes of eutrophication. The applicable surface water quality standards are listed in section 5. While sedimentation is important, no criterion exists for sedimentation and therefore none was applied to these lakes to determine their impairment status. Sedimentation can be biogenic in origin, cause by the deposition of organic matter in an excessively productive system, or it can result for excessive sediment loads form the watershed of a lake. Phosphorus control addresses both origins of sedimentation, since much of the runoff load of phosphorus is particulate and phosphorus in the lake controls the level of biological productivity. Also, stormwater controls intended to minimize phosphorus are more effective at controlling sediment than phosphorus. Due to the lake of criterion for sedimentation and to the overall importance of phosphorus, these TMDLs were developed around phosphorus budgets.

The pollutant of concern for these TMDLs is therefore 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. Furthermore, of the major nutrients, phosphorus is the most effectively controlled through engineering technology and land use management (Holdren *et al*, 2001). 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. Phosphorus is generally the nutrient responsible for overfertilization of inland lakes leading to eutrophication.

As reported in the *2002 Integrated List of Waterbodies*, the Department identified the following lakes in Raritan Water Region as being eutrophic for a total of 304 acres. These TMDLs will address 180 acres or approximately 59 percent of the total impaired acres in this region (Table 2). Davidson's Mill Lake is listed for both trophic status and aquatic life, which is based on a fishery assessment performed by the Department's Bureau of Freshwater Fisheries; secondary impacts of eutrophication include poorer fish quality and diversity, often due to oxygen depressions and fluctuations. Therefore, it is likely that management actions directed at addressing eutrophication impairments would also address aquatic life impairments based on fishery assessment. However, the exact causes of the aquatic life impairment have not been determined, therefore it is not certain that a TMDL for eutrophication will address the aquatic life impairment completely. Both eutrophic lakes and aquatic life impairments are ranked as Low Priority in the *2002 Integrated List of Waterbodies* because they are not directly related to human health issues; however, both issues are environmentally important.

Table 2 Abridged Sublist 5 of the 2002 Integrated List of Waterbodies, eutrophic lakes

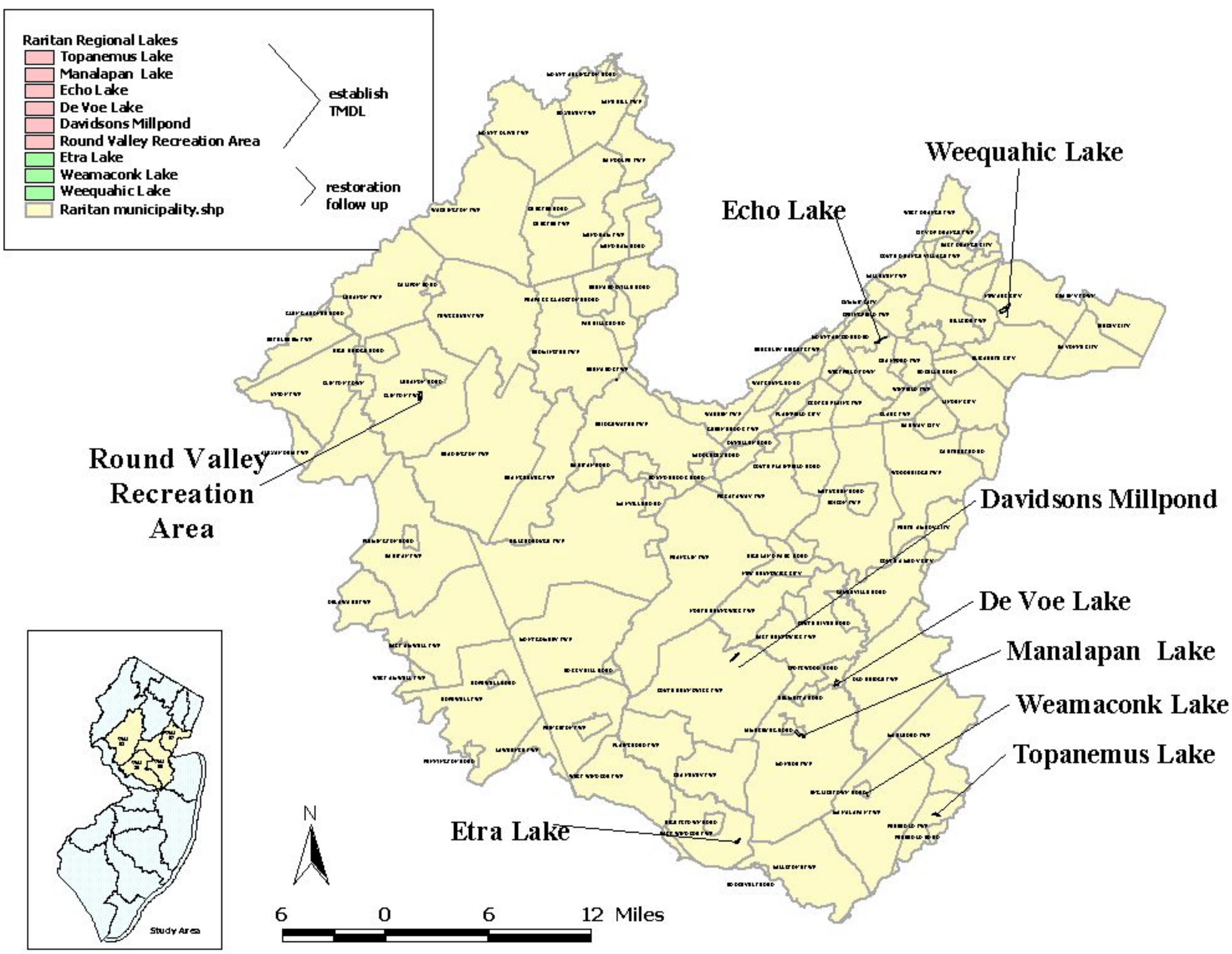
WMA	Lake[a]	Lake Acres	Watershed Acres	Management Response
07	Echo Lakes	17.8	2,280	establish TMDL
07	Weequahic Lake	69.4	878	restoration follow-up
08	Round Valley Recreational Area	31.0	240	establish TMDL
09	Davidson's Mill Lake	26.1	9,600	establish TMDL
09	Devoe Lake	35.1	8,670[b]	establish TMDL
09	Manalapan Lake	47.7	17,300	establish TMDL
09	Topanemus Lake	22.0	934	establish TMDL
09	Weamaconk Lake	3.9	4,360	restoration follow-up
10	Etra Lake	20.4	5,600[c]	restoration follow-up

a All of the waterbodies covered under these TMDLs have a FW2 classification.

b To avoid "double-counting," watershed area of Devoe Lake does not include Manalapan Lake and its watershed.

c Watershed acreage taken from F.X. Browne, 1988.

Figure 1 Eutrophic lakes in the Raritan Water Region on Sublist 5 of 2002 Integrated List



These TMDLs will address a total of 180 acres of lakes with a corresponding total of 39,000 acres of land.

The Department's Geographic Information System (GIS) was used extensively to describe the lakes and lakesheds (watershed of the lake), specifically the following data coverages:

- 1995/97 Land use/Land cover Update, published 12/01/2000 by NJDEP Bureau of Geographic Information and Analysis , delineated by watershed management area.
- NJDEP Statewide Lakes (Shapefile) with Name Attributes (from 95/97 Land Use/Land Cover) in New Jersey, published 7/13/2001 by NJDEP - Bureau of Freshwater and Biological Monitoring, http://www.state.nj.us/dep/gis/digidownload/zips/statewide/njlakes.zip.
- 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.
- 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).

4.1 Echo Lakes

Upper and Lower Echo Lakes, located in Echo Lake Park in the municipalities of Westfield and Mountainside, Union County, were constructed by the Union County Park Commission in 1929. Upper Echo Lake and Lower Echo Lake cover 9.3 acres and 8.5 acres, respectively. While Upper Echo Lake has an average depth of 2.2 feet (F.X. Browne, 2000), the combined average depth of both lakes is approximately 4 feet (NJDEP, 1983a). The watershed area that drains into Echo Lakes is approximately 2,283 acres and includes the Echo Lake Park area, medium density residential areas, commercial areas located along Route 22, and forested areas located in the Watchung Reservation. The lakeshed is 128.2 times the area of the lakes, making it very large[2]. Mean depth (1.22m) and total inflow (2,360,000 m^3/yr) were obtained from the Lakes Classification Study for Echo Lakes (NJDEP, 1983a).

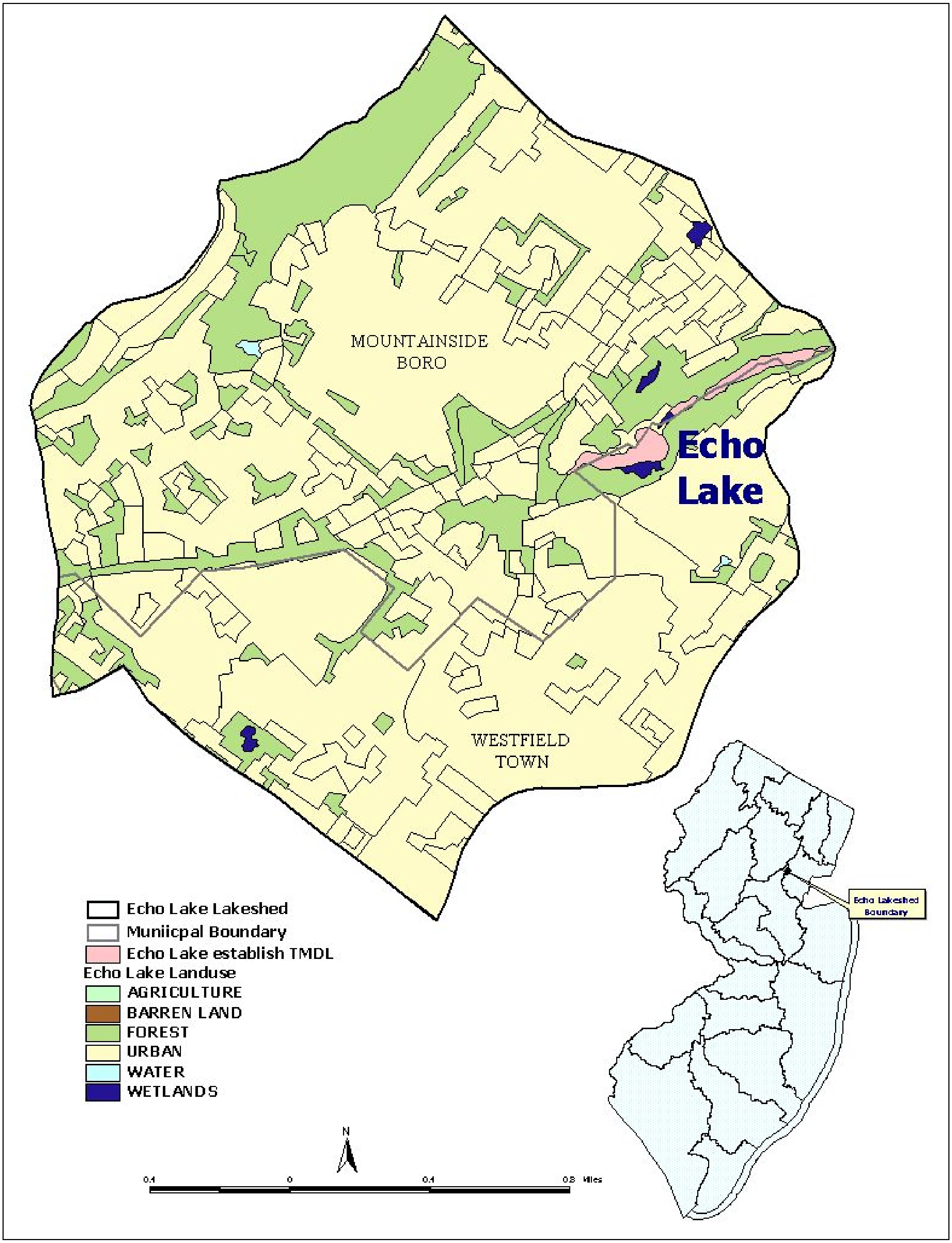
Echo Lakes are currently used for fishing and boating. Excessive siltation, algae blooms and an overabundance of aquatic plants and waterfowl are threatening the Lakes' recreational

[2] A lakeshed seven times the area of its lake is considered small, whereas a lakeshed ten times the area of its lake is considered large (Holdren *et al*, 2001).

uses. Since the lakes was created in 1929, there have been several remedial dredging events (1959, 1960, 1971, 1972, 1976, and 1992).

In 1995, Union County established a team to study and make recommendations to improve the County's waterbodies. Out of the 30 lakes evaluated by the team, Echo Lake was given a high priority rating of #3. In February 2000, F.X. Browne, Inc issued a report on the lake titled "Diagnostic-Feasibility Study of Upper Echo Lake". The report included remedial actions that included increasing the water depth in the lake, improving the lake's fishery, and reducing nonpoint sources of pollution from the surrounding watershed.

