Amendment to the
Atlantic County Water Quality Management Plan
Lower Delaware Water Quality Management Plan
Mercer County Water Quality Management Plan
Monmouth County Water Quality Management Plan
Tri-County Water Quality Management Plan

Total Maximum Daily Loads for Phosphorus To Address 13 Eutrophic Lakes in the Lower Delaware Water Region

BELL LAKE, GLOUCESTER COUNTY
BETHEL LAKE, GLOUCESTER COUNTY
BLACKWOOD LAKE, CAMDEN AND GLOUCESTER COUNTIES
BURNT MILL POND, CUMBERLAND COUNTY
GIAMPIETRO LAKE, CUMBERLAND COUNTY
HARRISONVILLE LAKE, GLOUCESTER AND SALEM COUNTIES
IMLAYSTOWN LAKE, MONMOUTH COUNTY
KIRKWOOD LAKE, CAMDEN COUNTY
MARY ELMER LAKE, CUMBERLAND COUNTY
MEMORIAL LAKE, SALEM COUNTY
SPRING LAKE, MERCER COUNTY
SUNSET LAKE, CUMBERLAND COUNTY
WOODBURY LAKE, GLOUCESTER COUNTY

Watershed Management Area 17
(Maurice, Salem, and Cohansey Watersheds)
Watershed Management Area 18
(Lower Delaware Watershed)
Watershed Management Area 20
(Assiscunk, Crosswicks, and Doctors Watersheds)

Proposed: April 21, 2003
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Approved (by EPA Region 2):
Adopted:

New Jersey Department of Environmental Protection
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1.0 Executive Summary

The State of New Jersey's *2002 Integrated List of Waterbodies* identified several lakes in the Northwest 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	Lake Name	Municipality	WMA	Acres
1	Burnt Mill Pond	Vineland City, Cumberland County	17	22.0
2	Giampietro Lake	Vineland City, Cumberland County	17	14.4
3	Mary Elmer Lake	Hopewell Township, Bridgeton City; Cumberland County	17	22.2
4	Memorial Lake	Woodstown Boro, Salem County	17	21.7
5	Sunset Lake	Hopewell, Upper Deerfield Townships; Bridgeton City; Cumberland County	17	87.0
6	Bell Lake	Woodbury City, Gloucester County	18	18.0
7	Bethel Lake	Mantua, Washington Townships; Gloucester County	18	1.8
8	Blackwood Lake	Washington Township, Gloucester County; Gloucester Township, Camden County	18	9.6
9	Harrisonville Lake	South Harrison Township, Gloucester County; Pilesgrove Township, Salem County	18	6.2
10	Kirkwood Lake	Voorhees Township, Lindenwold Boro; Camden County	18	24.9
11	Woodbury Lake	Woodbury City, Deptford Township; Gloucester County	18	46.8
12	Imlaystown Lake	Upper Freehold Township, Monmouth County	20	15.9
13	Spring Lake	Hamilton Township, Mercer County	20	21.8

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 basins 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 and, depending on the amount of information available, up to 14 source categories. In order to track effectiveness of remediation measures (including TMDLs) and to develop baseline and trend information on lakes, the Department will

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

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 for which TMDLs are being established. These plans will consider what specific measures are necessary to achieve the nutrient reductions required by the TMDL, as well as what in-lake measures need to be taken to supplement the nutrient reductions 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).

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 Lower Delaware Water Region (WMAs 17, 18, 19, and 20) as being eutrophic, as evidenced by elevated total phosphorus (TP), elevated chlorophyll-*a,* and/or macrophyte density that impairs recreational use (a qualitative assessment). This report establishes 13 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 "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 13 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, caused by the deposition of organic matter in an excessively productive system, or it can result from excessive sediment loads from 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 lack 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 supersaturation 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.

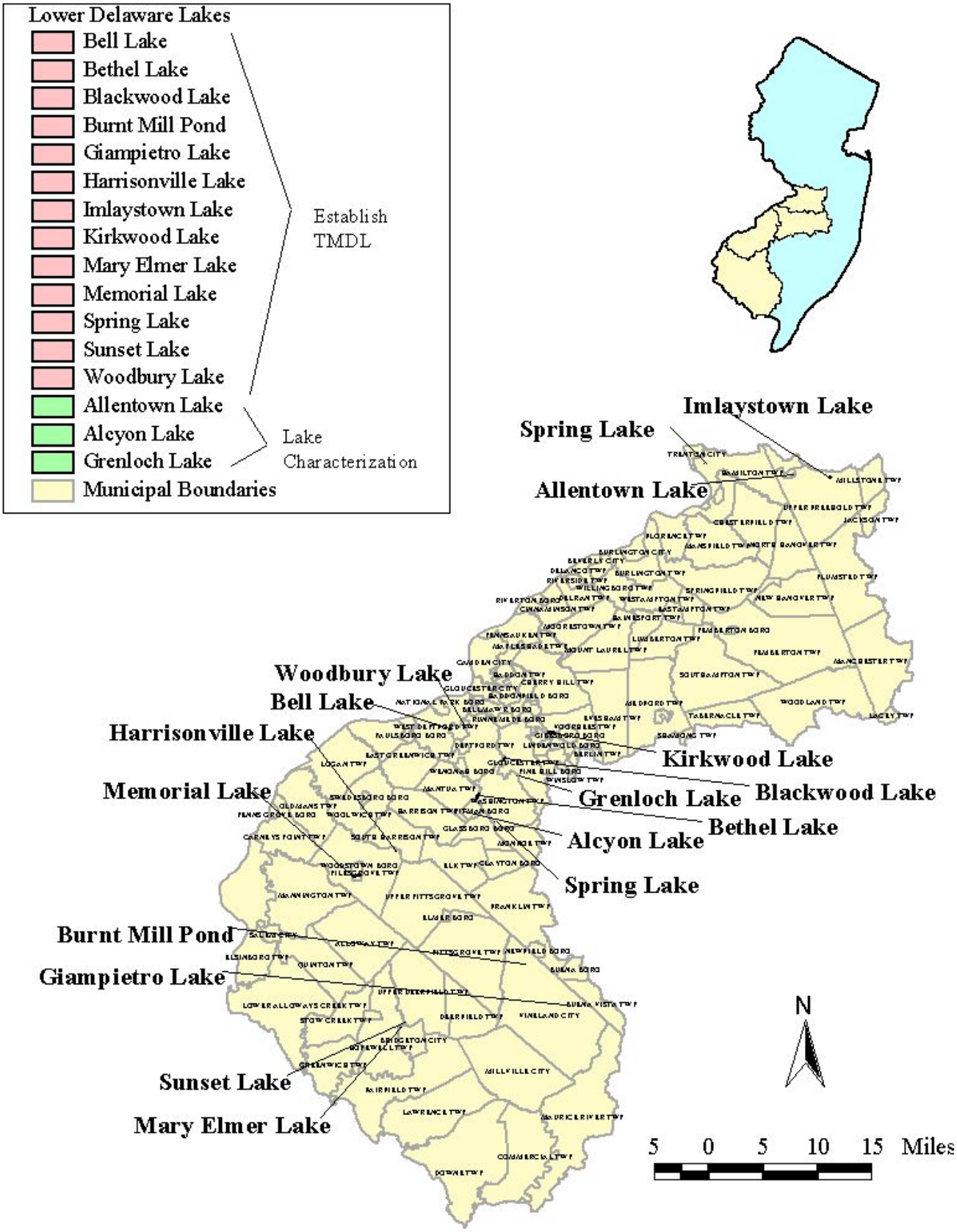
As reported in the *2002 Integrated List of Waterbodies*, the Department identified the following lakes in Northwest Water Region as being eutrophic for a total of 423 acres. These 13 TMDLs will address 312 acres or 74%of the total impaired acres in this region (Table 2). Both eutrophic lakes and aquatic 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	Lakeshed Acres	Management Response
17	Burnt Mill Pond	22.0	4411.5	Establish TMDL
17	Giampietro Lake	14.4	3645.6	Establish TMDL
17	Mary Elmer Lake	22.2	4828.2	Establish TMDL
17	Memorial Lake	21.7	9335.2	Establish TMDL
17	Sunset Lake	87.0	29305.8	Establish TMDL
18	Alcyon Lake	21.2	2800[b]	Lake Characterization
18	Bell Lake	1.8	275.2	Establish TMDL
18	Bethel Lake	9.6	4770.7	Establish TMDL
18	Blackwood Lake	6.2	12121.3	Establish TMDL
18	Grenloch Lake	19.3	9000[b]	Lake Characterization
18	Harrisonville Lake	18.0	5638.5	Establish TMDL
18	Kirkwood Lake	24.9	3252.7	Establish TMDL
18	Woodbury Lake	46.8	3208.6	Establish TMDL
20	Allentown Lake	23.3	7793.2	Lake Characterization
20	Imlaystown Lake	15.9	848.9	Establish TMDL
20	Spring Lake	21.8	115.0	Establish TMDL

[a]All of the waterbodies covered under these TMDLs have a FW2 classification.
[b]Lakesheds of these two lakes were estimated based on hydrology, not actually delineated.

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



These TMDLs will address a total of 312 acres of lakes with a corresponding total of 81,800 acres of land within the affected lakesheds.

The Department's Geographic Information System (GIS) was used extensively to describe the lakes and lakesheds (watersheds of the lakes), 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 Alcyon Lake, Grenloch Lake, Allentown Lake

Alcyon Lake, Grenloch Lake, and Allentown Lake are relatively small waterbodies (21, 20, and 23 acres, respectively) formed by stream impoundments that drain extremely large watersheds[2] relative to the size of the lakes (130, 470, 330 times the size of the lakes, respectively). Land use is largely urban throughout the lakesheds of Alcyon and Grenloch Lakes, while the lakeshed of Allentown Lake is largely agricultural. Both urban and agricultural land uses can contribute substantial loads of phosphorus, supporting the anecdotal evidence from local sampling programs that indicates these three waterbodies are impaired due to eutrophication. Hydrologic budgets have not been developed for these lakes, making it impossible to develop TMDLs at this time. Nevertheless, the Department has included these three lakes in the implementation plan in order to require both characterization and restoration plans for each lake.

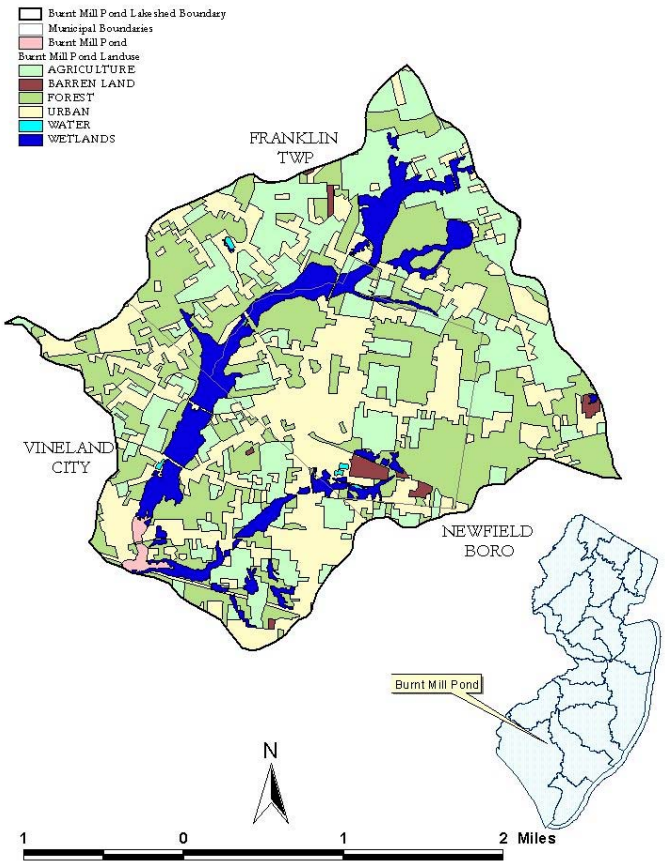
[2] A lakeshed seven times the area of its lake is considered small, whereas a lakeshed ten times the area of its lade is considered large (Holdren *et al*, 2002).

4.2 Burnt Mill Pond

Historically, the Burnt Mill Pond area was a natural cranberry bog and cedar swamp. Cedar was logged from this area until the sawmill burnt down in the early 1900's, thus giving it the name Burnt Mill Pond. In 1986, the Estate of the late Frank H. Stewart donated the pond and land to the City of Vineland. Since that time, the land has been dedicated for use as public parks, recreation areas, game refuges, fishing, bird sanctuaries, or grounds for wildlife protection (F.X. Brown, 1993).

The Burnt Mill Pond watershed is 4400 acres in size and is located in Cumberland and Gloucester Counties. The primary sources of water to the lake include two tributaries, Manaway Branch and Hudson Branch, and stormwater runoff from surrounding areas. Burnt Mill Pond itself is 22 acres, thus giving it a watershed to water surface area ratio of 200:1. The pond has a volume of 65,500 m^3, a mean depth of 2.4 feet, a maximum depth of 5.1 feet, a mean discharge of 8.1 cfs, and a mean hydraulic residence time of 3 days (depth and discharge from F.X. Brown, 1993).