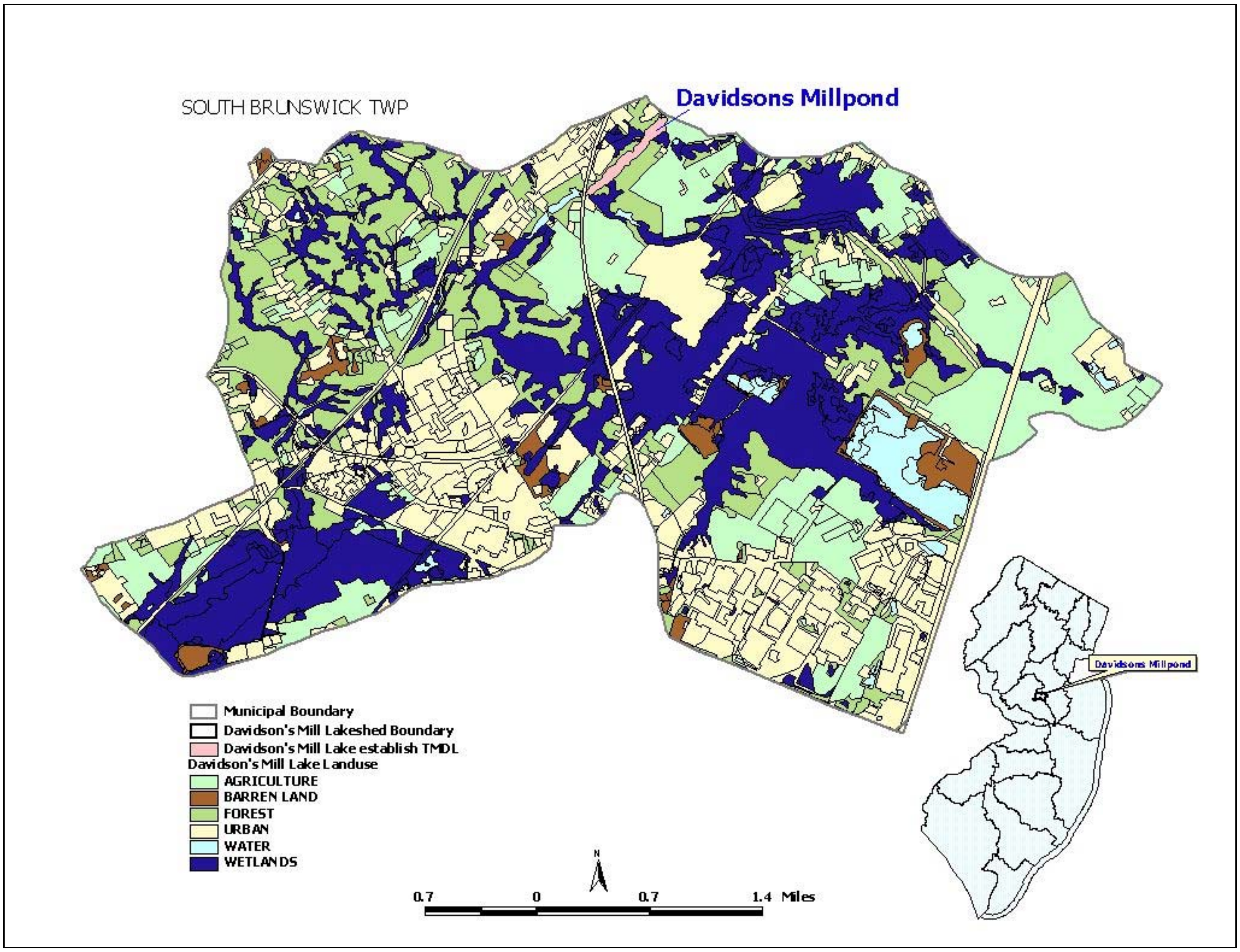
Figure 1 Lakeshed of Echo Lakes



4.2 Davidson's Mill Lake

Davidson's Mill Lake is a 26-acre impoundment of Lawrence Brook located in South Brunswick, Middlesex County, that drains a lakeshed (watershed of the lake) of 9595 acres mostly within South Brunswick township. The lakeshed is 368 times the area of the lake, making it extremely large. The lake consists of a widening of Lawrence Brook for a stretch of about seven tenths of a mile. Inflow into Davidson's Mill Lake is primarily comprised of tributary input from Lawrence Brook. Mean depth (1.52m) and total inflow (18,300,000 m^3/yr) were obtained from the Lakes Classification Study for Davidson's Mill Lake (NJDEP, 1983b).

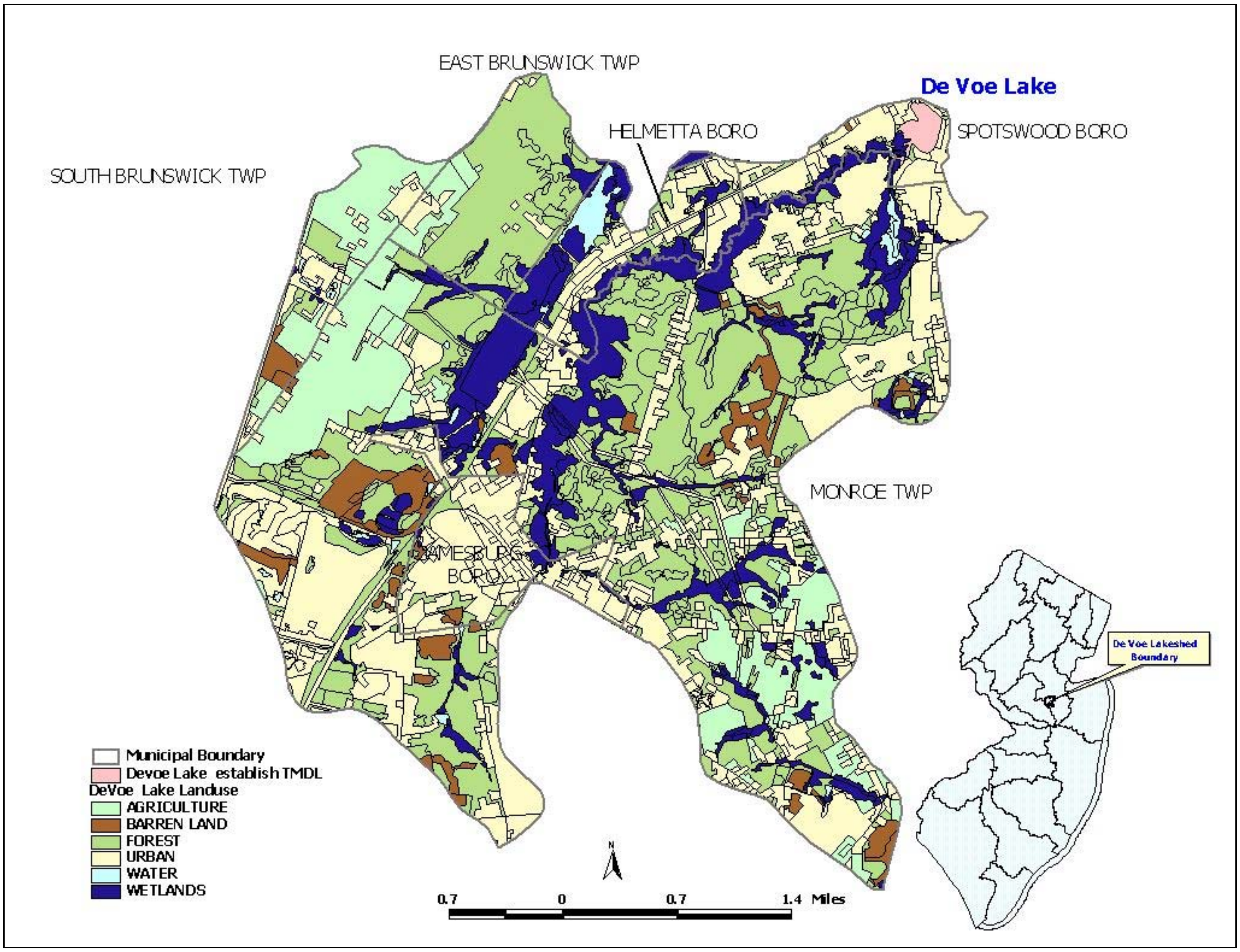
Figure 2 Lakeshed of Davidson's Mill Lake



4.3 Devoe Lake

Devoe Lake is a 35-acre impoundment of Manalapan Brook located in Spotswood Boro, Middlesex County, that drains an immediate lakeshed of 8667 acres extending into the municipalities of Monroe, Helmetta, East Brunswick, South Brunswick and Jamesburg. Since Manalapan Lake drains into Manalapan Brook upstream of Devoe Lake, the entire lakeshed encompasses the additional 17,254-acre lakeshed of Manalapan Lake, resulting in an extremely large total lakeshed that is 739 times the area of the lake. The lake consists of a single main basin upstream of the dam and a widening of Manalapan Brook and South River confluence at the inlet of the lake for a stretch of about 400 feet. Inflow into Devoe Lake is primarily comprised of tributary input from Manalapan Brook and South River. Mean depth (1.52m) and total inflow (53,600,000 m^3/yr) were obtained from the Lakes Classification Study for Devoe Lake (NJDEP, 1983c).

Figure 3 immediate Lakeshed of Devoe Lake

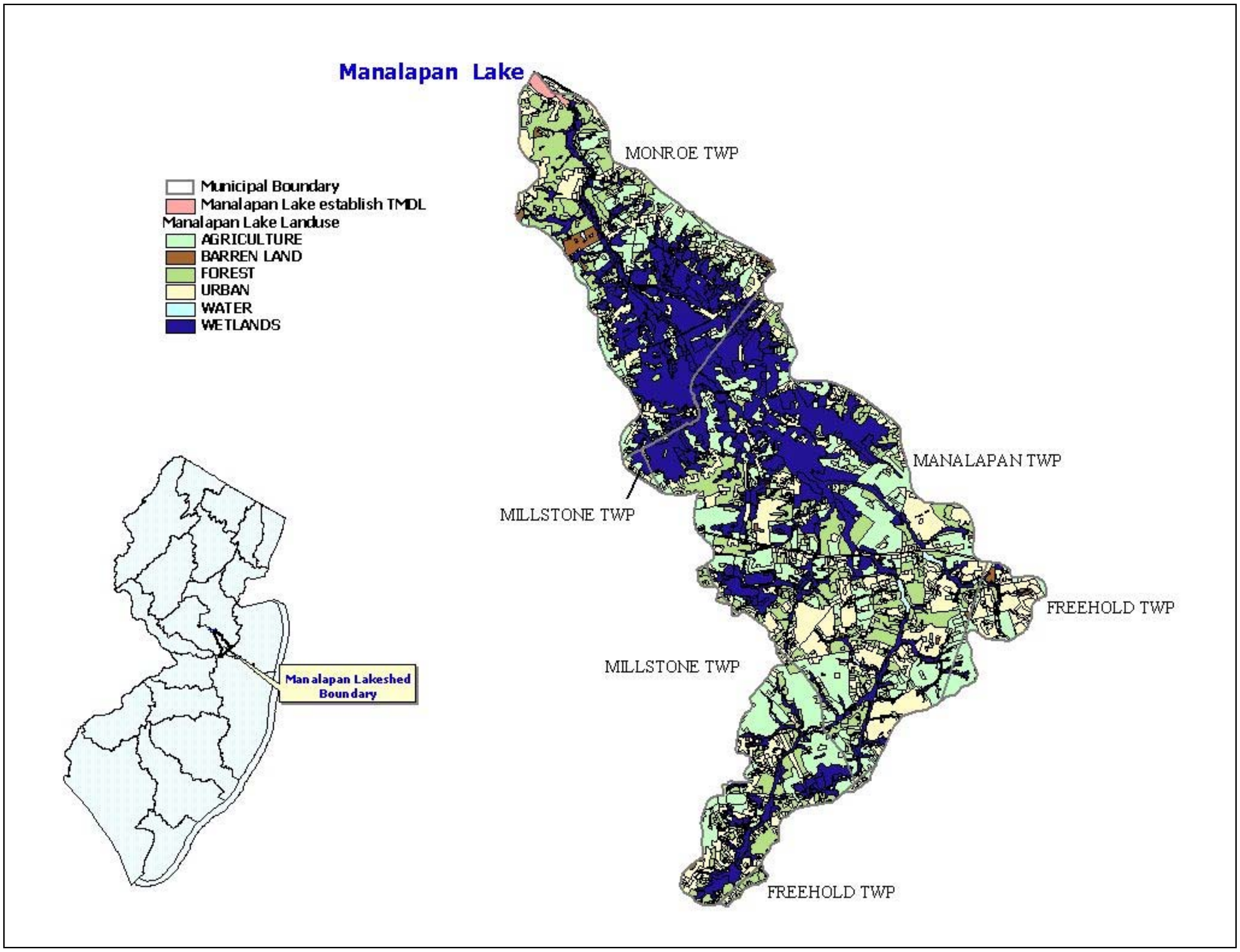


4.4 Manalapan Lake

Manalapan Lake is a 48-acre impoundment of Manalapan Brook located on the boundary of Monroe Township and Jamesburg Boro, Middlesex County, that drains an extremely large lakeshed of 17,254 acres (362 times the area of the lake) extending into the municipalities of Manalapan, Millstone and Freehold. The lake consists of two well-connected oval basins upstream of the dam along a stretch of Manalapan Brook about seven tenths of a mile long. Inflow into Manalapan Lake is primarily comprised of tributary input from Manalapan Brook and its upstream tributaries. Mean depth (2.23m) and total inflow (14,200,000 m^3/yr) were obtained from the Lakes Classification Study for Manalapan Lake (NJDEP, 1983d). The 1.68m depth reported in the Lakes Classification Study was increased to account for the dredging that subsequently occurred.

Between August, 1997 and January, 1998 Manalapan lake was drained and approximately 138,000 cubic yards of lake bed material was removed. Prior to establishing the water levels, a sediment catch was incorporated into the lake bottom. After completion of the dredging operations, the site was returned to original or improved condition.

Figure 4 Lakeshed of Manalapan Lake



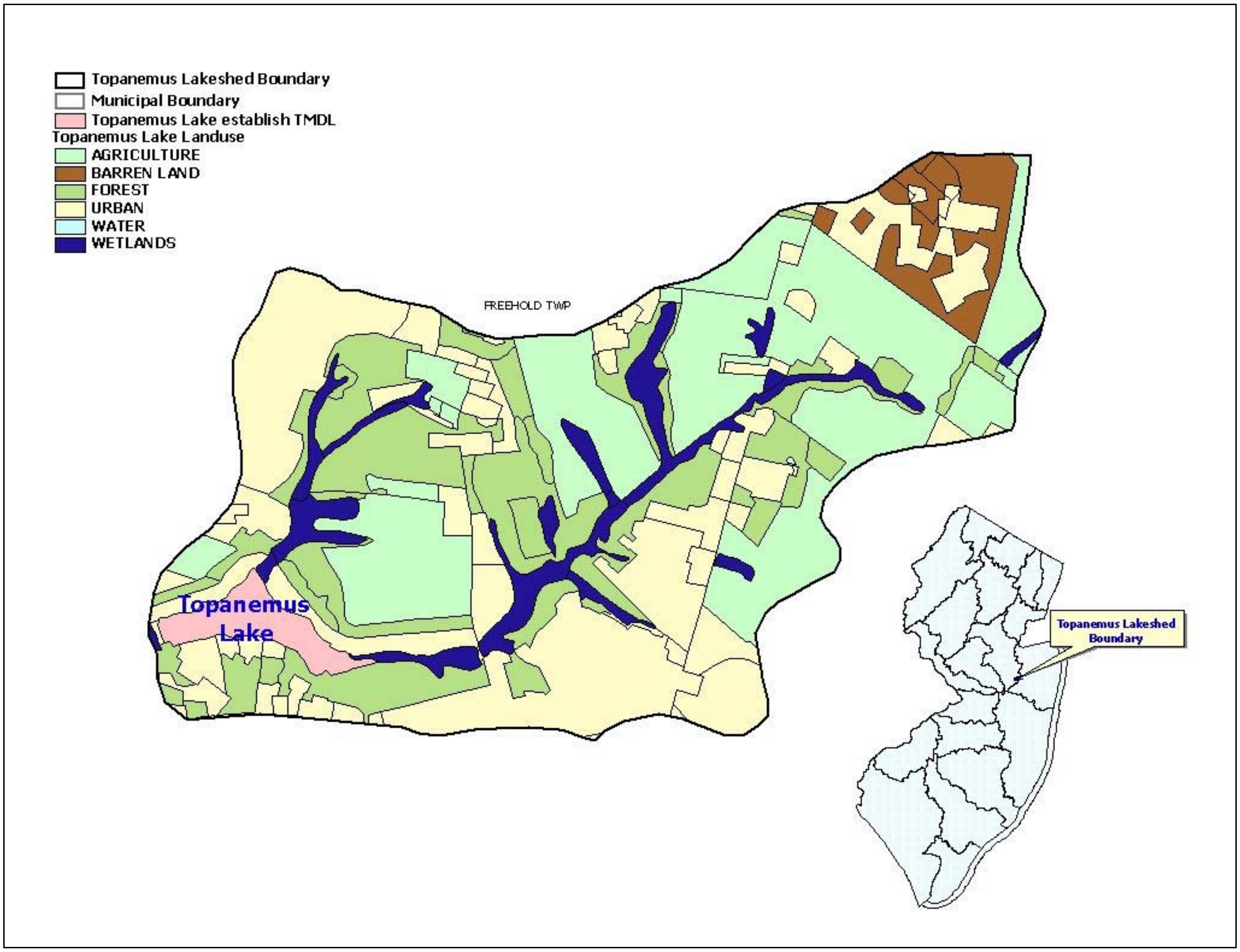
4.5 Topanemus Lake

Topanemus Lake is a 22-acre impoundment of McGellairds Brook located Freehold Township that drains a large lakeshed of 934 acres within Freehold Township, 42.5 times the area of the lake. The lake consists of a widening of the upstream portion of McGellairds Brook at a confluence with one of its tributaries. Inflow into Topanemus Lake is primarily comprised of tributary input from McGellairds Brook and its upstream tributaries. Mean depth (1.83m) and total inflow (2,320,000 m^3/yr) were obtained from the Lakes Classification Study for Topanemus Lake (NJDEP, 1983e).

In March, 1996, the Lake Topanemus Watershed Management Study was completed. The report concluded that Lake Topanemus was undergoing eutrophication and the process must be reversed to protect and restore the lake and its watershed system to insure that Lake Topanemus Park be preserved as a public asset. As a result the Lake Topanemus Watershed Management Action Plan was developed and approved. The Freehold Township Committee changed the Master Plan to create the Lake Topanemus watershed zone, similar to the

Pinelands, which governs the use of the surrounding land. This should act as a tool to help in the reduction of eutrophication in this lake and assist in meeting the TMDL goals.

Figure 5 Lakeshed of Topanemus Lake



4.6 Weequahic Lake

Weequahic Lake is a 69– acre lake located in the City of Newark, Essex County New Jersey. Two brooks and several springs feed into Weequahic Lake. The Lake is also an integral part of the storm sewer system for the City of Newark, Hillside, Elizabeth, NJDOT and Weequahic Park.

In 1996, the Weequahic Park Association (WPA) received a grant from EPA to improve the water quality of the lake. Four areas of environmental improvement were identified: Shoreline stabilization; Stormwater management programs; Lake management programs; and implementation of Soil stabilization/filtrations methods.

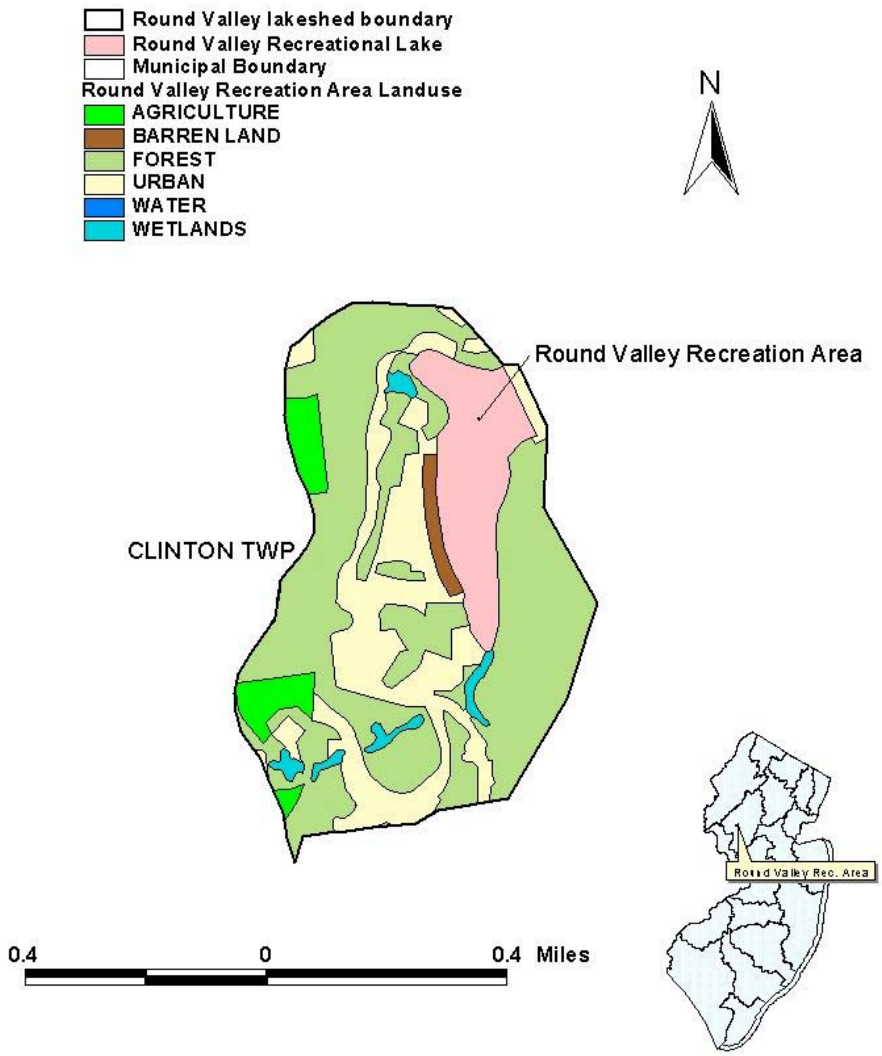
The first phase of the lake restoration began in 1999 with a $3 million grant from the USEPA. The restoration included a 2.2 mile resilient surface path, shoreline restoration, monitoring and data gathering to determine and assess the origins and impacts that the surrounding land uses and storm sewer infrastructure have on the lakes water quality. The first phase has addressed the problems associated with approximately one third of the shoreline and adjoining slopes. Additional funding is currently being sought to continue this work.

The Department will follow up on the restoration of Weequahic Lake with monitoring through the Lakes Monitoring Network (section 9.0).

4.7 Round Valley Recreation Area

Round Valley Recreational Area is a 31-acre cove adjacent to Round Valley Reservoir in Round Valley State Park that drains a lakeshed of 240 acres within Clinton Township, Hunterdon County. The lakeshed is 7.7 times the area of the lake, making it moderately sized. The lake was listed as impaired due to eutrophication based on extremely limited data collected by the Department in 1991 as part of its Lake Water Quality Assessment efforts. While Total Phosphorus levels were only 0.02 mg/l, the lake was listed based on a qualitative assessment that indicated macrophytes and algae were too dense. Inflow into Round Valley Recreational Area is primarily comprised of surface runoff and groundwater. Mean depth (4.0 m), total inflow (570,000 m^3/yr) and groundwater inflow (260,000 m^3/yr) were obtained from the Diagnostic / Feasibility Study for Round Valley Recreational Area (Princeton Hydro, 2002).

Figure 4 **Lakeshed of Round Valley Recreational Area**



4.7 Weamaconk Lake

Weamaconk Lake is a small 4 acre, public, man-made lake located in the Borough of Englishtown, Monmouth County. The Weamaconk Creek, Wemrock Brook, and Middle Brook are the feeder streams to the lake. The entire drainage of Weamaconk Lake's watershed is approximately 6.79 square miles. There is no direct discharge of storm water into the lake from sewers. All non-point source pollutants and sediments originate from the Weamaconk Creek watershed. Land use in this area is described as urban, suburban, rural, agricultural, and parkland. The agricultural land use is field crops, livestock, ornamentals, and fruits.

The Weamconk Lake is in a eutrophic state. It is described as being silt-laden, fairly heavily vegetated and shallow. This eutrophic condition limits the environmental value of the lake by reducing its storage capacity, increasing turbidity and temperature, decreasing dissolved oxygen content and decreasing light penetration. Eutrophication has diminished the lake's recreational uses. Examples of this condition include a reduction in number of people fishing at the lake and a reduction in the available areas to fish.

Information gained through the Lakes Monitoring Network (Section 9.0) will be used to further assess the lake impairment and to gather data to develop a TMDL if necessary.

4.8 Etra Lake

Etra Lake is an 20-acre lake located in East Windsor Township, Mercer County. Etra Lake is used in conjunction with Etra Lake Park for recreation and education, including boating, fishing, aesthetics and observation of aquatic life.

The Phase I diagnostic –feasibility study conducted from 1981 to 1983, made several conclusions and observations. The study identified that Etra Lake was in an advanced stage of eutrophication. Siltation and aquatic weed growth had severely impaired the lake's recreational uses. The lake was experiencing severe oxygen depletion problems throughout the summer. The study claimed that nonpoint sources (stormwater runoff, groundwater inflow, septic system influent, and channel erosion), accounted for 100% of the pollutants entering the lake. The study recommended dredging the lake from a mean depth of 3.6 feet to 6 feet.

The Phase II Etra Lake Restoration Project to dredge Etra Lake began in 1985 and was funded by USEPA, NJDEP, Mercer County and East Windsor Township. The Lake was dredged from December 1985 until June 1986. Approximately 76,000 cubic yards of sediment were removed at a cost of $650,917. The Phase II Project improved the general aesthetics of Etra Lake.

The Department will follow up on the restoration of Etra Lake with monitoring through the Lakes Monitoring Network (section 9.0).

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 any of these lakes.

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."

Finally N.J.A.C. 7:9B-1.5(c) states:

> "The natural water quality shall be used in place of the promulgated water quality criteria of N.J.A.C. 7:9B-1.14 for all water quality characteristics that do not meet the promulgated water quality criteria as a result of natural causes."

These TMDLs are designed to meet both numeric and narrative criteria of the SWQS.

All of the waterbodies covered under these TMDLs 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

Phosphorus sources 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

Point sources of phosphorus other than stormwater were identified using the Department's GIS as all Major Municipal (MMJ), Minor Municipal (MMI), and Combined Sewer Overflow (CSO) discharges within each lakeshed. Other types of discharges, such as Industrial, were not included because their contribution, if any, is negligible compared to municipal discharges and runoff from land surfaces. No municipal point sources exist anywhere within the lakesheds of any of the lakes for which TMDLs are being established. Therefore, point source contributions other than stormwater were assumed to be zero for the purposes of TMDL calculations for all five lakes.