Figure 2 Lakeshed of Burnt Mill Pond



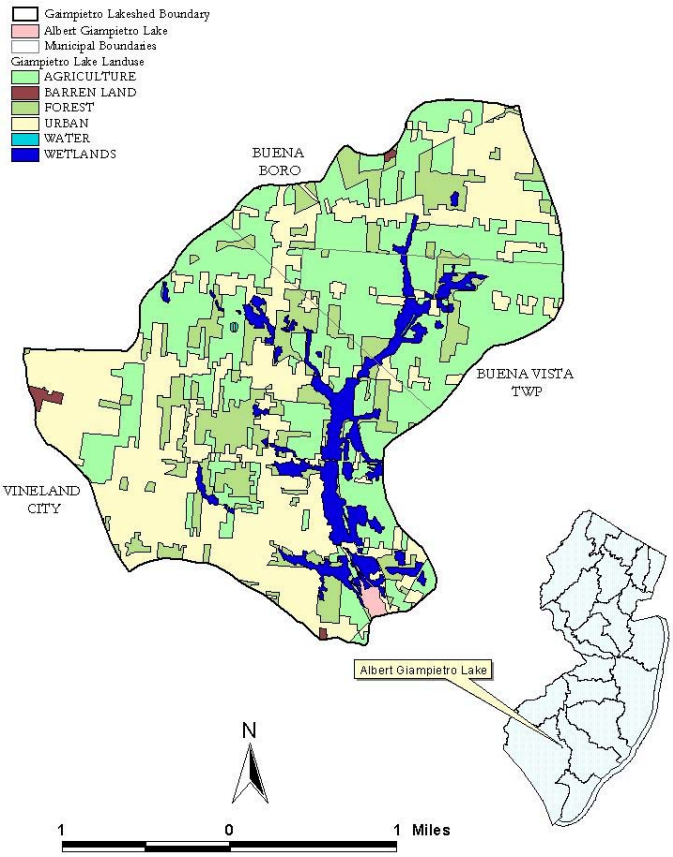
4.3 Giampietro Lake

In the mid-1800s, the area now occupied by the Giampietro Park and lake was the site of Coopers Mill. In 1960 the land was acquired by the City of Vineland and during the mid-1960s a great deal of interest was shown in developing the park and improving the landscaping. Concerns as to the conditions of the lake in Giampietro Park resulted in the adoption of Resolution Number 87-184 by the Vineland City Council in April 1987 which authorized for a Phase I Diagnostic-Feasibilty study of the lake. Today, the park today consists of approximately sixty acres of parklands and multipurpose areas, including a lake, a wetland area, and recreational facilities. The lake is an aesthetic focal point of the park where fishing and wildlife are enjoyed (F.X. Brown, 1989).

Giampietro Park Lake is a 14.4 acre rectangular lake with a mean depth of 3.7 feet, a maximum depth of 6 ft, a lake volume of 65,900 ft^3, a mean discharge of 8.6 cfs, and a mean hydraulic residence time of 3 days. The primary tributary sources to the lake, Bear Branch and Cedar Branch, are branches of Manantico Creek and join just before entering the lake. Other inputs include stormwater collection systems and direct runoff from the park area. Outflow is below the dam (southwest corner) to Cedar Branch (F.X. Brown, 1989).

The Giampietro Park lakeshed includes a 5.3 square mile area in Cumberland and Atlantic Counties. The entire lakeshed extends over 3600 acres, making it extremely large relative to the lake (250:1). Much of the lakeshed contains agriculture and urban land uses.

Figure 3 Lakeshed of Giampietro Lake

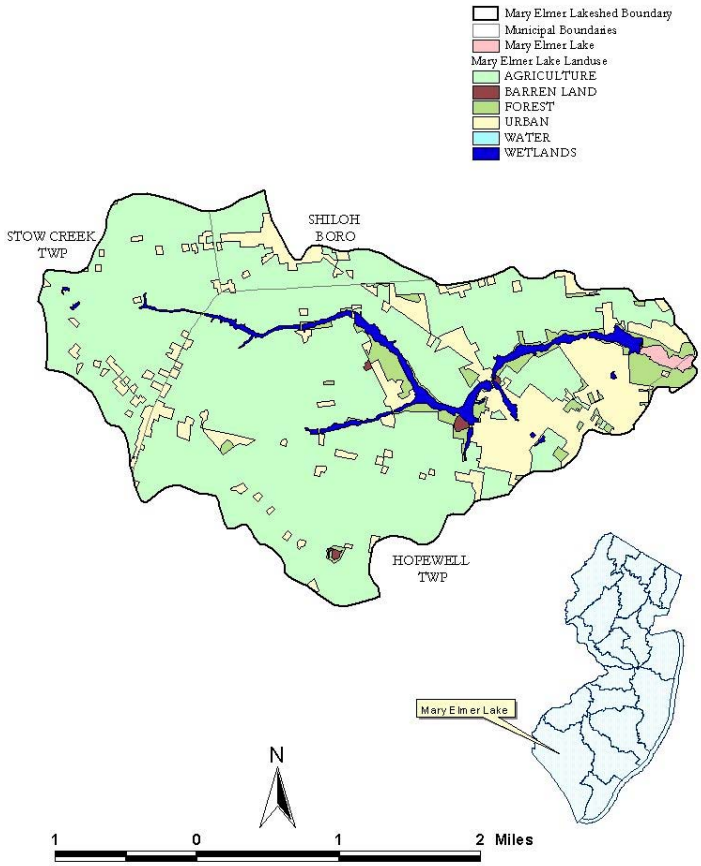


4.4 Mary Elmer lake

Mary Elmer Lake is a small protozoan shaped lake located in Hopewell Township Cumberland County. Mean depth has been estimated at 6 feet reaching a maximum of 10 feet. Total lake volume is about 164,000 m3. The lake's surface area is 22 acres and the lakeshed area is 4,800 acres making the watershed-to-lake surface area ratio approximately 218:1. The estimated mean detention time is about 6 days Depth and discharge information taken from NJEP, 1983). The lake is an impoundment of Barret Run a tributary of the Cohansey River and is also a headwater of Sunset Lake.

Much of the land use within the Mary Elmer lakeshed consists of agriculture, although substantial residential development also exists. Historically efforts have been made to improve the condition of the lake by performing restorative techniques such as drawdowns and dredging. Recreational uses of the lake included boating fishing and swimming. Today although fishing still occurs, the bathing beach has been closed.

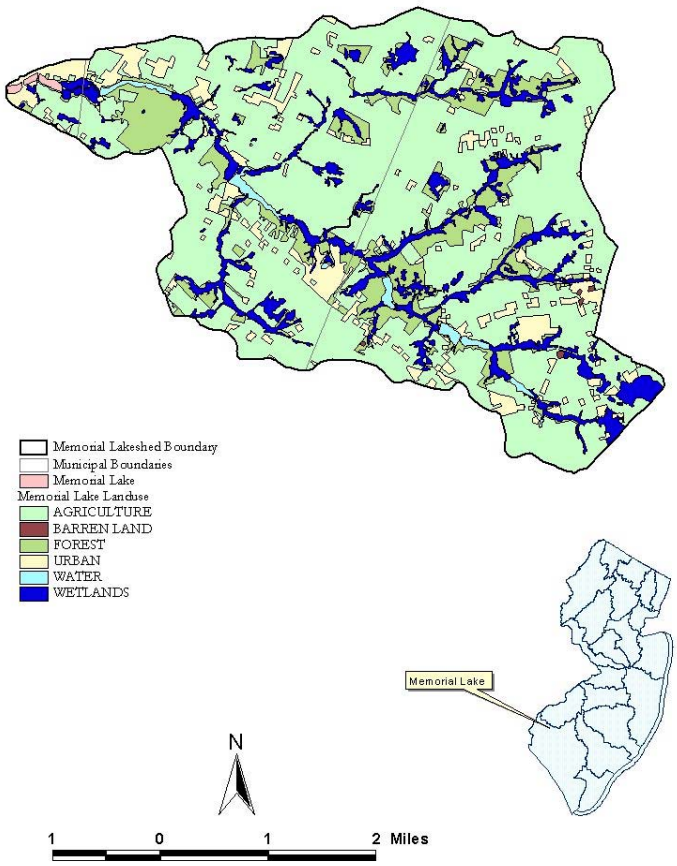
Figure 4 Lakeshed of Lake Mary Elmer Lake



4.5 Memorial Lake

Memorial Lake, an impoundment of the Salem River, is located in Woodstown, Salem County. This boomerang shaped lake has a mean depth of 4 feet with maximum depths reaching 6 feet. The total lake volume is 107,000 m^3, with total annual discharge estimated at 25,000,000 m^3 (depth and discharge taken from NJDEP, 1983). The lake's area is 22 acres and the total lakeshed area is 9300 acres, making lakeshed 15 times the area of the lake. The estimated mean detention time is 1.5 days, making this a rapidly flushing system. Land use throughout the lakeshed is dominated by agriculture. There are no known point sources to memorial lake but agricultural run-off specifically from livestock may be significant. Recreational uses include fishing, boating and ice skating.

Figure 5 Lakeshed of Memorial Lake

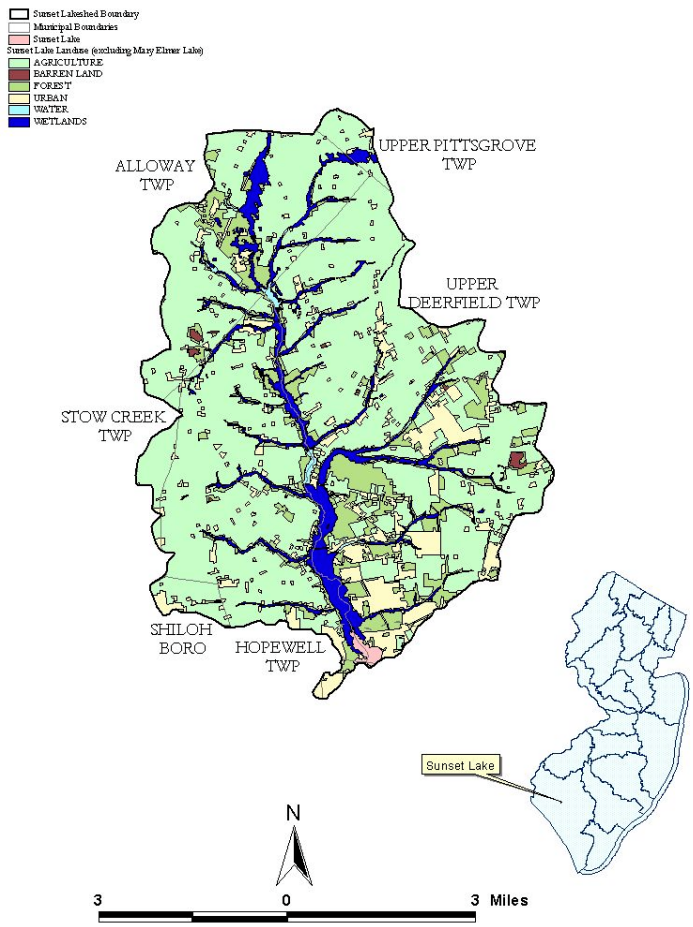


4.6 Sunset Lake

Sunset Lake is located on the Cohansey River in Upper Deerfield, Cumberland County. Sunset Lake has displayed symptoms of accelerated eutrophication since as early as the 1940's. The lake provides swimming, boating and fishing, however the quality of the lake's recreational potential has diminished. While numbers of fish individuals per species is low, the species diversity of the lake's fishery is good (NJDEP, 1983).

The watershed area of Sunset Lake is over 29,000 acres, resulting in an extremely large watershed area to surface area ratio of about 300 to 1. Sunset Lake itself is approximately 89 acres in size with mean and maximum depths of 2.0 and 3.4 meters, respectively, and a total volume of approximately 700,000 m^3. Groundwater seepage is assumed to contribute the difference between discharge (66,000,000 m^3/yr) and inflow (58,000,000 m^3/yr). Hydraulic detention time has been estimated at about 4 days. Depth and discharge information were taken from NJDEP, 1983.