6.2 Assessment of Nonpoint Sources and Stormwater

Runoff from land surfaces comprises most of the nonpoint and stormwater sources of phosphorus into lakes. Watershed loads for total phosphorus were therefore estimated using the Unit Areal Load (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). Land use was determined using the Department's GIS system using the 1995/1997 land use coverage. The Department reviewed phosphorus export coefficients from an extensive database (Appendix B) and selected the land use categories and values shown in Table 3.

Table 4 Phosphorus export coefficients (Unit Areal Loads)

land use / land cover	LU/LC codes[3]	UAL (kg TP/ha/yr)
medium / high density residential	1110, 1120, 1150	1.6
low density / rural residential	1130, 1140	0.7
Commercial	1200	2.0
Industrial	1300, 1500	1.7
mixed urban / other urban	other urban codes	1.0
Agricultural	2000	1.5
forest, wetland, water	4000, 6000, 5000	0.1
barren land	7000	0.5

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

For all lakes in this TMDL document, 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). For Devoe Lake, land use runoff loads were only calculated for the immediate watershed downstream of Manalapan Lake. An additional annual tributary load from Manalapan Lake into Devoe Lake was estimated by multiplying the annual discharge from the lake by the mean phosphorus concentration as calculated under Current Condition in section 7.1 below. Land uses and calculated loading rates for the lakes are shown in Table 4.

Table 5 Nonpoint and Stormwater Sources of Phosphorus Loads*

	Echo Lakes		Davidson's Mill Lake		Devoe Lake		Manalapan Lake		Round Valley Recreational A	
Nonpoint Source	acres	Kg TP/yr	acres	Kg TP/yr	acres	Kg TP/yr	acres	Kg TP/yr	acres	Kg T
medium / high density residential	1,110	721	329	213	1,075	696	216	140	0	
low density / rural residential	390	110	567	161	806	228	2,420	685	1.400	
commercial	92.5	74.8	115	92.8	200	162	124	101	0	
industrial	45.6	31.4	573	394	45.1	31.0	50.9	35.0	0	
mixed urban / other urban	177	71.8	1,360	549	930	376	1,090	442	55.1	
agricultural	0.0	0.0	1,850	1,125	1,100	665	5,080	3,080	11.6	
forest, wetland, water	446	18.1	4,430	179	4,050	164	7,950	322	137	
barren land	0.0	0.0	347	70.1	434	87.8	276	55.8	3.4	
internal	n/a		n/a		n/a		n/a		n/a	
Direct air deposition on lake surface	17.8	0.5	26.1	0.7	35.1	1.0	47.7	1.3	31.0	
groundwater	n/a		n/a		n/a		n/a		n/a	
tributary load	n/a		n/a			3,590	n/a		n/a	
TOTAL	**2,280**	**1,030**	**9,600**	**2,790**	**8,670**	**6,000**	**17,300**	**4,870**	**240**	

* all figures rounded to not more than three significant digits

[3] LU/LC code is an attribute of the land use coverage that provides the Anderson classification code for the land use. The Anderson classification system is a hierarchical system based on four digits. The four digits represent one to four levels of classification, the first digit being the most general and the fourth digit being the most specific description.

7.0 Water Quality Analysis

Empirical models were used to relate annual phosphorus load and steady-state in-lake concentration of total phosphorus. 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. The Department surveyed the commonly used models in Table 5.

Table 1 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
Walker, 1977	$\frac{P_a \times {DT}/{D_m}}{(1 + 0.824 \times DT^{0.454})}$	none	oxic lakes with ${D_m}/{DT} < 50$ m/yr
Jones and Bachmann, 1976	$\frac{0.84 \times P_a}{(D_m \times (0.65 + DT^{-1}))}$	none	may overestimate P in shallow lakes with high ${D_m}/{DT}$
Vollenweider, 1975	$\frac{P_a}{(D_m \times (DT^{-1} + S))}$	$S = {10}/{D_m}$	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

reference	steady-state TP concentration in lake (mg/l)	Secondary term	Application
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 ($g/m^2/yr$)
DT = detention time (yr)
D_m = mean depth (m)
Q_a = areal water load (m/yr)
Q_i = total inflow (m^3/yr)
A_l = area of lake (m^2)
S = settling rate (per year)

Reckhow (1979a) model was selected because the hydrologic, morphological and loading characteristics of these lakes fit best within the assumptions of the model and because it appeared to give the best predictive results for phosphorus concentration. 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, which exhibit the following ranges of characteristics (see Symbol definitions after Table 5):

phosphorus concentration: $0.004 < P < 0.135$ mg/l
average influent phosphorus concentration: $P_a * DT / D_m < 0.298$ mg/l
areal water load: $0.75 < Q_a < 187$ m/yr
areal phosphorus load: $0.07 < P_a < 31.4$ $g/m^2/yr$

For comparison, Table 6 below summarizes the characteristics for each lake based on their current and target conditions as described below. The current phosphorus concentration is not provided, since it represents the result of loadings, morphology and hydrology, not an intrinsic lake property. While the target concentration for each lake (section 7) is well within the range, the areal phosphorus load provides a better representation of a lake's intrinsic loading characteristics. Also, it is the model's prediction of target condition that is being used to calculate the TMDL; if current loads are higher than the range that can produce reliable model results, this has no affect on the model's reliability to predict target condition under reduced loads. It should also be noted that no attempt was made to recalibrate the Reckhow (1979a) model for lakes in New Jersey or in this Water Region, since sufficient lake data were not available to make comparisons with model predictions of steady-state in-lake concentration of total phosphorus. The model was already calibrated to the dataset on which it is based, and is generally applicable to north temperate lakes that exhibit the range of characteristics listed previously.

Table 6 Hydrologic and loading characteristics of lakes

Lake	Current Avg Influent [TP] (mg/l)	Target Avg Influent [TP] (mg/l)	Current Areal TP load (g/m²/yr)	Target Areal TP load (g/m²/yr)	Areal Water Load (m/year)
Echo Lakes	0.436	0.039	14.26	1.28	32.7
Davidson's Mill Lake	0.153	0.025	26.39	4.35	173
Devoe Lake	0.112	0.024	42.26	9.23	378
Manalapan Lake	0.342	0.049	25.23	3.62	73.8
Round Valley Rec Area	0.123	0.075	0.56	0.34	4.5
Topanemus Lake	0.144	0.033	3.75	0.85	26.1

7.1 Current Condition

Using these estimated physical parameters and external loads, the predicted steady-state phosphorus concentration of each lake was calculated using the Reckhow (1979a) formulation and listed in Table 7. The current phosphorus load distribution for each lake is shown in Figures 7 to 11 below.