Figure 6 Lakeshed of Sunset Lake



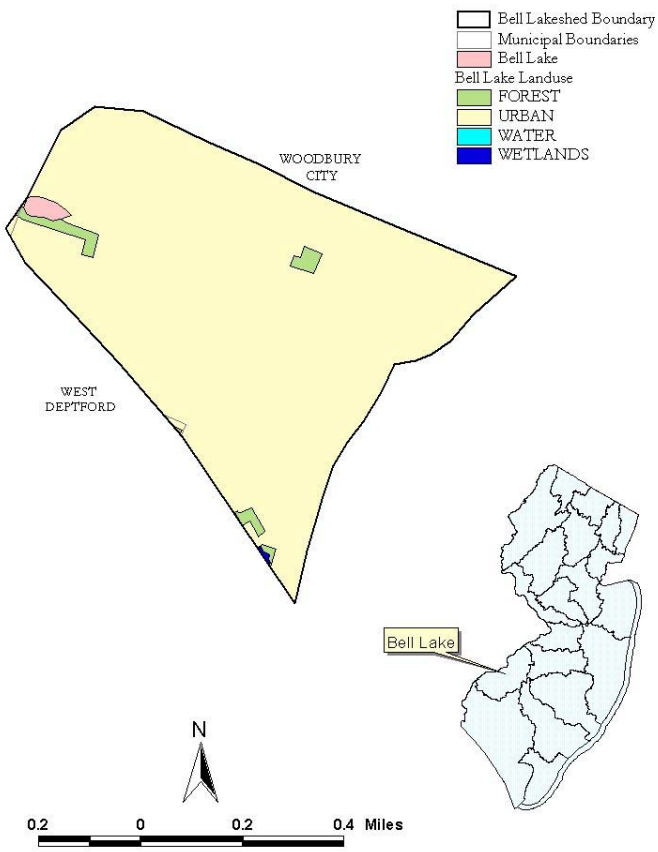
4.7 Bell Lake

Bell Lake is located in the City of Woodbury in Gloucester County. Historically Bell Lake and the surrounding park were part of a farm owned by Samuel Bell Jr. In 1937, after the death of Mr. Bell, some homes were constructed at this site and then the remaining land near the lake was deeded to the City of Woodbury for the creation of a public park. In the same year, a portion of the dam had deteriorated, lowering the level of the lake. After complaints from residents, the dam was repaired and the banks of the lake were filled resulting in the Bell Lake that exists today. (F.X. Browne Associates, Inc., 1989)

Bell Lake is a shallow bean shaped lake with a mean depth of 2.6 feet reaching a maximum of 5.4 feet. The lake is primarily stormwater feed through the storm sewer system of the city and discharges into the Matthews Branch of Woodbury Creek. The drainage basin area of the lake is about 275 acres lying entirely within the city boundaries and the surface area of the lake is 1.8 acres, making the drainage area to lake surface area ratio about 150:1. Total Lake volume is estimated to be 5,800 m^3. Mean discharge is approximately 409,000 m^3 / yr, making the mean hydraulic residence time for the lake 5.2 days. (depth and discharge taken from F.X. Browne Associates, Inc., 1989).

The major land use within the Bell Lake watershed is urban comprising of over 93% of the area. The majority of the urban land is single family homes with the remainder consisting of multi family apartments as well as industrial and manufacturing uses. There are no point source discharges in the Bell Lake Watershed; therefore the primary source of pollutants to the waterbody are nonpoint sources, specifically urban run-off.

Figure 7 Lakeshed of Bell Lake



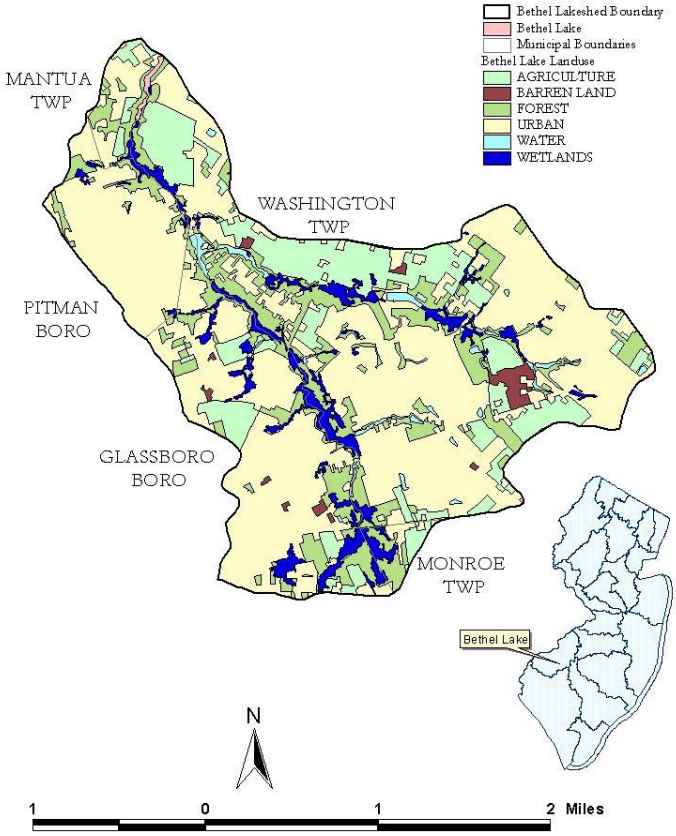
4.8 Bethel Lake

Bethel Lake is located in Mantau, Gloucester County, within the Mantau Creek watershed. Historically, Bethel Lake has provided a variety of recreational opportunities including fishing, boating, and swimming.

Bethel lake has a surface area of 9.6 acres, a volume of 120,000 m^3, a mean depth of 3.0 meters, and a detention time estimated at 3 days (depth and discharge taken from NJDEP, 1983). The lakeshed of Bethel Lake is almost 4800 acres, about 500 times the area of the lake. Furthermore, the lakeshed is largely urban. A number of small lakes are located within the watershed of Bethel Lake and serve as headwaters to either Mantau Creek or Duffield Run, the two main tributaries of Bethel Lake. Included are Lake Oberst, Senior Lakes, Kandle Lake,

Ward Lake, Spring Lake (not the same Spring Lake discussed in section 4.14), and Kressey Lake. While the majority of the lake's inflow is attributable to Mantau Creek and Duffield Run, significant hydrologic and nutrient inputs are also supplied by storm runoff from the high-density residential areas of Pitman. A fish survey published in the 1983 report revealed an overall high level of fish diversity but with a low number of resident species.

Figure 8 Lakeshed of Bethel Lake



4.9 Blackwood Lake

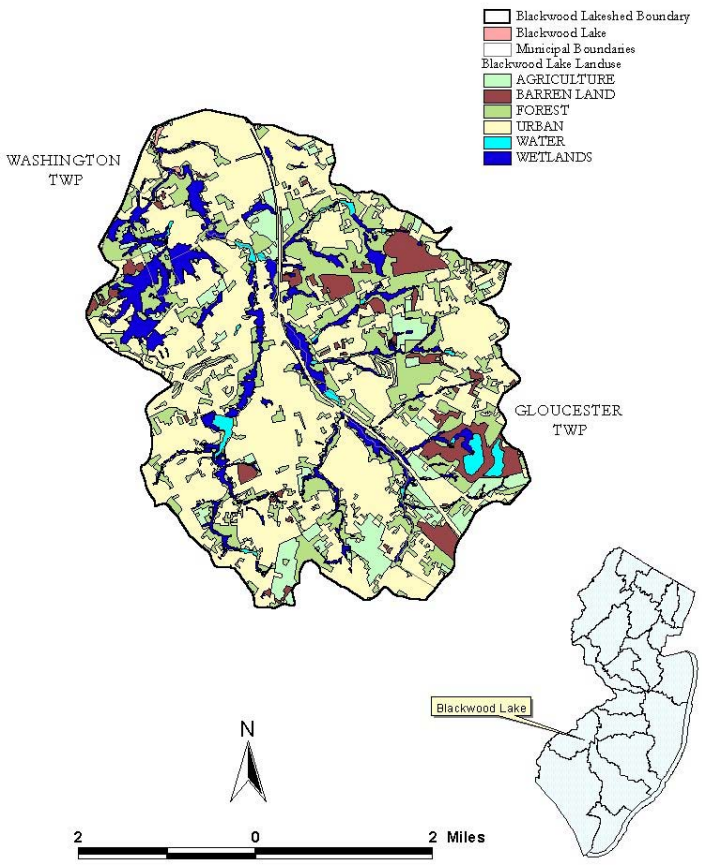
Blackwood Lake is a small waterbody impoundment located on the South Branch of Timber Creek, between the County and Township lines of Gloucester Township, Camden County and Washington Township, Gloucester County. Studies conducted in 1992 (F. X. Brown Associates, Inc.) indicated that significant sedimentation had occurred in the lake and that water depth average was 1.3 feet in depth with a maximum depth of 3.3 feet.

While the original surface area of Blackwood Lake was approximately 67.0 acres, aerial photographs in 1995 show the surface area to be about 16 acres. The lakeshed, much of which is urban, totals 12,000 acres, resulting in an enormous watershed to lake surface area ratio of

almost 800:1. The lake volume is about 25,000, with a mean discharge of 36.3 cfs, and a mean hydraulic residence time of 0.3 days (depth and discharge taken from F.X Browne, 1992).

Blackwood Lake supports a natural population of bass, pickerel, bullheads and other game fish and is heavily used for fishing (Remington & Vernick, 1998). While it is fed primarily by the South Branch of Timber Creek and Farrow's Run, other inputs include drainage from stormwater and direct runoff from a local park area.

Figure 9 Lakeshed of Blackwood Lake



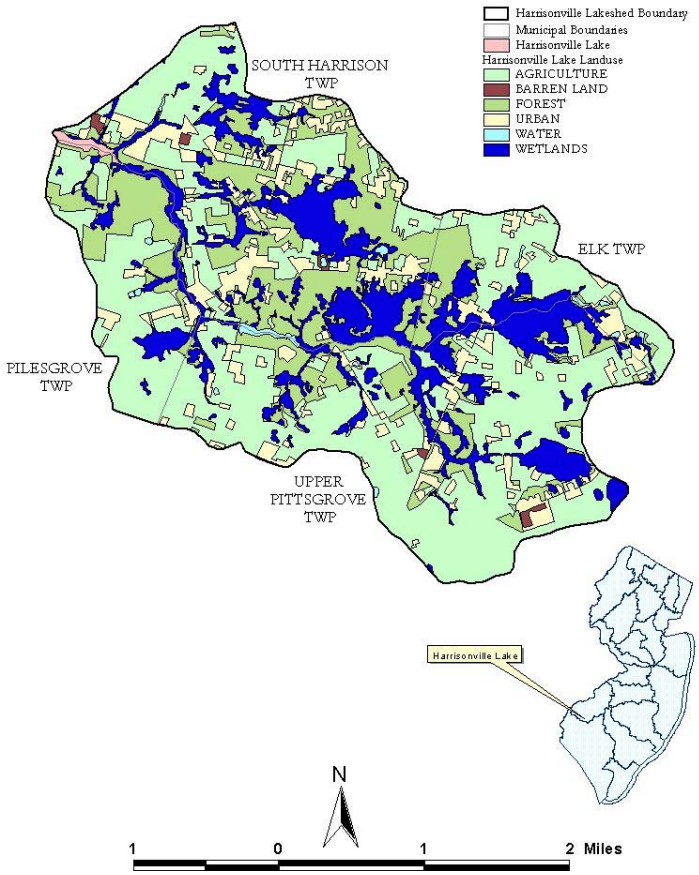
4.10 Harrisonville Lake

Harrisonville lake is a 18 acre cylindrically-shaped impoundment on Oldmans Creek. Water from the lake flows over a man-made dam via Oldmans Creek to wetlands associated with the Delaware River. The lake is owned by the New Jersey Division of Fish and Wildlife. Over the past several decades Harrisonville Lake has developed a severe eutrophication problem that progressively worsens in late summer.

In April 2001 a bathymetric survey and hydrologic analysis of Harrison Lake was conducted by Princeton Hydro and revealed: a mean depth of 3.08 ft, maximum depth of 7.4 ft, lake

volume of 6.8 x 10^4 m^3, mean discharge of 13.2 x 10^6 m^3/yr, and a hydraulic residence time of 1.9 days. From this survey, the total amount of unconsolidated sediments was estimated to be approximately 28 acre-ft (34,441 cubic meters or 45,049 cubic yards) (Princeton Hydro, LLC, 2003). The watershed associated with Harrison Lake is 5,600 acres resulting in an extremely large watershed area/lake surface area ratio of over 300 to 1.

Figure 10 Lakeshed of Harrisonville Lake



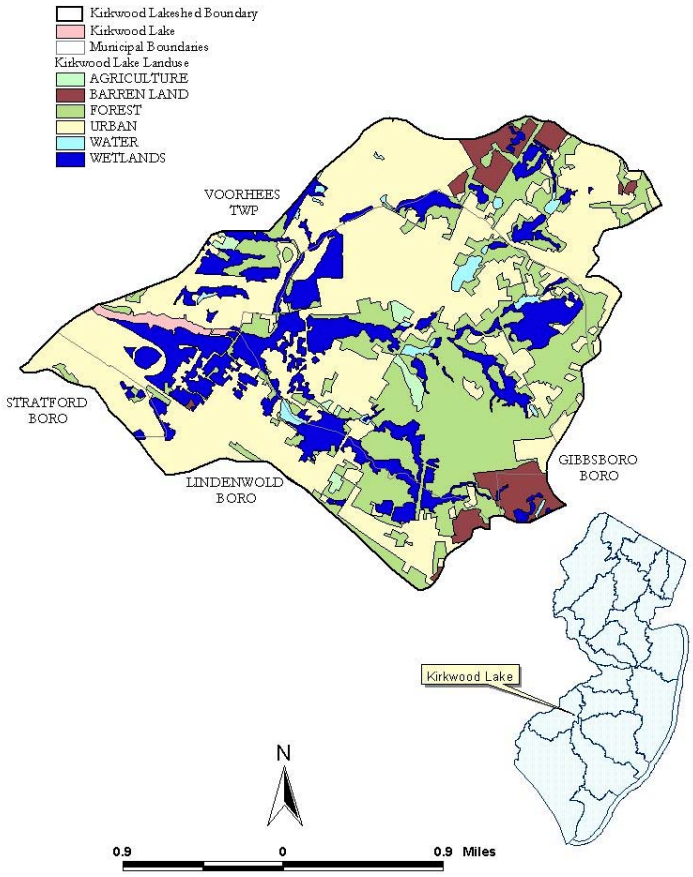
4.11 Kirkwood Lake

Kirkwood Lake is a small, narrow lake approximately 0.75 miles in length and is located on the boundary of Voorhhes and Lindenwold, Camden County. Historically, the lake has been used for fishing, boating and swimming purposes. More recently, these uses have lessened with the associated decrease in water quality. It has a total surface area of 25 acres, a volume of 215,000 m^3, a mean depth of 2.1 m, and a hydraulic detention time of around 8 days (depth and discharge taken from NJDEP 1983). The 3250-acre lakeshed is about 130 times the size of the lake and has a high percentage of urban land use.

The primary tributaries to Kirkwood Lake include the Cooper River, Millard Creek, and Nicholson Branch. The lake also receives additional input from two small tributaries that

flow directly to the lake. Urban stormwater contributes a substantial portion of the water load to the lake.

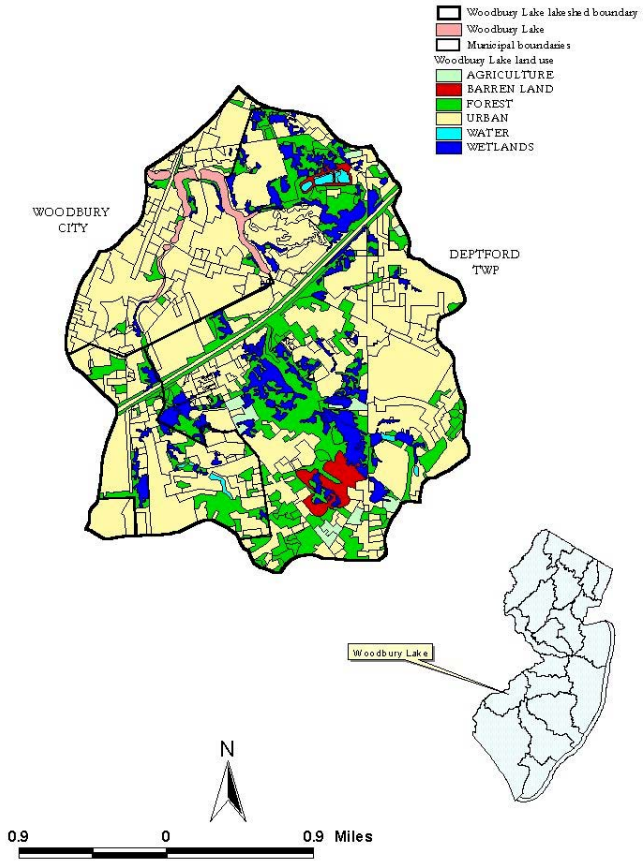
Figure 11 Lakeshed of Kirkwood Lake



4.12 Woodbury Lake

Woodbury Lake (also known as Stewart Lake) is a 47-acre lake located on Woodbury Creek in Woodbury, Gloucester County. Woodbury Lake has two main tributaries, Woodbury Creek and an unnamed tributary flowing into the western section of the lake. The lake consists of two long, narrow arms divided into an interconnected series of small impoundments. Mean depth (1.52 meters) and total annual inflow (7,780,000 m^3) were obtained from NJDEP, 1983. Detention time is estimated to be about 14 days. The lake's 3200-acre watershed area (69 times the lake area) is predominately composed of urban landuse.

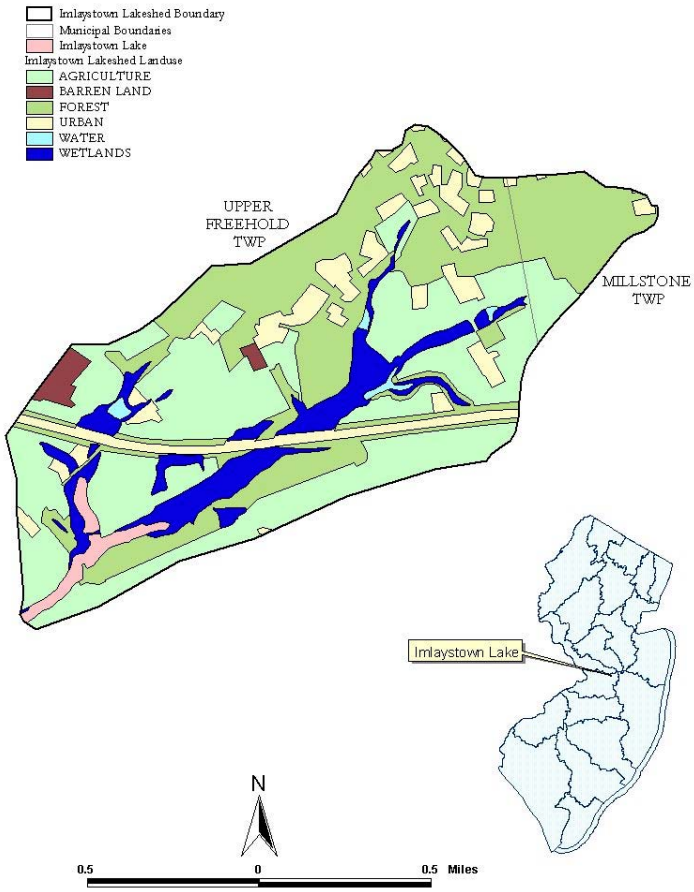
Figure 12 **Lakeshed of Woodbury Lake**



4.13 Imlaystown Lake

Imlaystown Lake is a 16-acre located in Upper Freehold, Monmouth County that drains a lakeshed area of 850 acres. Historically, this lake was used for boating, swimming, fishing, and ice-skating. Imlaystown Lake is fed by Doctor's Creek and its numerous tributaries. The lakeshed/lake area ratio is large at about 50:1. The lake is shallow (mean depth is 1.22 meters) with high annual discharge (20,300,000 m^3), resulting in a hydraulic detention time of 1.4 days (depth and discharge from NJDEP, 1983). The landuse within this watershed is predominantly agriculture and forest.

Figure 13 Lakeshed of Imlaystown Lake

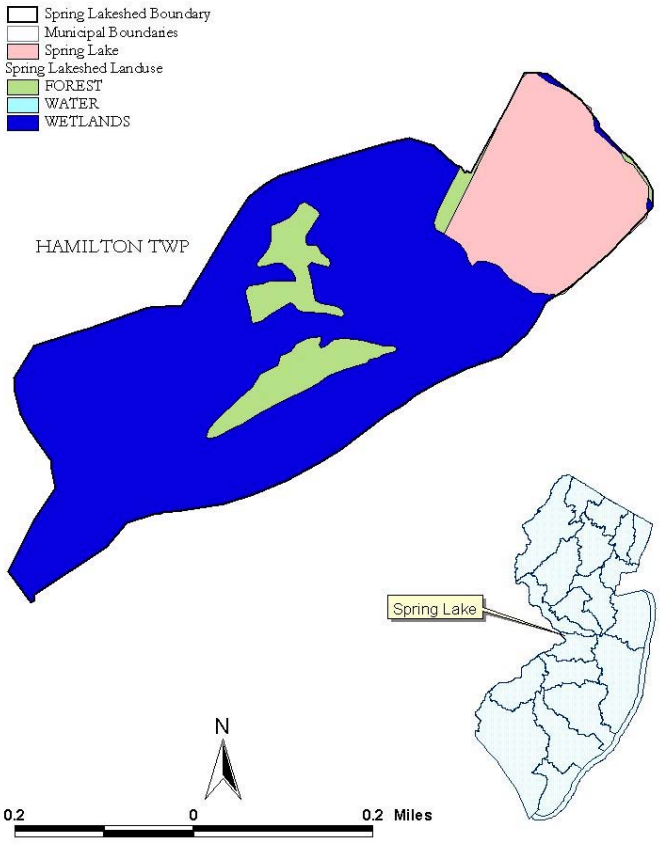


4.14 Spring Lake

Spring Lake is a 22-acre lake located in Hamilton, Mercer County. The lake drains a small portion (115 acres) of the Trenton Marshes, an extensive wetland area that borders the Delaware River. The lakeshed is very small, only 5.3 times the area of the lake, and consists entirely of forest and wetland. Spring Lake was once part of a small amusement park, serving primarily an aesthetic purpose, and has been used for fishing; however, more recently excessive weed growth has interfered with its use.

The majority of inflow into the lake is through groundwater seepage and springs. Lake mean depth (1.22 meters) and total outflow (379,000 m^3) were taken from NJDEP (1983). Lake volume and detention time were estimated to be 107000 m^3 and 103 days, respectively. For the purposes of this TMDL analysis, 75% of the water load was assumed to be due to groundwater infiltration.

Figure 14 **Lakeshed of Spring Lake**



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.

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.

Finally, N.J.A.C 7:9B-1.5(c)1 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."

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. All Major Municipal (MMJ), Minor Municipal (MMI), and Combined Sewer Overflow (CSO) discharges within each lakeshed were identified as point sources of phosphorus, as were all other discharger types with a limit for phosphorus in their NJPDES permit, including both "monitor only" and numeric limits. 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 point source other than stormwater exist anywhere within the lakesheds any of the Lower Delaware Region lakes for which TMDLs are being proposed.

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 3 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 Sunset Lake, land use runoff loads were only calculated for the immediate watershed downstream of Mary Elmer Lake. An additional annual tributary load from Mary Elmer Lake into Sunset Lake was estimated by multiplying

[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.

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 runoff loading rates for each of the lakes are shown in Tables 4-6. Also included in Tables 4-6 are estimates of loading rates from septic systems, waterfowl and from internal sources (sediment regeneration, macrophyte decomposition) where such estimates had already been developed previously for each of the lakes. Finally, groundwater loads were estimated for lakes known to have a substantial groundwater flow component. The annual groundwater flow was multiplied by a phosphorus concentration of 0.1 mg TP/l and then converted to kg TP/yr.

Table 4 Nonpoint and Stormwater Sources of Phosphorus Loads

Nonpoint Source	Burnt Mill Pond		Giampietro Lake		Mary Elmer Lake		Memorial Lake		Sunset Lake	
	acres	kg/yr	acres	kg/yr	acres	kg/yr	acres	kg/yr	acres	kg/yr
land use loads										
medium / high density residential	179	116	466	302	196	127	22.8	14.7	461	298
low density / rural residential	774	219	444	126	426	121	485	137	2160	613
commercial	75.6	61.2	149	121	58.7	47.5	62.2	50.4	200	162
industrial	121	83.3	34.5	23.7	1.5	1.0	73.9	50.9	65.7	45.2
mixed urban / other urban	217	87.9	277	112	103	41.7	185	74.9	640	259
agricultural	1170	707	1470	895	3690	2240	6530	3970	20500	12400
forest, wetland, water	1810	73.1	769	31.1	315	12.8	1930	78.1	5120	207
barren land	51.6	10.4	17.7	3.6	14.3	2.9	20.7	4.2	95.2	19.3
other loads										
septic systems	n/a		n/a		n/a		n/a		n/a	
waterfowl				8.0						
internal load										
tributary load										1990
natural loads										
air deposition	22.0	0.6	14.4	0.4	22.2	0.6	21.7	0.6	87.0	2.5
groundwater	n/a		n/a		n/a		n/a		n/a	80.0
TOTAL	**4410**	**1360**	**3650**	**1620**	**4830**	**2600**	**9340**	**4380**	**29300**	**16100**

Table 5 Nonpoint and Stormwater Sources of Phosphorus Loads (cont'd)

Nonpoint Source	Bell Lake		Bethel Lake		Blackwood Lake		Harrisonville Lake		Kirkwood Lake	
	acres	kg/yr	acres	kg/yr	acres	kg/yr	acres	kg/yr	acres	kg/yr
land use loads										
medium / high density residential	194	126	1620	1050	3450	2230	9.8	6.3	742	481
low density / rural residential	2.3	0.7	505	143	1040	295	567	161	212	60.1
commercial	58.6	47.5	227	184	727	588	8.7	7.0	260	211
industrial	1.7	1.1	63.5	43.7	109	75.1	4.3	3.0	38.6	26.6
mixed urban / other urban	11.5	4.6	476	193	1200	486	61.1	24.7	342	139
agricultural	0.0	0.0	740	449	770	467	2780	1690	39.3	23.9
forest, wetland, water	5.0	0.2	1070	43.4	4100	166	2170	88	1410	57.0
barren land	0.0	0.0	62.8	12.7	713	144	23.2	4.7	184	37.3
other loads										
septic systems	n/a		n/a		n/a		n/a	157	n/a	
waterfowl										
internal load								5.2		
tributary load										
natural loads										
air deposition	1.8	0.1	9.6	0.3	15.5	0.4	18.0	0.5	24.9	0.7
groundwater	n/a		n/a		n/a		n/a	71.0	n/a	
TOTAL	**275.2**	**180**	**4770**	**2110**	**12100**	**4460**	**5640**	**2210**	**3250**	**1040**

Table 6 Nonpoint and Stormwater Sources of Phosphorus Loads (cont'd)

Nonpoint Source	Woodbury Lake		Imlaystown Lake		Spring Lake - 20	
	acres	kg/yr	acres	kg/yr	acres	kg/yr
land use loads						
medium / high density residential	995	644	0.0	0.0	0.0	0.0
low density / rural residential	464	132	62.2	17.6	0.0	0.0
commercial	249	201	0.0	0.0	0.0	0.0
industrial	66.4	45.7	0.0	0.0	0.0	0.0
mixed urban / other urban	328	133	31.9	12.9	0.0	0.0
agricultural	55.4	33.6	343	208	0.0	0.0
forest, wetland, water	932	37.7	386	15.6	93.3	3.8
barren land	72.4	14.6	10.9	2.2	0.0	0.0
other loads						
septic systems	n/a		n/a		n/a	
waterfowl						
internal load						
tributary load						
natural loads						
air deposition	46.8	1.3	15.9	0.5	21.8	0.6
groundwater	n/a		n/a		n/a	2.8
TOTAL	**3210**	**1240**	**849**	**257**	**115**	**7.2**

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 7.