Figure 6 Current distribution of phosphorus load for Echo Lakes

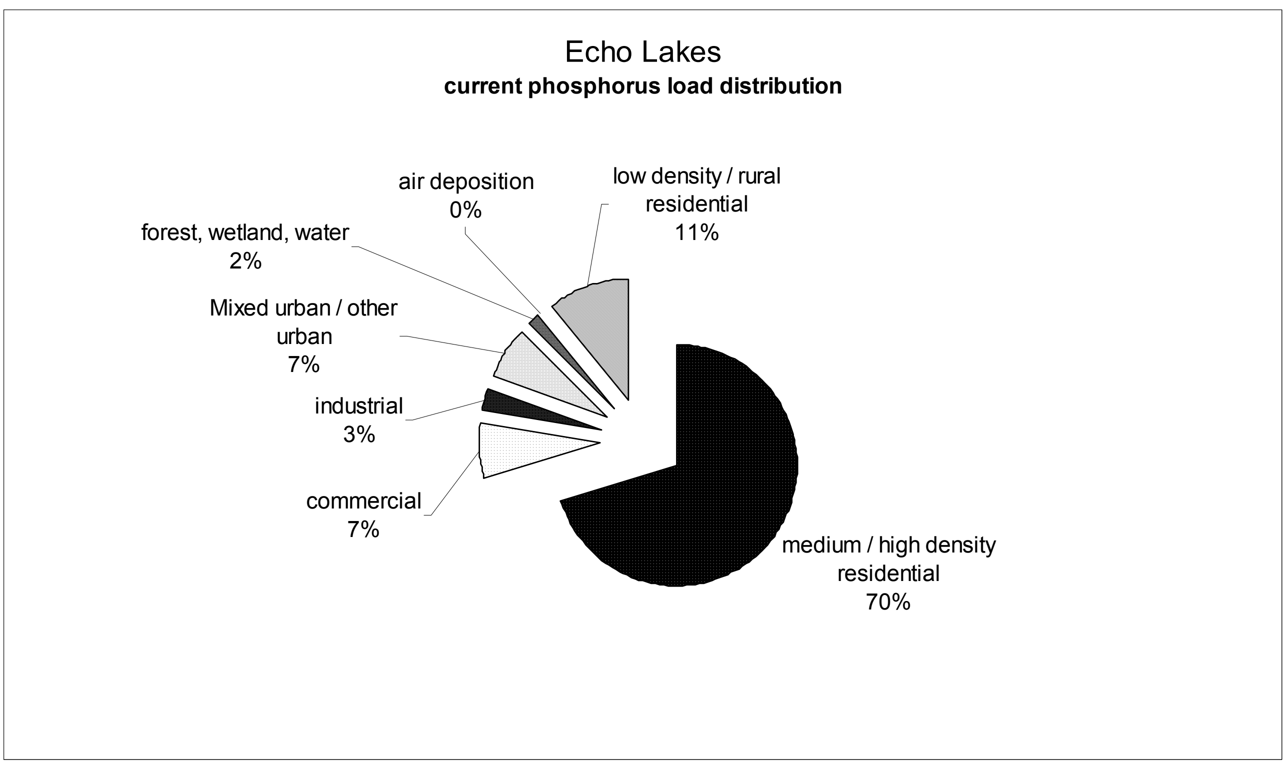


Figure 7 Current distribution of phosphorus load for Davidson's Mill Lake

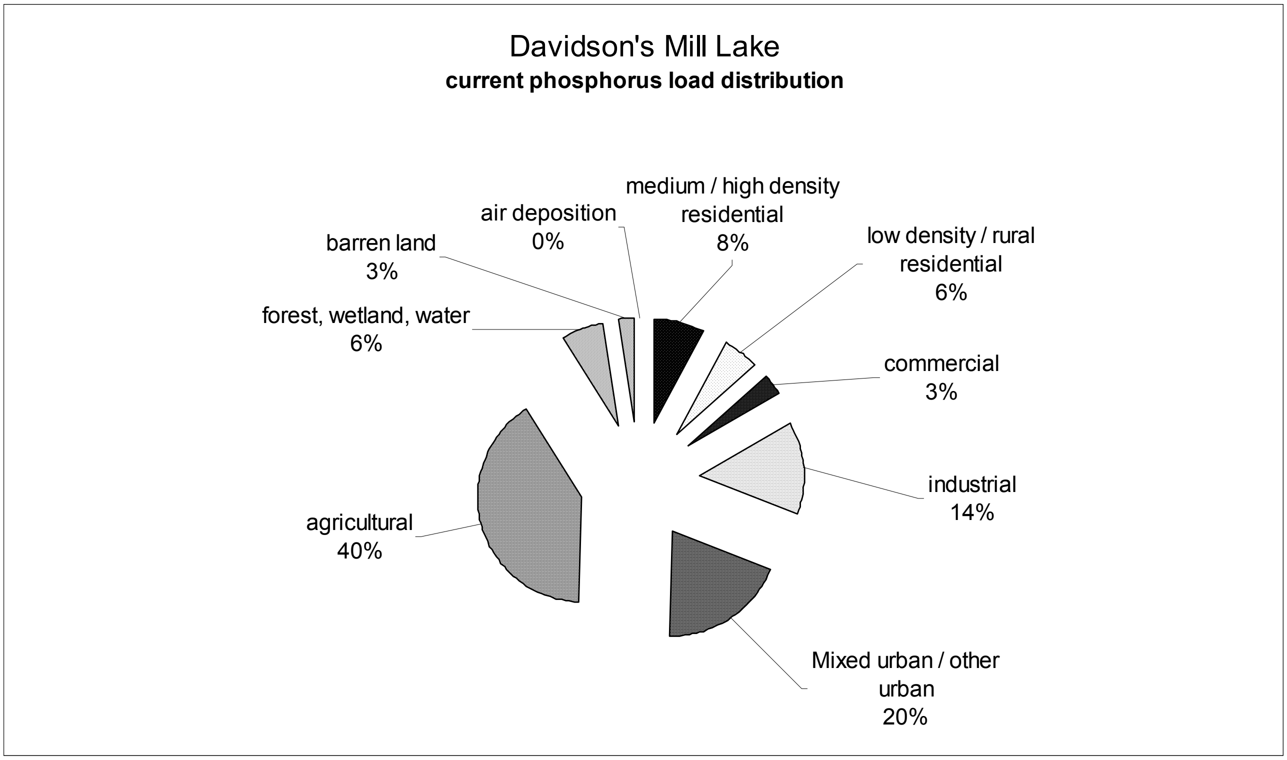


Figure 8 Current distribution of phosphorus load for Devoe Lake

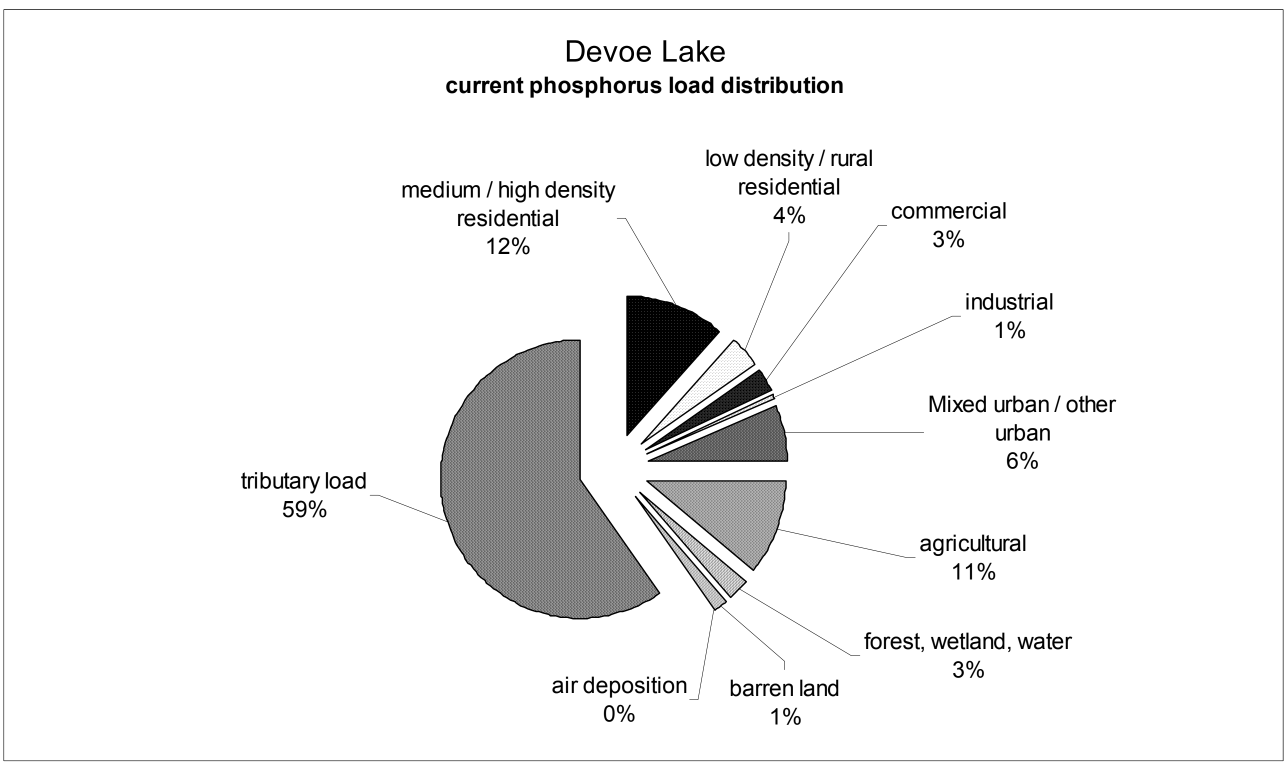


Figure 9Current distribution of phosphorus load for Manalapan Lake

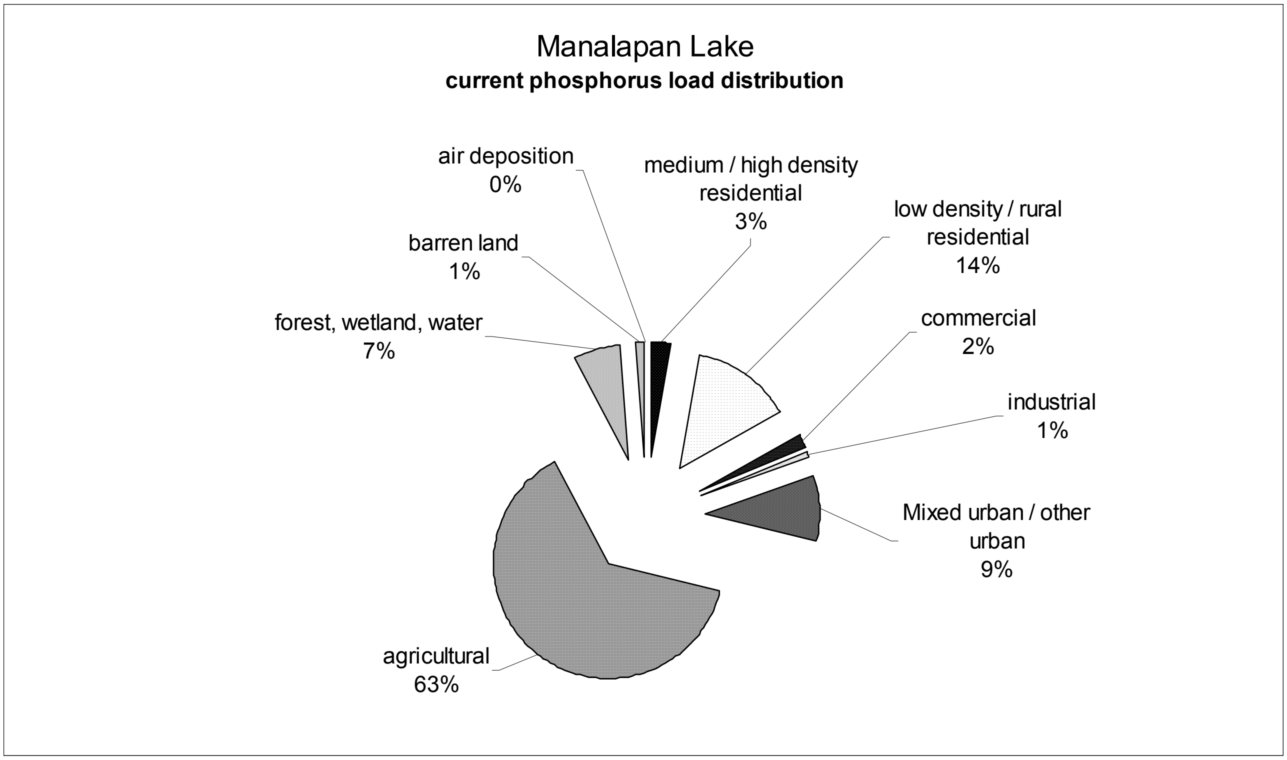


Figure 11 Current distribution of phosphorus load for Round Valley Recreational Area

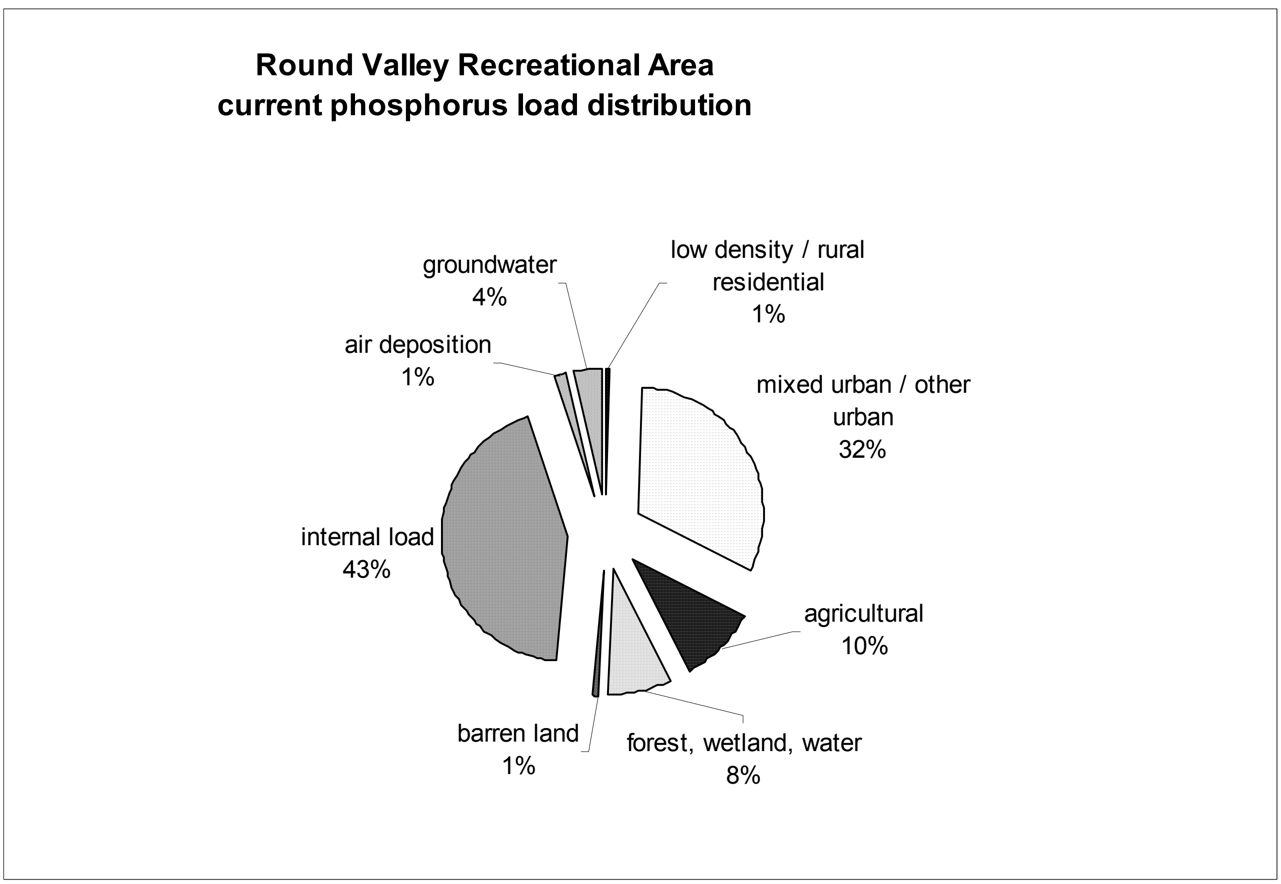
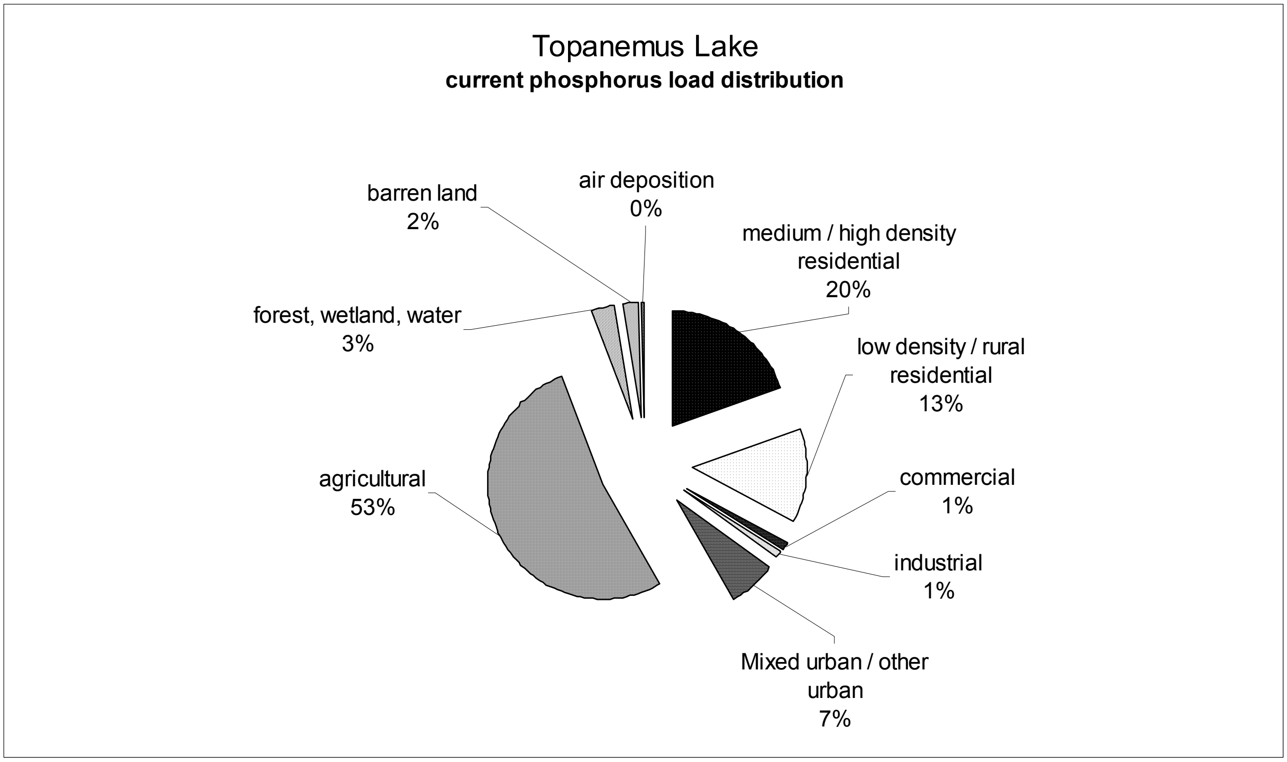


Figure 10 **Current distribution of phosphorus load for Topanemus Lake**



7.2 Reference Condition

A reference condition for each lake was estimated by calculating external loads as if the land use throughout the lakeshed were completely forest and wetlands. Using the same physical parameters and external loads from forest and wetlands, a reference steady-state phosphorus concentration was calculated for each lake using the Reckhow (1979a) formulation and listed in Table 7.