Table 7 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)
Qa = areal water load (m/yr) [4]
Q_i = total inflow (m³/yr)
A_l = area of lake (m²)
S = settling rate (per year)

Reckhow (1979a) model was selected because it has the broadest range of hydrologic, morphological and loading characteristics in its database. Also, the model includes an uncertainty estimate that was used to calculate a Margin of Safety. 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

[4] Areal water load is defined as the annual water load entering a lake divided by the area of the lake. Since, under steady-state conditions, the water coming in to the lake is equal to the water leaving the lake, either total inflow or total outflow can be used to calculate areal water load. If different values were reported for total inflow and total outflow, the Department used the higher of the two to calculate areal water load.

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 7):

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/m²/yr

For comparison, Table 8 below summarizes the characteristics for each lake based on their current and target conditions as described below. The above ranges of characteristics apply to most of the lakes covered under these TMDLs; however, the areal water loads for Memorial Lake, Bethel Lake, and Blackwood Lake are outside the calibration range (284, 373, and 518 m/year, respectively). Nevertheless, the model still remains the best choice since it has the broadest range of lake characteristics in its database. 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 8 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)
Burnt Mill Pond	0.187	0.027	15.24	2.17	81.4
Giampietro Lake	0.211	0.026	27.74	3.36	131
Mary Elmer Lake	0.266	0.026	28.95	2.82	109
Memorial Lake	0.175	0.025	49.74	7.00	284
Sunset Lake	0.244	0.025	45.74	4.73	187
Bell Lake	0.440	0.028	24.49	1.56	55.7
Bethel Lake	0.145	0.024	54.29	9.13	373
Blackwood Lake	0.137	0.025	71.22	12.77	518
Harrisonville Lake	0.168	0.025	30.41	4.55	181
Kirkwood Lake	0.109	0.026	10.27	2.47	94.0
Woodbury Lake	0.160	0.029	6.56	1.21	41.1
Imlaystown Lake	0.013	0.013	3.98	3.98	315
Spring Lake	0.019	0.019	0.08	0.08	4.3

7.1 Current Condition

Using these estimated physical parameters and current loads, the predicted steady-state phosphorus concentration of each lake was calculated using the Reckhow (1979a) formulation and listed in Table 9. The current phosphorus load distribution for each lake is shown in Figures 15 to 27 below.

Figure 15 **Current distribution of phosphorus load for Burnt Mill Pond**

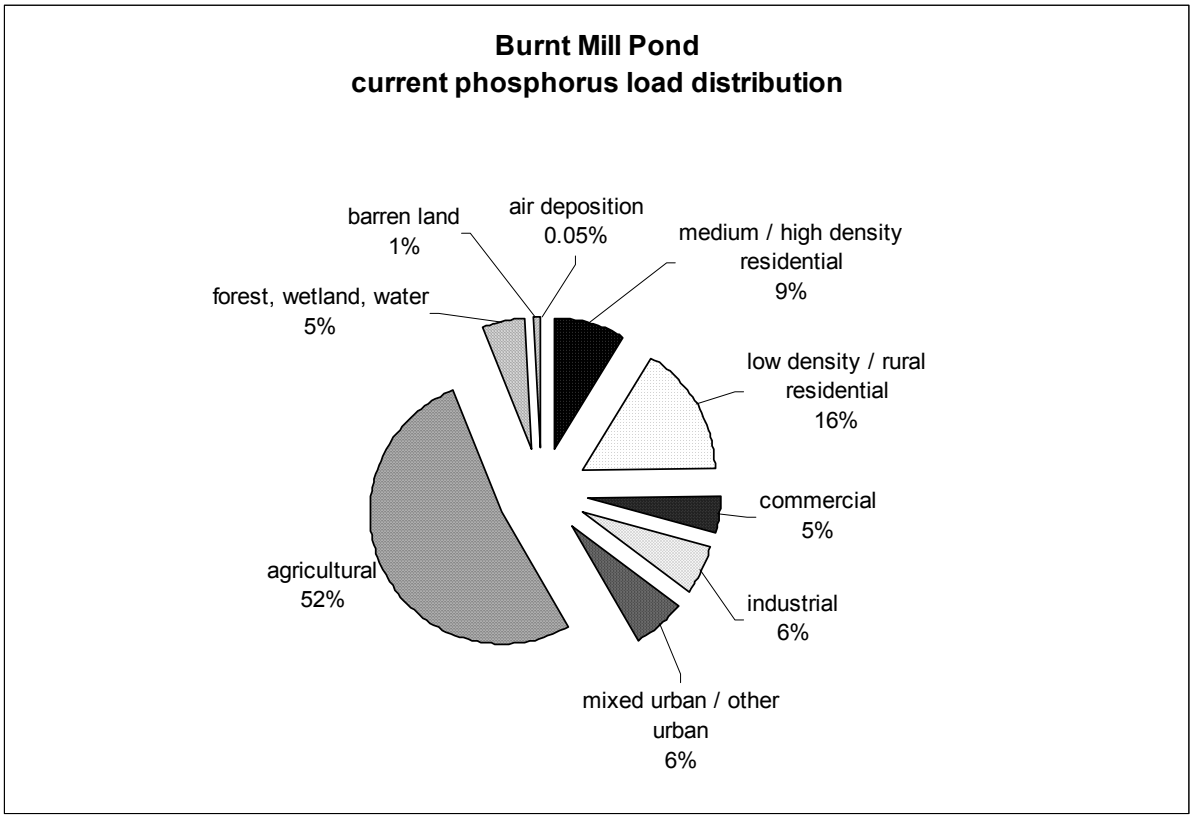


Figure 16 **Current distribution of phosphorus load for Giampietro Lake**

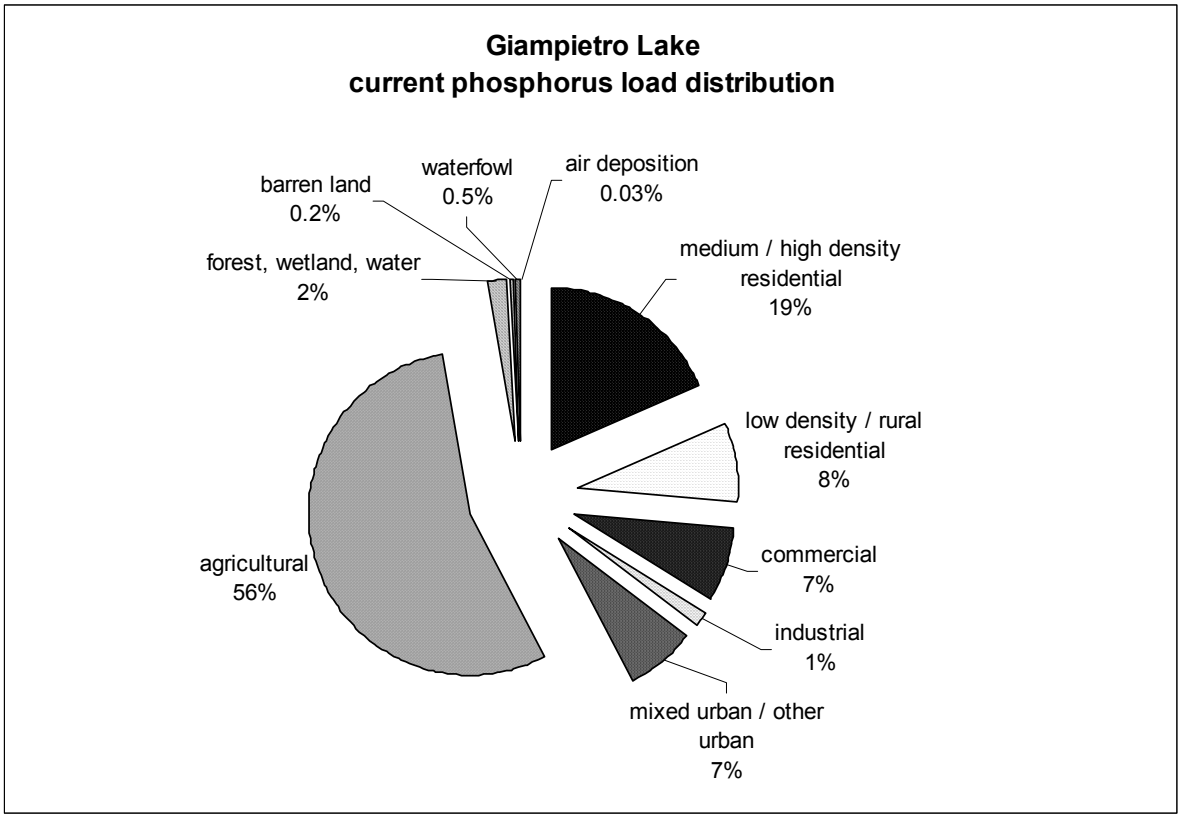


Figure 17 **Current distribution of phosphorus load for Mary Elmer Lake**

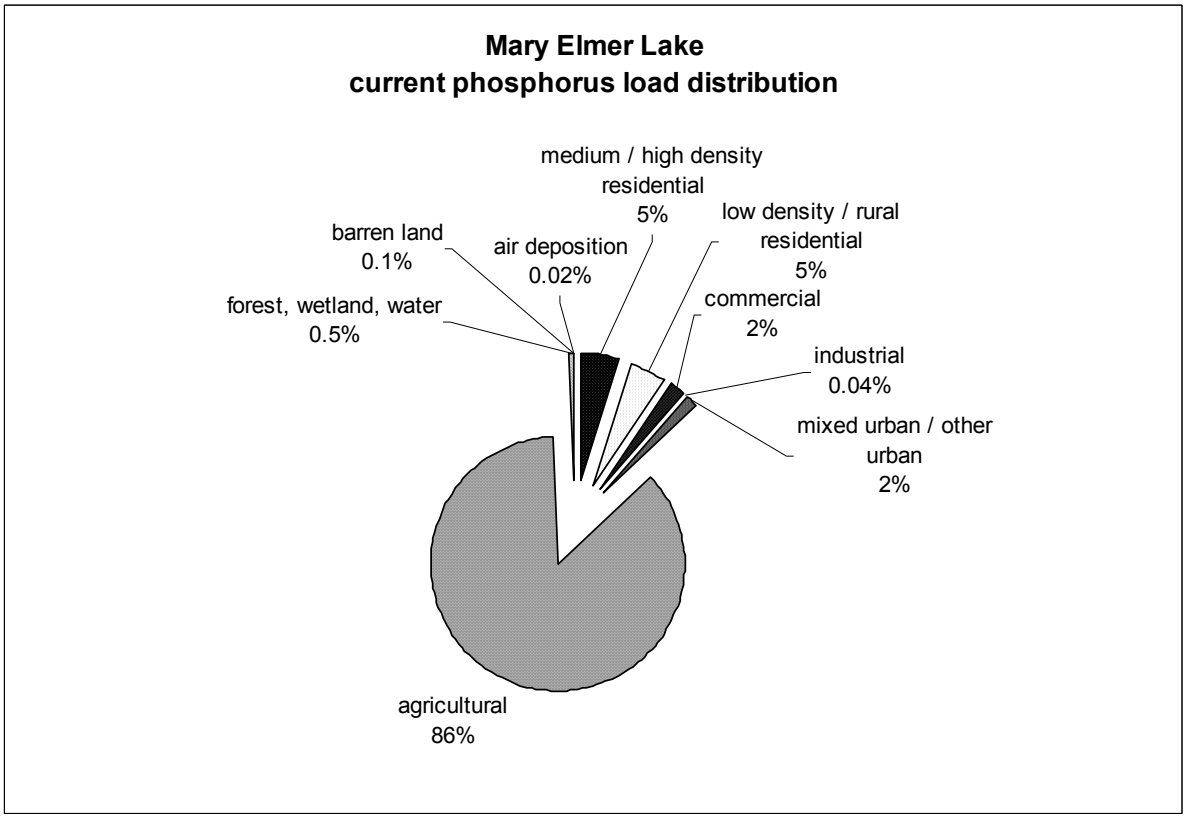


Figure 18 **Current distribution of phosphorus load for Memorial Lake**

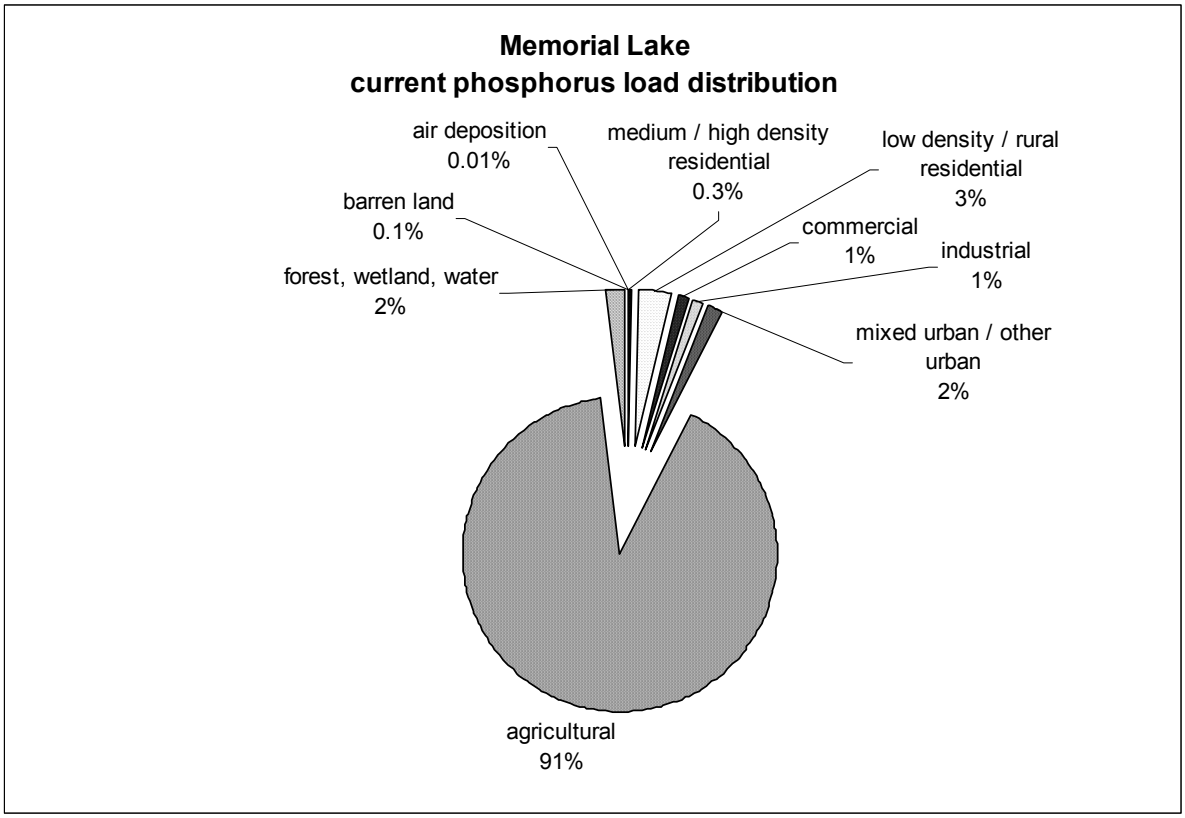


Figure 19 **Current distribution of phosphorus load for Sunset Lake**

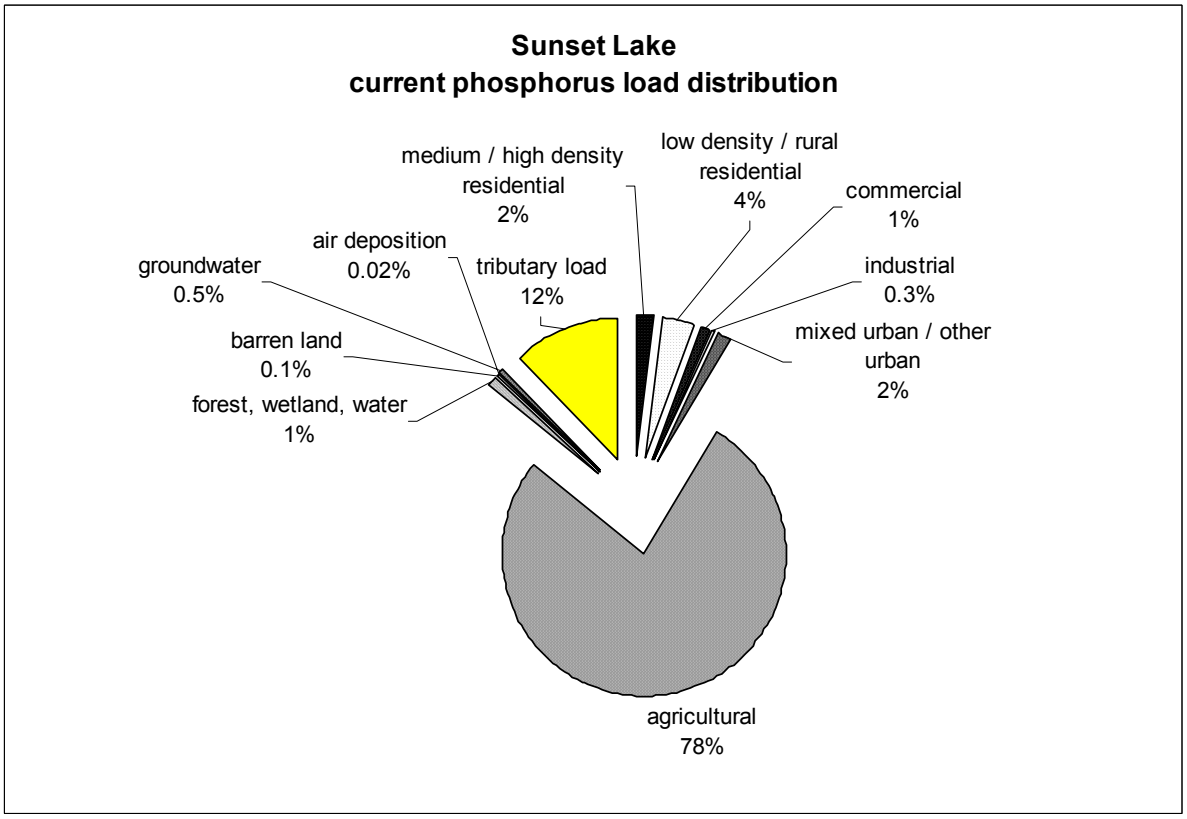


Figure 20 **Current distribution of phosphorus load for Bell Lake**

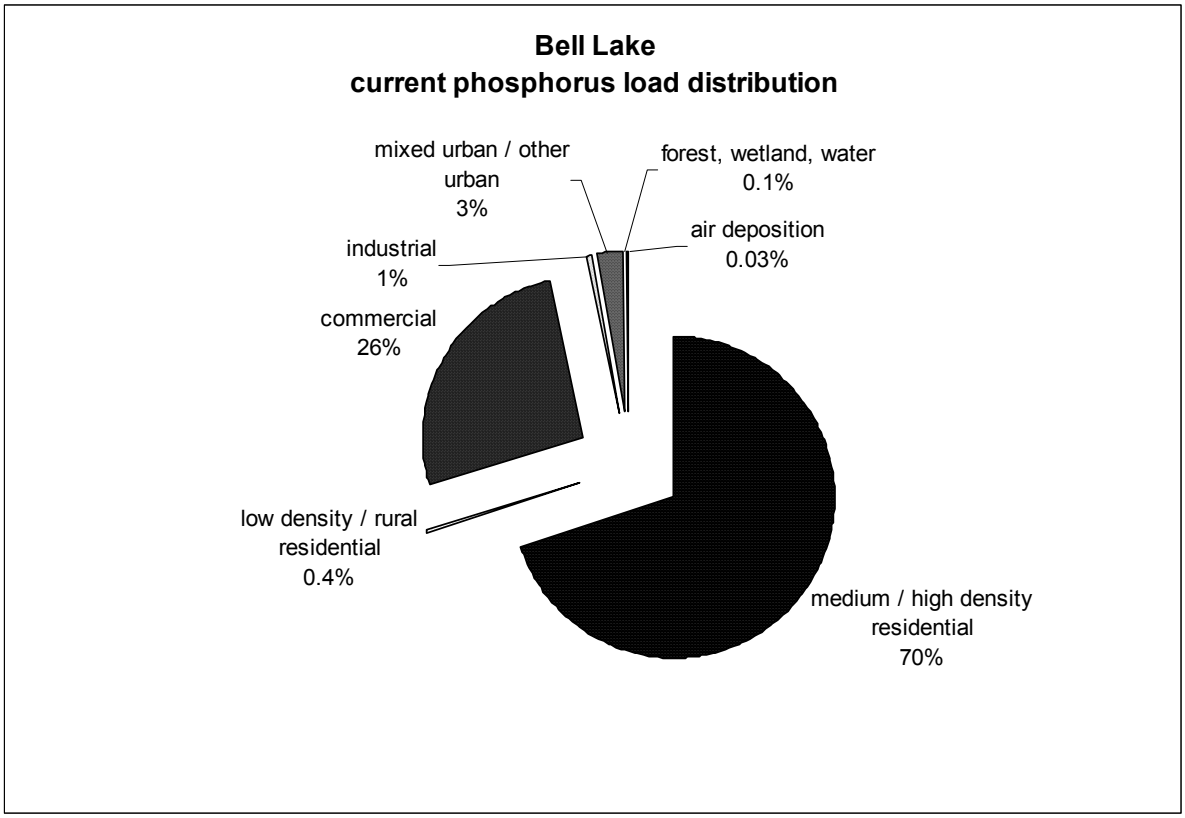


Figure 21 **Current distribution of phosphorus load for Bethel Lake**

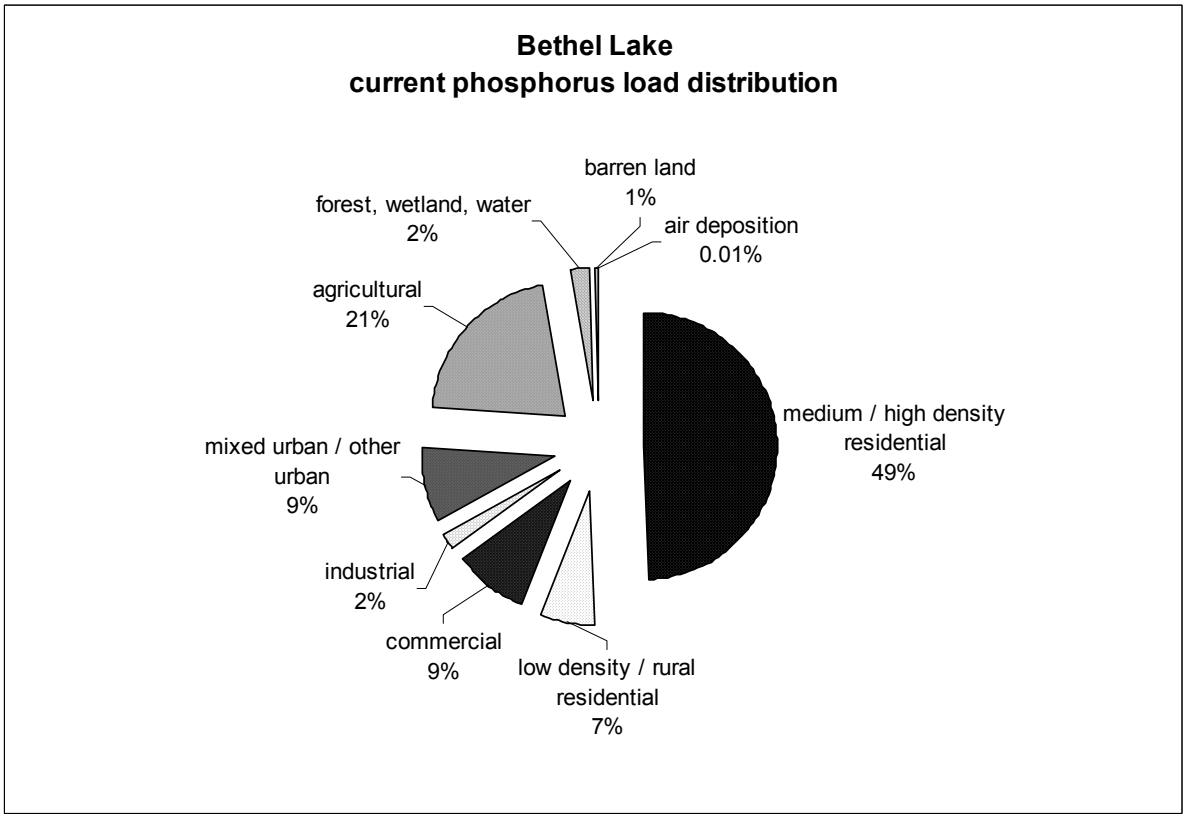


Figure 22 **Current distribution of phosphorus load for Blackwood Lake**

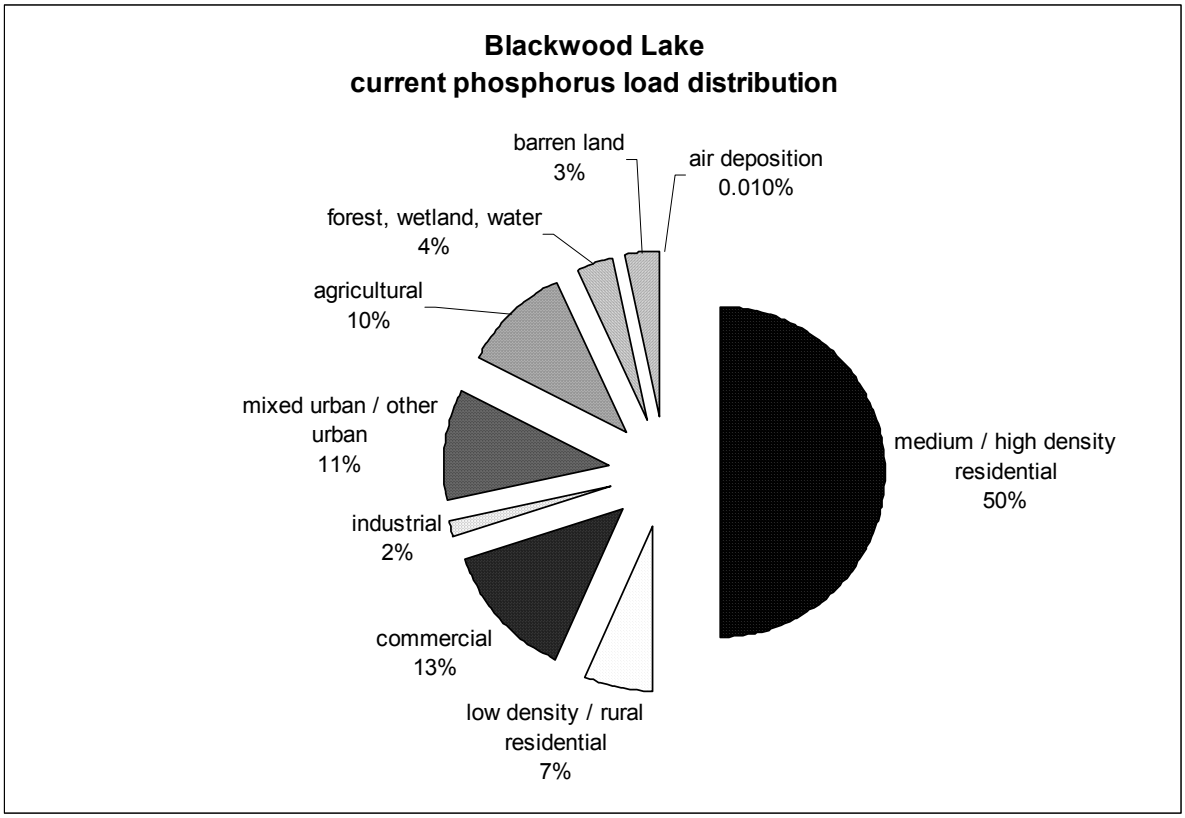


Figure 23 **Current distribution of phosphorus load for Harrisonville Lake**

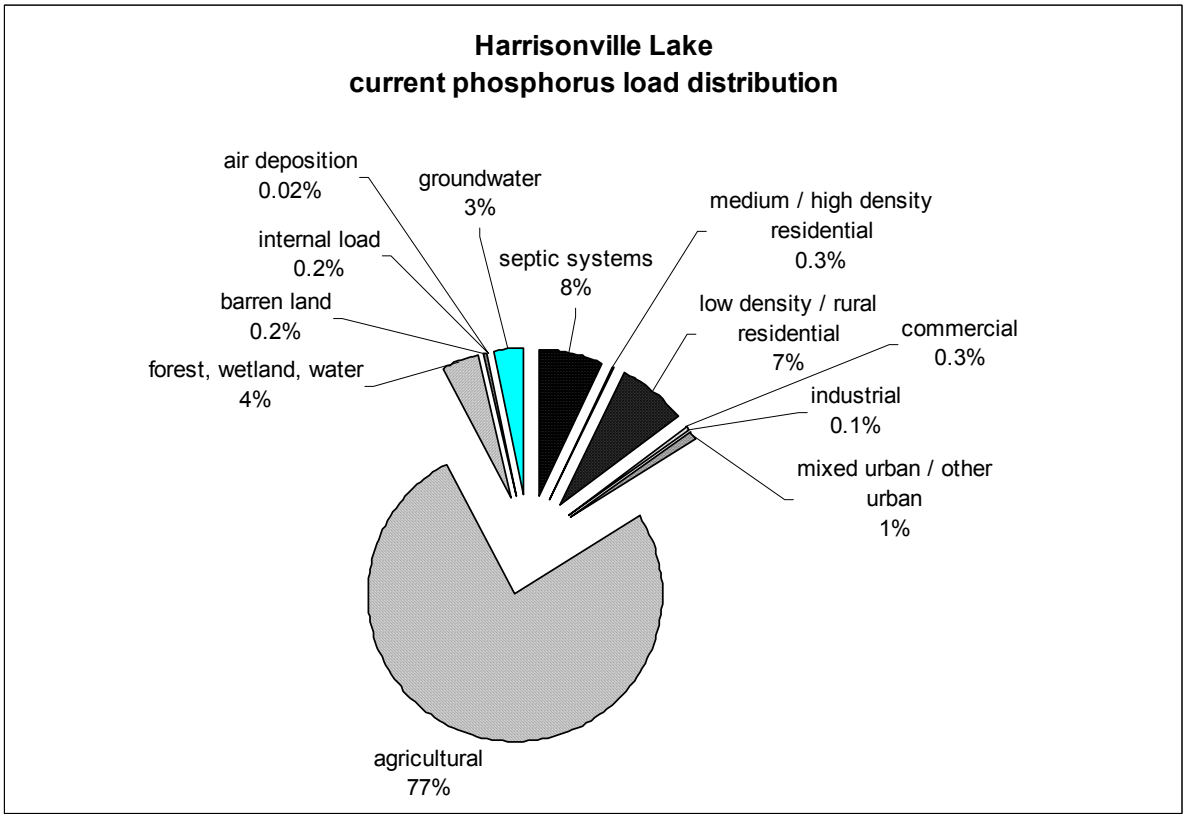


Figure 24 **Current distribution of phosphorus load for Kirkwood Lake**

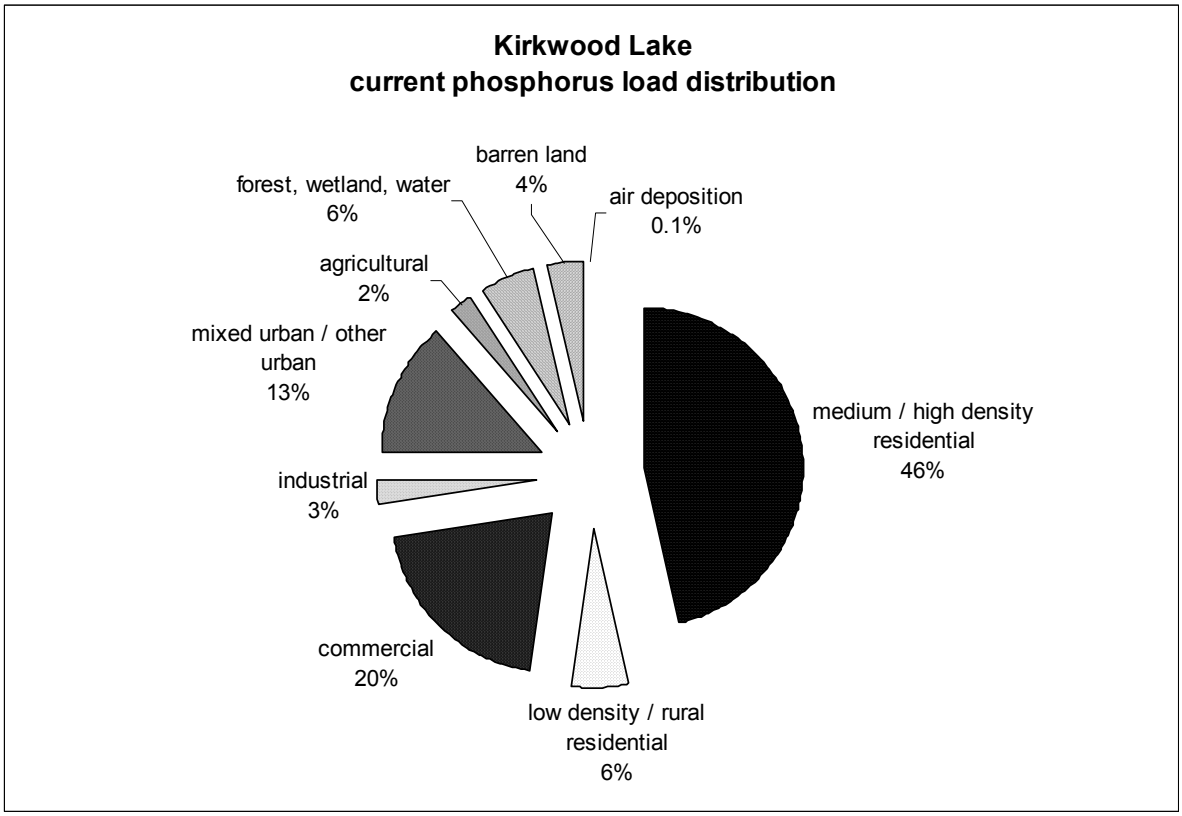


Figure 25 **Current distribution of phosphorus load for Woodbury Lake**

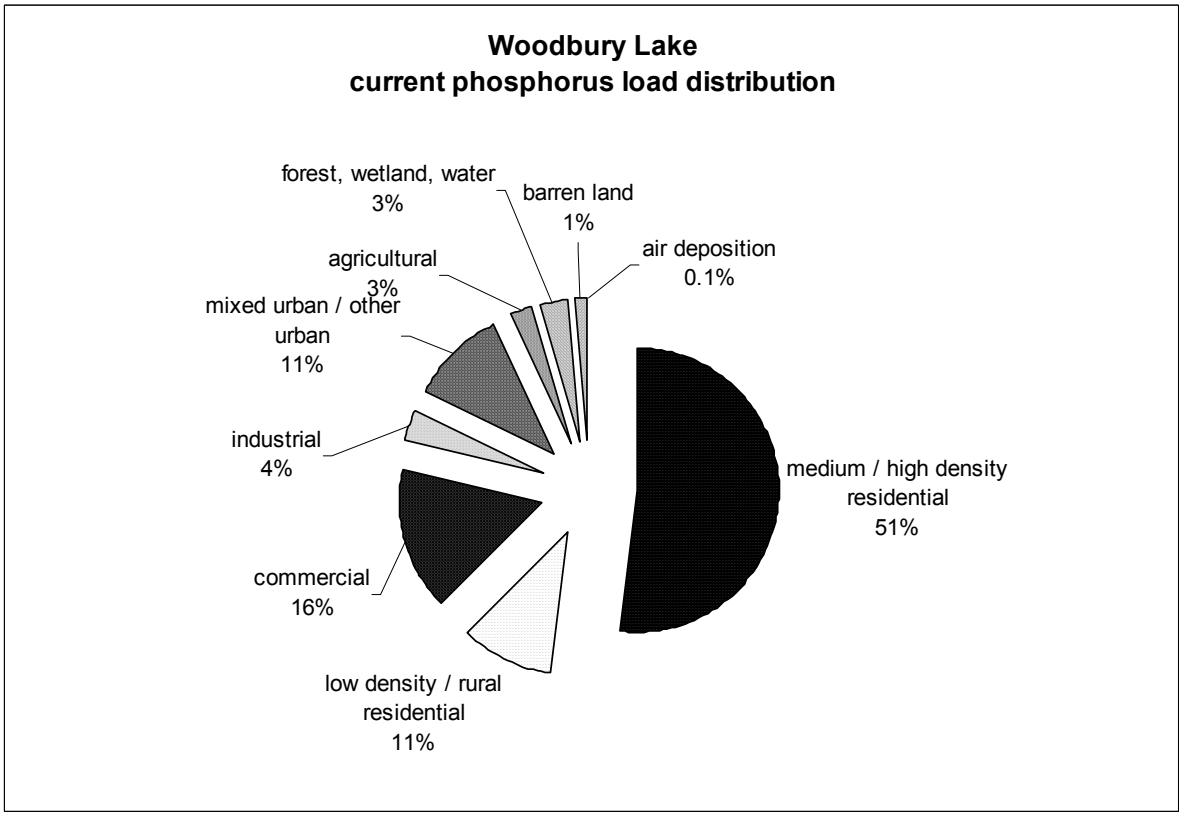


Figure 26 **Current distribution of phosphorus load for Imlaystown Lake**

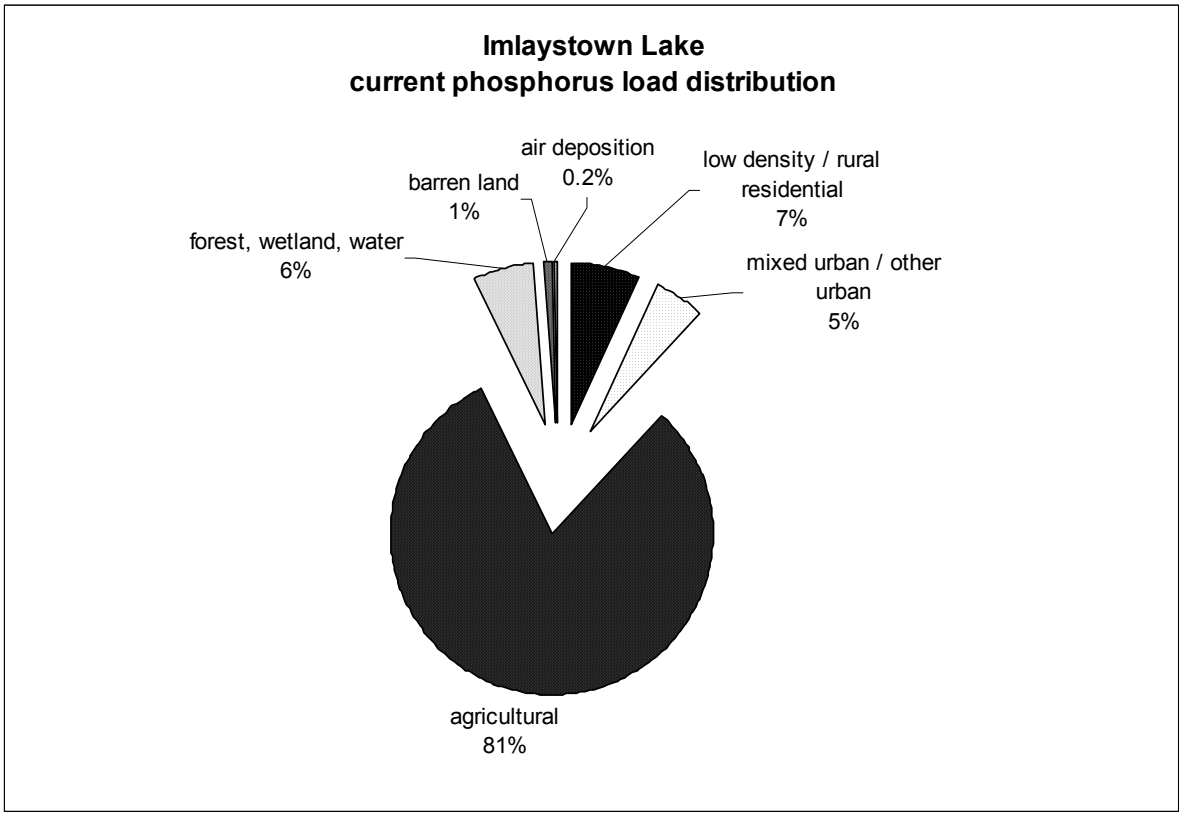
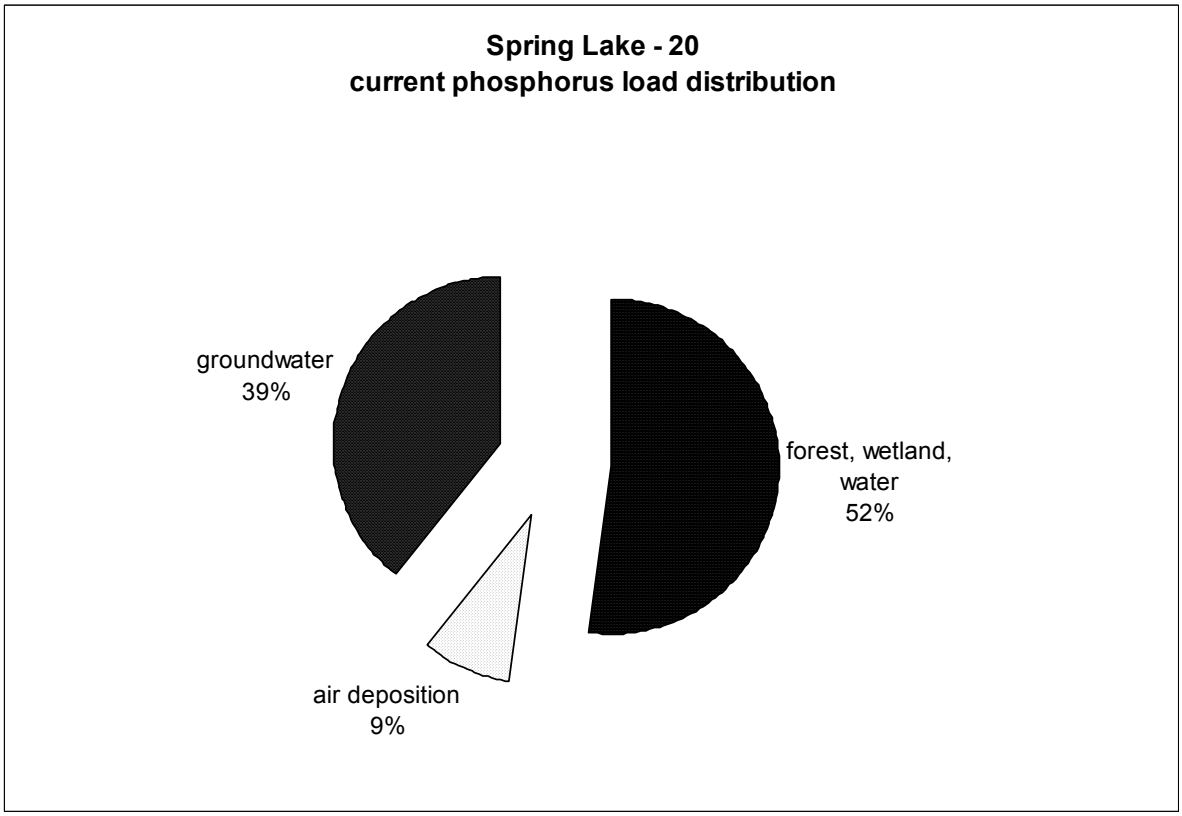


Figure 27 **Current distribution of phosphorus load for Spring Lake**



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. Estimates of air deposition and groundwater loads were included to calculate the reference condition. 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 9.

7.3 Seasonal Variation/Critical Conditions

These TMDLs will attain applicable surface water quality standards year round. The Reckhow model predicts steady-state phosphorus concentration. To account for data variability, the Department generally interprets threshold criteria as greater than 10% exceedance for the purpose of defining impaired waterbodies. 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 9. 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 conditions for Imlaystown Lake and Spring Lake was set equal to the current condition, since the upper bound prediction assuming current loads is already less than the target phosphorus concentration of 0.03 mg TP/l. The target condition for Mary Elmer Lake was used to calculate the tributary load for the target condition of Sunset 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 9). Because most of these lakes drain very large watersheds, the reference condition is very close to the target condition; overall load reduction necessary to achieve the target conditions are therefore quite substantial.