7.3 Seasonal Variation/Critical Conditions

Data from two lakes in New Jersey for which the Department had ready access to data (Strawbridge Lake, NJDEP 2000a; Sylvan Lake, NJDEP 2000b) exhibit peak (based on the 90th percentile) to mean ratios of 1.56 and 1.48, resulting in target phosphorus concentrations of 0.032 and 0.034 mg TP/l, respectively. Since the peak to mean ratios were close and the target concentration not very sensitive to differences in peak to mean ratios, the Department determined that a target phosphorus concentration of 0.03 mg TP/l is reasonably conservative. The seasonal variation was therefore assumed to be 67%, resulting in a target phosphorus concentration of 0.03 mg TP/l. 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 these TMDL calculations, an implicit as well as explicit Margin of Safety (MOS) is provided.

These TMDLs contain an implicit margin of safety by using conservative critical conditions, over-estimated loads, and total phosphorus. Each conservative assumption is further explained below.

Critical conditions are accounted 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 to the conservative approach used for critical conditions, the land use export methodology does not account for the distance between the land use and the lake, which will result in phosphorus reduction due to adsorption onto land surfaces and in-stream kinetic processes**.** Furthermore, the lakesheds are based on topography without accounting for the diversion of stormwater from lakes, which is common in urban areas. Neither are any reductions assumed due to the addition of lakeside vegetative buffer construction or other management practices aimed at minimizing phosphorus loads. Finally, 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 multiple conservative assumptions built in to the calculation, an additional explicit margin of safety 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):

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

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 margin of safety 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 margin of safety 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 Margin of Safety is equal to 51% when expressed as a percentage over the predicted phosphorus concentration; when expressed as a percentage of total loading capacity, the Margin of Safety is equal to 34%:

$$\left(MoS_{lc} = \frac{MoS_p \times P}{P + \left(MoS_p \times P\right)} = \frac{MoS_p}{1 + MoS_p} = \frac{0.51}{1.51} = 0.34 \right),$$

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, the current steady state concentration of phosphorus in each lake must be reduced to a steady state concentration of 0.03 mg/l to avoid exceeding the 0.05 mg/l phosphorus criterion. Using the Reckhow (1979a) formulation, the target conditions were calculated by reducing the loads as necessary to make the upper bound predictions (which incorporate the Margin of Safety) equal to the target phosphorus concentration of 0.03 mg TP/l. The target condition for each lake was adjusted as necessary (as in the cases of Echo Lakes and Manalapan Lake) to prevent it from being lower than the reference condition. The target condition for Manalapan Lake was used to calculate the tributary load for the target condition of Devoe Lake. Overall reductions necessary to attain the target steady state concentration of total phosphorus in each lake were calculated by comparing the current condition to the target condition (Table 7).

Table 7 Current condition, reference condition, target condition and overall percent reduction for each lake

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
Echo Lakes	0.281	0.025	0.038	0.025	91%
Davidson's Mill Lake	0.120	0.017	0.030	0.020	84%
Devoe Lake	0.091	0.005	0.030	0.020	78%
Manalapan Lake	0.252	0.036	0.055	0.036	86%
Round Valley Rec Area	0.033	0.006	0.030	0.020	39%
Topanemus Lake	0.087	0.010	0.030	0.020	77%

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 (which incorporates the Margin of Safety) or the reference condition, whichever is higher. Reducing the current loading rates by the percentages in Table 7 yields the same results. The acceptable loading capacity for each 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. Reserve capacities are not included at this time. Therefore, the loading capacities and accompanying WLAs and LAs must be attained in consideration of any new sources that may accompany future development. The primary means by which future growth could increase phosphorus load is through the development of forest land within the lakesheds. The implementation plan includes the development of Lake Restoration Plans that require the collection of more detailed information about each lakeshed. If the development of forest with the watershed of a particular lake is planned, the issue of reserve capacity to account for the additional runoff load of phosphorus may be revisited.

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 all nonpoint sources and stormwater sources that are not subject to NJPDES regulation. 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 described previously. 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 them. 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. WLAs are hereby established for all NJPDES-regulated point sources, including stormwater, according to their source category. Quantifying WLAs and LAs according to source categories provides the best estimation defined as narrowly as data allow. However it is clearly noted that 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 nonpoint sources. The WLAs and LAs in Table 8 are not themselves "Additional Measures" under proposed N.J.A.C. 7:14A-25.6 or 25.8.

Table 2 **Distribution of WLAs and LAs among source categories**

Source category	TMDL allocation
Point Sources other than Stormwater	WLA
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
tributary load	LA

In order to attain the TMDLs, the overall load reductions shown in Table 7 must be achieved. Since loading rates have been defined for at least eight source categories, countless combinations of source reductions could be used to achieve the overall reduction target. The selected scenarios focus on land use sources that can be affected by BMP implementation or NPDES regulation, requiring equal percent reductions from each in order to achieve the necessary overall load reduction (Table 9). The Lake Restoration Plans developed for each lake as part of the TMDL implementation (section 10) may revisit the distribution of reductions among the various sources in order to better reflect actual implementation projects. The resulting TMDLs, rounded to two significant digits, are shown in Table 9 and illustrated in Figures 12 to 16.

Table 9 TMDL calculations for each lake (annual loads and percent reductions[a])

lake	Echo Lakes		%	Davidson's Mill		%	Dev
	kg TP/yr	% of LC	reduction	kg TP/yr	% of LC	reduction	kg TP/y
loading capacity (LC)	140	100%	n/a	690	100%	n/a	200
Point Sources other than Stormwater	n/a			n/a			
Nonpoint and Stormwater Sources							
medium / high density residential	53	38%	93%	18	2.5%	92%	18
low density / rural residential	8.1	5.8%	93%	13	1.9%	92%	5
commercial	5.5	3.9%	93%	7.7	1.1%	92%	4
industrial	2.3	1.6%	93%	33	4.7%	92%	7.
Mixed urban / other urban	5.2	3.8%	93%	45	6.5%	92%	9
agricultural	0.0	0.0%	n/a	93	13%	92%	17
forest, wetland, water	18	13%	0%	180	26%	0%	16
barren land	0.0	0.0%	n/a	70	10%	0%	8
air deposition onto lake surface	0.5	0.4%	0%	0.7	0.1%	0%	1.
tributary load	n/a			n/a			52
Other Allocations							
explicit Margin of Safety	47	34%		230	34%	n/a	67
Reserve Capacity	n/a			n/a			

a Percent reductions shown for individual sources are necessary to achieve overall

Table 9 (cont'd) TMDL calculations for each lake (annual loads and percent reductions[a])

lake	Manalapan Lake		%	Topanemus Lake		%	Round V Recreat
	kg TP/yr	% of LC	reduction	kg TP/yr	% of LC	reduction	kg TP/y
loading capacity (LC)	1100	100%	n/a	110	100%	n/a	6
Point Sources other than Stormwater	n/a			n/a			
Nonpoint and Stormwater Sources							
medium / high density residential	10	0.9%	93%	12	10%	82%	0.
low density / rural residential	49	4.6%	93%	7.6	6.7%	82%	0.
commercial	7.2	0.7%	93%	0.7	0.7%	82%	0.
industrial	2.5	0.2%	93%	0.7	0.6%	82%	0.
Mixed urban / other urban	31	3.0%	93%	4.0	3.5%	82%	1
agricultural	220	21%	93%	31	27%	82%	3.
forest, wetland, water	320	31%	0%	11	9.4%	0%	5.

barren land	56	5.3%	0%	8.1	7.1%	0%	0.
internal		n/a			n/a		1
air deposition onto lake surface	1.3	0.1%	0%	0.6	0.5%	0%	0.
groundwater		n/a			n/a		2.
tributary load		n/a			n/a		
Other Allocations							
explicit Margin of Safety	360	34%	n/a	39	34%	n/a	2
Reserve Capacity		n/a			n/a		

a Percent reductions shown for individual sources are necessary to achieve overall

Figure 11 **Phosphorus allocations for Echo Lakes TMDL**

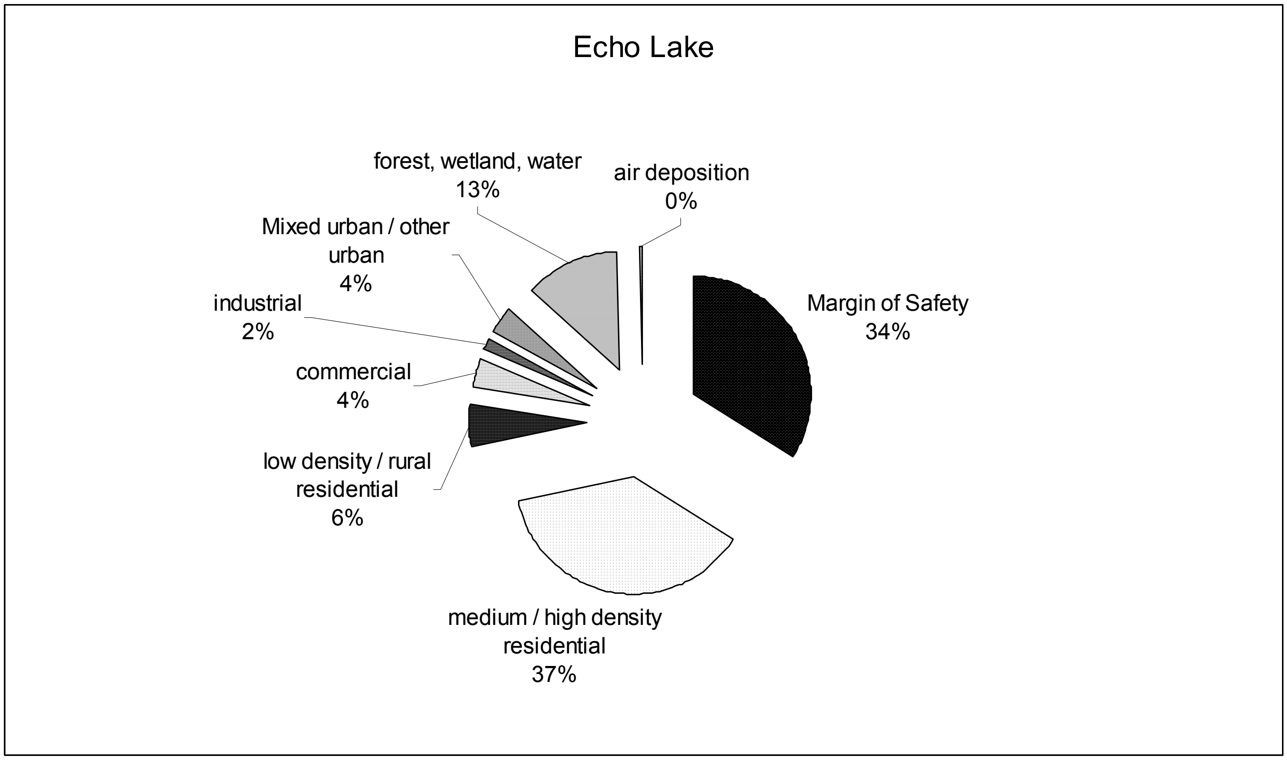


Figure 12 **Phosphorus allocations for Davidson's Mill Lake TMDL**

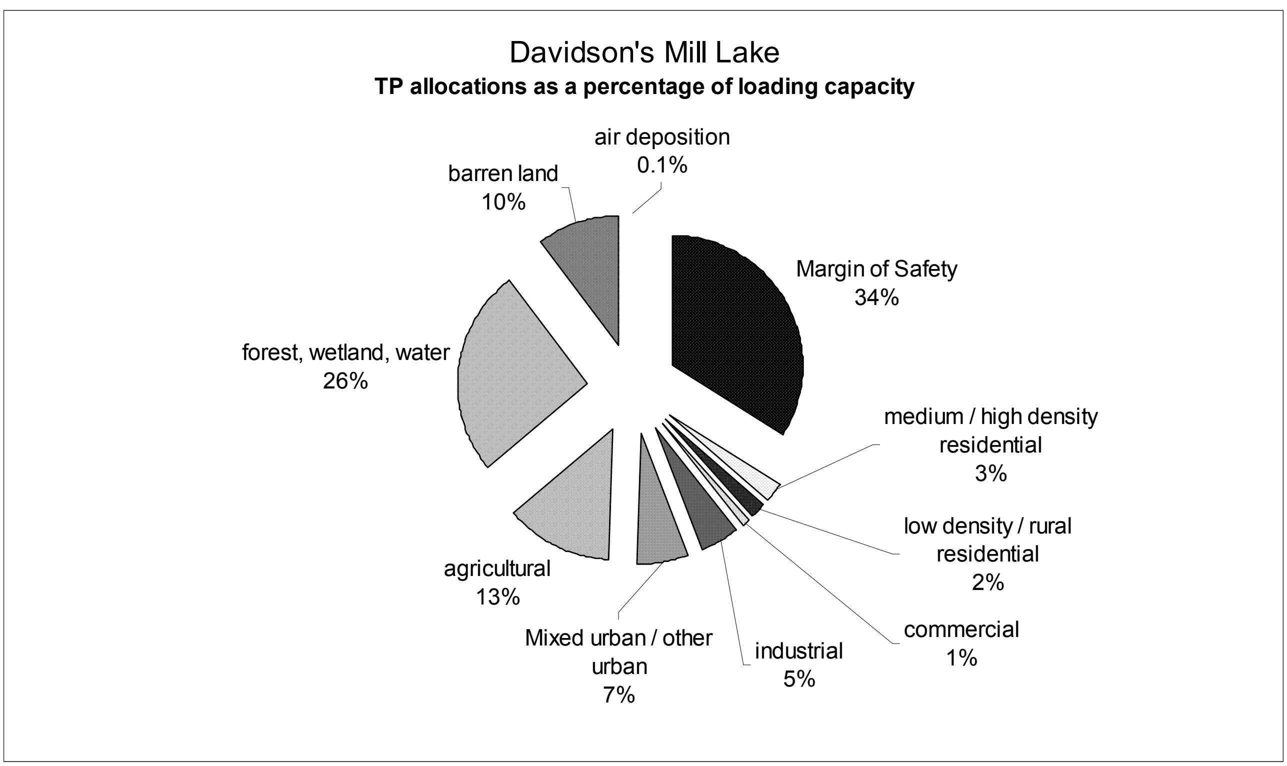


Figure 13 Phosphorus allocations for Devoe Lake TMDL

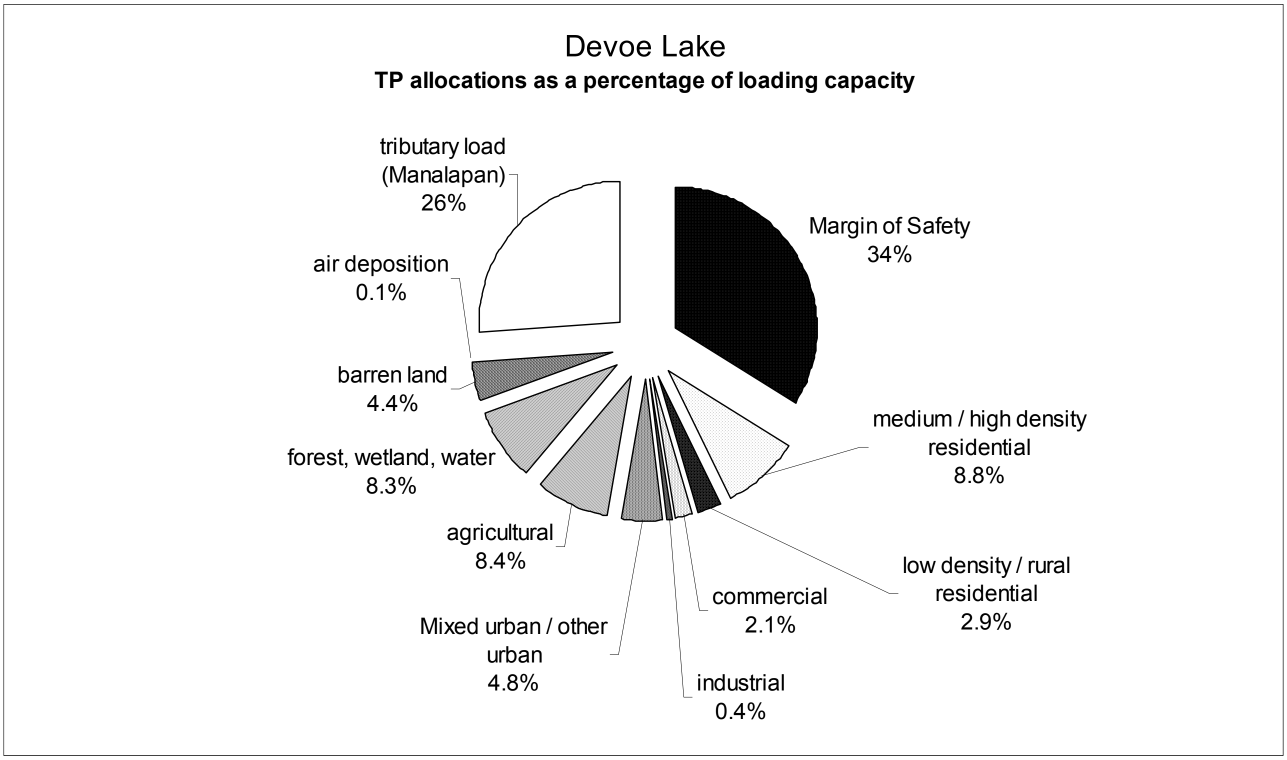


Figure 14 Phosphorus allocations for Manalapan Lake TMDL

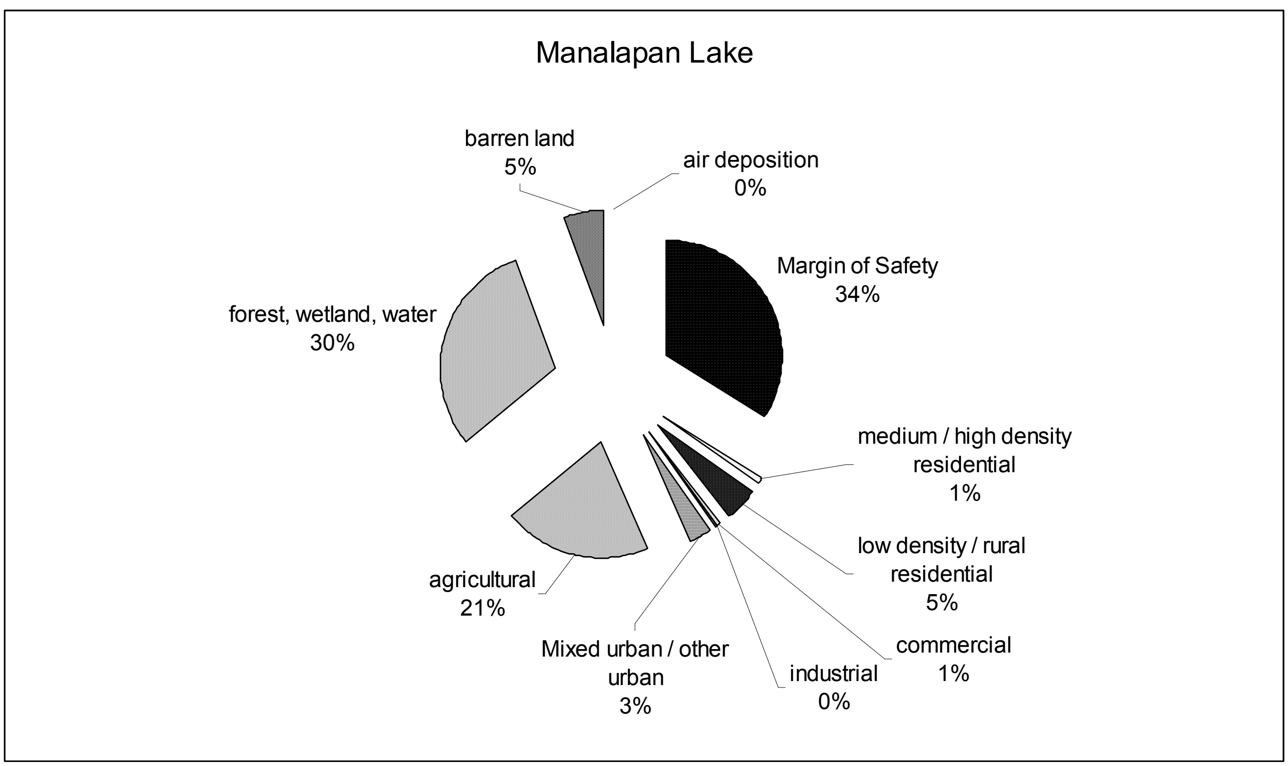


Figure 15 Phosphorus allocations for Topanemus Lake TMDL

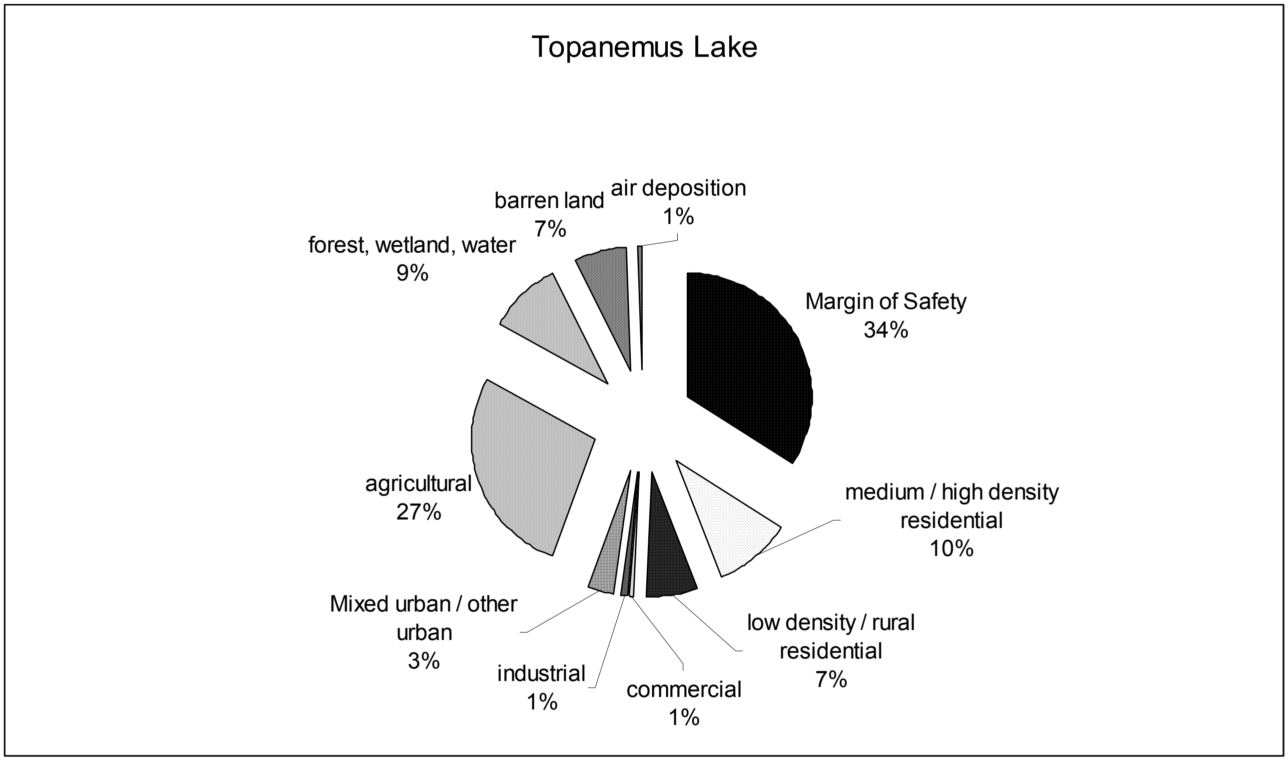
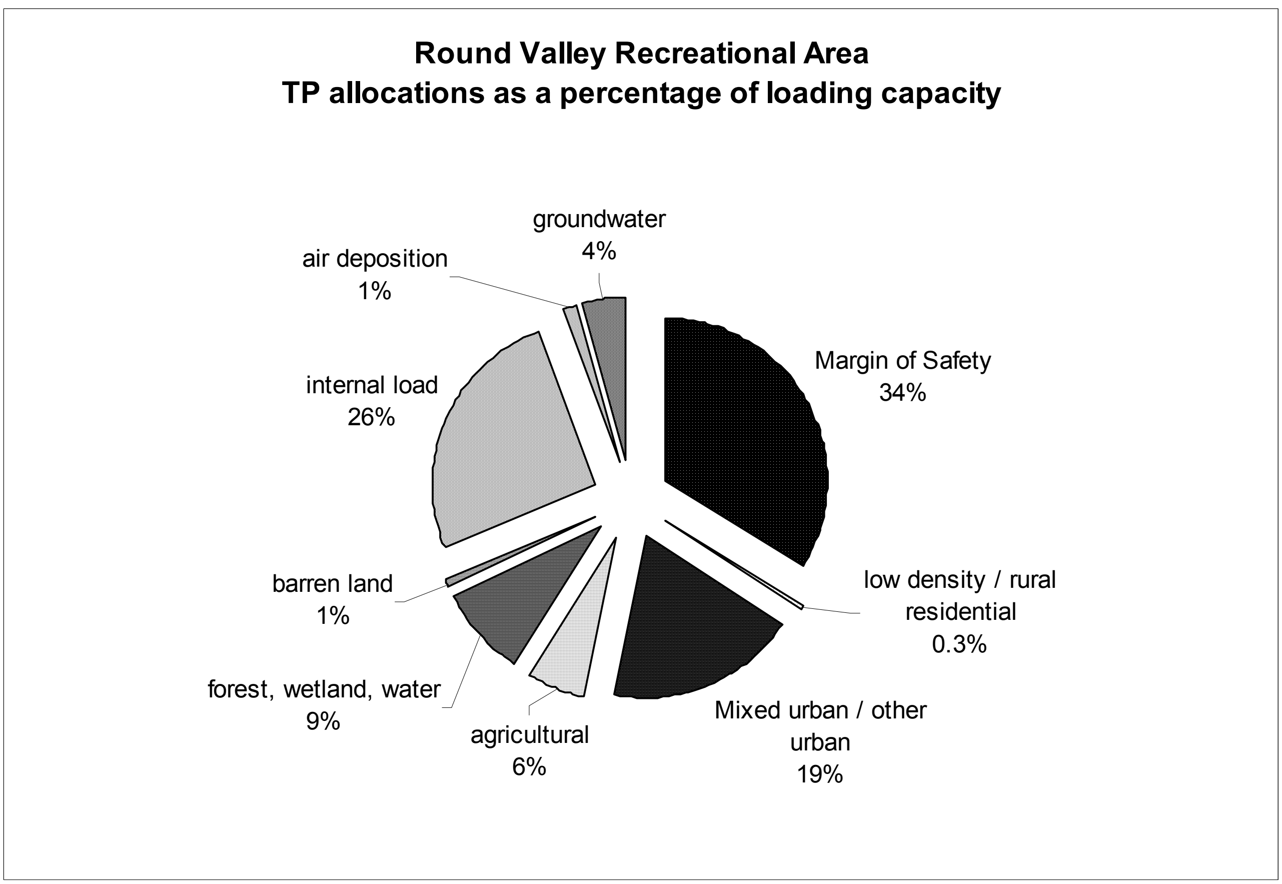


Figure 17 Phosphorus allocations for Round Valley Recreational Area TMDL



9.0 Follow-up Monitoring

In order to track effectiveness of remediation measures (including TMDLs) and to develop baseline and trend information on lakes, the Department will augment its ambient monitoring program to include lakes on a rotating schedule. The details of a new Lakes Monitoring Network will be published by December 31, 2003. Lakes for which remediation measures have been performed will be given top priority on whatever rotating schedule is developed.