Table 9 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
Burnt Mill Pond	0.139	0.018	0.030	0.020	86%
Giampietro Lake	0.164	0.015	0.030	0.020	88%
Mary Elmer Lake	0.204	0.015	0.030	0.020	90%
Memorial Lake	0.141	0.012	0.030	0.020	86%
Sunset Lake	0.193	0.018	0.030	0.020	90%
Bell Lake	0.312	0.019	0.030	0.020	94%
Bethel Lake	0.118	0.011	0.030	0.020	83%
Blackwood Lake	0.112	0.012	0.030	0.020	82%
Harrisonville Lake	0.133	0.018	0.030	0.020	85%
Kirkwood Lake	0.083	0.011	0.030	0.020	76%
Woodbury Lake	0.108	0.011	0.030	0.020	82%
Imlaystown Lake	0.010	0.001	0.015	0.010	0%
Spring Lake	0.005	0.005	0.007	0.005	0%

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). Reducing the current loading rates by the percentages in Table 9 yields the same results. The acceptable loading capacity for each lake is provided in Tables 11-15.

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 (Tables 11-15):

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

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. 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 10. 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 10, 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 Tables 11-15 are not themselves "Additional Measures" under proposed N.J.A.C. 7:14A-25.6 or 25.8.

Table 10 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
septic systems	LA
internal load	LA
tributary load	LA

In order to attain the TMDLs, the overall load reductions shown in Table 9, or those determined through additional monitoring, 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 and septic sources that can be affected by BMP implementation or NJPDES regulation, requiring equal percent reductions from each in order to achieve the necessary overall load reduction (Tables 11-15). 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 Tables 11-15 and illustrated in Figures 28 to 40.

Table 11 TMDL calculations for each lake (annual loads and percent reductions[a])

lake	Burnt Mill Pond		%	Giampietro Lake		%	Mary Elmer Lake		%
	kg TP/yr	% of IC	reduction	kg TP/yr	% of IC	reduction	kg TP/yr	% of IC	reduction
loading capacity (LC)	290	100%	n/a	300	100%	n/a	380	100%	n/a
Point Sources other than Stormwater									
minor municipal	n/a			n/a			n/a		
Nonpoint and Stormwater Sources									
medium / high density residential	9.9	3.4%	91%	31	10%	90%	12	3.0%	91%
low density / rural residential	19	6.4%	91%	13	4.3%	90%	11	2.9%	91%
commercial	5.3	1.8%	91%	12	4.1%	90%	4.4	1.1%	91%
industrial	7.1	2.4%	91%	2.4	0.8%	90%	0.1	0.02%	91%
Mixed urban / other urban	7.5	2.6%	91%	11	3.8%	90%	3.8	1.0%	91%
agricultural	61	21%	91%	91	31%	90%	210	54%	91%
forest, wetland, water	73	25%	0%	31	11%	0%	13	3.3%	0%