Follow-up monitoring will include evaluations (qualitative using a field index or quantitative) of algal blooms (presence, severity, extent) and aquatic vegetation (density, extent, diversity). Measurements such as secchi depths, nutrient concentrations, and chlorophyll-*a* will be included, in addition to dissolved oxygen, temperature and pH profiles. Basic hydrologic and morphometric information will be measured as necessary to obtain current data, including discharge and bathymetry. The details as to what data will be collected by the Lakes Monitoring Network will be included in the network description.

10.0 Implementation

The Department recognizes that TMDLs alone are not 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 and the development of a Lake Restoration Plan for each lake. The plans will consider in-lake measures that need to be taken to supplement the nutrient reduction measures required by the TMDL. In addition, the plans will consider the ecology of the lake and adjust the eutrophication indicator target as necessary to protect the designated uses.

For instance, all five of these lakes are shallow lakes, as defined by having a mean depth less than 3 meters, meaning that most of the lake volume is within the photic zone and therefore more able to support aquatic plant growth (Holdren *et al*, 2001). 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 visa-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. The Lake Restoration Plans for each lake will need to consider the ecological nuances of shallow and deep lakes.

The State of New Jersey has adopted a watershed approach to water quality management. That plan divides the state into five watershed management regions, one of which is the Raritan Region. The Department recognizes that lake restoration requires a watershed approach. Lake Restoration Plans will be used as a basis to address overfertilization and sedimentation issues in watersheds that drain to these sensitive lakes. In addition, the Department will direct research funds to understand and demonstrate biomanipulation and other techniques that can be applied in New Jersey lakes to promote the establishment of healthy and diverse aquatic plant communities in shallow lakes. Finally, outreach education efforts will focus on the benefits of aquatic plants in shallow lakes and the balance of aquatic life uses with recreational uses of these lakes.

The Department has initiated a renewed ambient lake monitoring network designed to provide the water quality data necessary to assess the ecological health of the State's lentic water resource. This program will involve the testing of randomly selected lakes from the state's approximately 1100 named lakes. The water quality measurements conducted at each lake will include parameters such as dissolved oxygen, pH, nutrients, and chlorophyll a. Such testing will assist New Jersey in determining the status and trends in lake water quality, to meet our Clean Water Act requirements and our Total Maximum Daily Load (TMDL)-related water quality assessment needs.

In addition, on February 2, 2004 the Department promulgated two sets of stormwater rules. The first set, N.J.A.C. 7: 8 update the state's Stormwater Management Rules for the first time since their original adoption in 1983. The rules establish new statewide minimum standards for stormwater management. These standards will also become requirements of several state-issued permits such as freshwater wetlands and stream encroachment permits. The second set of adopted stormwater rules are the Phase II New Jersey Pollutant Discharge Elimination System Stormwater Regulation Program Rules N.J.A.C. 7:12A, which require municipalities, large public complexes such as hospitals, and highway systems to develop stormwater management programs consistent with Tier A or B requirements through the New Jersey Pollutant Discharge Elimination System (NJPDES) permit program.

A 300-foot buffer to protect Category One (C1) waterbodies will be required. C1 protection is the highest form of water quality protection in the state, preventing any measurable deterioration in the existing water quality. The rules also apply the buffer to tributaries of C1 waterbodies within the immediate watershed of C1 waterbodies. In total, the buffers will impact 6,093 stream miles – including the 3,307 miles of currently designated C1 rivers and streams and an additional 2,786 miles of non-C1 tributaries to C1 streams.

The Stormwater Management Rules include performance standards for ground water recharge to protect the integrity of the state's aquifers. They establish a standard of maintaining 100 percent of the average annual ground water recharge for new development projects, a major initiative toward mitigating future droughts and flooding.

In addition to recharge standards, the regulations also stress water quality controls, such as best management practices to reduce runoff of total suspended solids (TSS) by 80 percent and other pollutants including nutrients to the maximum extent feasible. The rules require low impact designs for stormwater management systems that maintain natural vegetation and drainage and reduce clear-cutting and the unnecessary loss of trees and minimize impervious surface.

With the combination of New Jersey's strong commitment to the collection and use of high quality data to support environmental decisions and regulatory programs, including TMDLs, the Department is reasonably assured compliance with the total phosphorus criteria applicable to these eutrophic lakes.

10.1 Lake Characterization

Extensive monitoring will be performed in order to develop the Lake Restoration Plans to implement these TMDLs. Basic hydrologic and morphometric information will be measured to obtain current data, including discharge and bathymetry. During at least one or two summer trips, lakes will be assessed as follows.

- for shallow lakes, vegetation mapping using shore to center transects, measuring density and composition (emergents, rooted floaters, submergents, free-floating plants, submerged macro-algae)
- 1-5 mid-lake sampling stations as needed to characterize the lake
  - at least 2 samples per station per day; min 4 samples per trip
  - secchi depths
- chemistry (nutrients, chlorophyll-*a*, etc.)
  - surface, metalimnion, hypolimnion, and bottom if stratified
  - otherwise surface and bottom
- biology (integrated sample from mixed surface layer)
  - algal abundance and composition (greens, diatoms, blue-greens)
  - zooplankton abundance, composition and size ranges
- DO, temperature and pH profiles (hourly throughout day)

Where necessary, flow and water quality measurements of influent and effluent streams will be taken periodically from Spring to Fall, and fish abundance and composition will be assessed in early autumn.

The schedules for lake characterization and development of Lake Restoration Plans to implement these TMDLs are provided in Table 9.

Table 10 Implementation Schedule

Lake	Lake Characterization	Lake Restoration Plan
Echo Lakes[a]	Summer 2004	Spring 2005
Davidson's Mill Lake	Summer 2007	Spring 2008
Devoe Lake	Summer 2006	Spring 2007
Manalapan Lake	Summer 2006	Spring 2007
Round Valley Recreational Area	Completed 2000 and 2001	Completed February 2002
Topanemus Lake	Summer 2005	Spring 2006

a The Diagnostic-Feasibility Study of Upper Echo Lake (F.X. Browne, 2000) provides much of the Lake Characterization information necessary to develop the Lake Restoration Plan. This schedule provides for any additional monitoring, evaluation of nutrient control measures, and development of a more comprehensive restoration plan.

b The Diagnostic / Feasibility Study of Round Valley Recreational Area (Princeton Hydro, 2002) fulfills the TMDL requirements for lake characterization and lake restoration planning.

10.2 Reasonable Assurance

Reasonable assurance for the implementation of these TMDLs has been considered for point and nonpoint sources for which phosphorus load reductions are necessary. These TMDLs obligate the Department to routinely monitor lake water quality as well as characterize and develop specific restoration plan for these particular lakes according to the schedule in Table 10. Moreover, stormwater sources for which WLAs have been established will be regulated as NJPDES point sources.

With the implementation of follow-up monitoring and development of Lake Restoration Plans through watershed management process, the Department is reasonably assured that New Jersey's Surface Water Quality Standards will be attained for these lakes. Activities directed in the watersheds to reduce nutrient loadings shall include a whole host of options, included but not limited to education projects that teach best management practices, approval of projects funded by CWA Section 319 Nonpoint Source (NPS) Grants, recommendations for municipal ordinances regarding feeding of wildlife, and pooper-scooper laws, and stormwater control measures.

11.0 Public Participation

The Water Quality Management Planning Rules NJAC 7:15-7.2 encourages 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. Accordingly the

Department shall propose each TMDL as an amendment to the appropriate area wide water quality management plan. As stated previously, part of the public participation process for the development and implementation of the TMDLs in the RaritanWater Region, The New Jersey Department of Environmental Protection's (Department) Division of Watershed Management – Raritan Bureau worked collaboratively with a series of stakeholder groups throughout New Jersey as part of the Department's ongoing watershed management efforts.

The Department's watershed management process was designed to be a comprehensive stakeholder driven process that is representative of members from each major stakeholder group (agricultural, business and industry, academia, county and municipal officials, commerce and industry, purveyors and dischargers, and environmental groups). Through the creation of this watershed management planning process over the past several years Public Advisory Committees (PACs) and Technical Advisory Committees (TACs) were created in all 20 WMAs. Whereas the PACs serve in an advisory capacity to the Department, and examined and commented on a myriad of issues in the watersheds, the TACs were focused on providing the scientific, ecological, and engineering integrity of the issues relevant to the mission of the PAC.

The Raritan Bureau discussed with the WMA 7, WMA 8, WMA 9 and WMA 10 TAC members the Department's TMDL process through a series of presentations and discussions that lead up the development of the Expedited TMDLs for eutrophic lakes in the Raritan Water Region.

- Integrated Listing Methodology Presentation was made by the Raritan Basin Project's staff to the Raritan TAC on June 5, 2002. Public comments on the Integrated List were to be submitted to the Department by the September deadline.
- Expedited Fecal Coliform and Lake TMDL Presentations were given at two WMA#7 Steering Committee meeting; October 11, 2002 and October 21, 2002. The Raritan Bureau presented the TMDL Video "A Local Official's Guide to TMDLs" which explained TMDLs in practical terms. The Department also provided the public with the finalized Sublist 5 list, a fact sheet titled "TMDLs in the Metropolitan Watershed", and the Memorandum of Agreement between the Department and EPA Region 2.
- Expedited Fecal Coliform and Lake TMDL Presentations was given at the WMA#10 Millstone Watershed Steering Committee on October 17th, 2002. The Raritan Bureau presented the TMDL Video "A Local Official's Guide to TMDLs" which explained TMDLs in practical terms. The Department also provided the public with the finalized Sublist 5 list, a fact sheet titled "TMDLs in the Millstone Watershed", and the Memorandum of Agreement between the Department and EPA Region 2.
- A Presentation by the Raritan Bureau was given at the November 4, 2002 TAC meeting on the Expedited Fecal Coliform and Lake TMDLs. The TMDL Video "A Local Official's Guide to TMDLs" was presented. The Department also provided the TAC with the finalized Sublist 5 list, a fact sheet titled "TMDLs in the Millstone Watershed", and the Memorandum of Agreement between the Department and EPA Region 2.
- The Raritan Bureau has begun engaging the public in the process by meeting with Environmental Commissions and local Watershed Associations. In September 2002,

the Raritan Bureau met with Environmental Commission Chairman from 2 townships in Hunterdon County to discuss the TMDL process and impaired surface water bodies in their areas. On November 7, the Raritan met with approximately 8 Environmental Commisisions in Union County to discuss the TMDL process and the Phase II Stormwater Regulations.

Additional public participation and input was received through the NJ EcoComplex. The Department contracted with Rutgers NJ EcoComplex (NJEC) in August 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 by the Northeast Bureau at the SETAC Fall Workshop on September 13, 2002.

In accordance with N.J.A.C. 7:15–7.2(g), these TMDLs are hereby proposed by the Department as an amendment to the Northeast Water Quality Management Plan, Lower Raritan-Middlesex Water Quality Management Plan and Monmouth County Water Quality Management Plan. N.J.A.C. 7:15-3.4(g)5 states that when the Department proposes to amend the areawide plan on its own initiative, the Department shall give public notice by publication in a newspaper of general circulation in the planning area, shall send copies of the public notice to the applicable designated planning agency, if any, and may hold a public hearing or request written statements of consent as if the Department were an applicant. The public notice shall also be published in the New Jersey Register.

Notice of these TMDLs was published January 21, 2003 pursuant to the above noted Administrative Code, in order to provide the public an opportunity to review the TMDLs and submit comments. The Department has determined that due to the level of interest in these TMDLs, a public hearing will be held. Public notice of the hearing, provided at least 30 days before the hearing, was published in the New Jersey Register and in two newspapers of general circulation and will be mailed to the applicable designated planning agency, if any, and to each party, if any, who was requested to issue written statement of consents for the amendment.

All comments received during the public notice period and at any public hearings will become part of the record for these TMDLs. All comments will be considered in the establishment of these TMDLs and the ultimate adoption of these TMDLs. When the Department takes final agency action to establish these TMDLs, the final decision and supporting documentation will be sent to U.S.E.P.A. Region 2 for review and approval pursuant to 303(d) of the Clean Water Act (33 U.S.C. 1313(d)) and 40 CFR 130.7.

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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 judgement 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):

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

where:
- V = lake volume (10^3 m^3)
- 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:

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

where:
- v_s = effective settling velocity (m/yr)
- A = area of lake (10^3 m^2)
- Q = annual outflow (10^3 m^3/yr).

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

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

where:
- P_a = areal phosphorus loading rate (g/m^2/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:

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