barren land	10	3.6%	0%	3.6	1.2%	0%	2.9	0.8%	0%
septic systems									
waterfowl				0.8	0.3%	90%			
internal load									
tributary load	n/a			n/a			n/a		
Natural Sources / Background									
air deposition onto lake surface	0.6	0.2%	0%	0.4	0.1%	0%	0.6	0.2%	0%
groundwater									
Other Allocations									
explicit Margin of Safety	99	34%	n/a	100	34%	n/a	129	34%	n/a

a Percent reductions shown for individual sources are necessary to achieve overall reductions in Table 9.

Table 12 TMDL calculations for each lake (annual loads and percent reductions[a], cont'd)

lake	Memorial Lake		%	Sunset Lake		%	Bell Lake		%
	kg TP/yr	% of IC	reduction	kg TP/yr	% of IC	reduction	kg TP/yr	% of IC	reduction
loading capacity (LC)	930	100%	n/a	2500	100%	n/a	17	100%	n/a
Point Sources other than Stormwater									
minor municipal	n/a			n/a			n/a		
Nonpoint and Stormwater Sources									
medium / high density residential	1.8	0.2%	88%	25	1.0%	92%	7.8	45%	94%
low density / rural residential	17	1.8%	88%	52	2.1%	92%	0.04	0.2%	94%
commercial	6.3	0.7%	88%	14	0.5%	92%	3.0	17%	94%
industrial	6.3	0.7%	88%	3.8	0.2%	92%	0.1	0.4%	94%
Mixed urban / other urban	9.3	1.0%	88%	22	0.9%	92%	0.3	1.7%	94%
agricultural	490	53%	88%	1000	42%	92%		0.0%	94%
forest, wetland, water	78	8.4%	0%	210	8.2%	0%	0.2	1.2%	0%
barren land	4.2	0.5%	0%	19	0.8%	0%			
septic systems									
waterfowl									
internal load									
tributary load	n/a			190	7.7%	90%	n/a		
Natural Sources / Background									
air deposition onto lake surface	0.6	0.1%	0%	2.5	0.1%	0%	0.1	0.3%	0%
groundwater				80	3.2%	0%			
Other Allocations									
explicit Margin of Safety	310	34%	n/a	850	34%	n/a	5.8	34%	n/a

a Percent reductions shown for individual sources are necessary to achieve overall reductions in Table 9.

Table 13 TMDL calculations for each lake (annual loads and percent reductions[a], cont'd)

lake	Bethel Lake		% reduction	Blackwood Lake		% reduction	Harrisonville Lake		% reduction
	kg TP/yr	% of IC		kg TP/yr	% of IC		kg TP/yr	% of IC	
loading capacity (LC)	540	100%	n/a	1200	100%	n/a	500	100%	n/a
Point Sources other than Stormwater									
minor municipal	n/a			n/a			n/a		
Nonpoint and Stormwater Sources									
medium / high density residential	150	28%	85%	260	21.8%	88%	0.5	0.1%	92%
low density / rural residential	21	3.9%	85%	35	2.9%	88%	13	2.6%	92%
commercial	27	5.0%	85%	69	5.7%	88%	0.6	0.1%	92%
industrial	6.4	1.2%	85%	8.8	0.7%	88%	0.2	0.1%	92%
Mixed urban / other urban	28	5.2%	85%	57	4.7%	88%	2.0	0.4%	92%
agricultural	65	12%	85%	55	4.6%	88%	134	28%	92%
forest, wetland, water	43	8.1%	0%	170	13.7%	0%	88	18%	0%
barren land	13	2.4%	0%	140	12.0%	0%	4.7	0.9%	0%
septic systems							12	2.5%	92%
waterfowl									
internal load							5.2	1.0%	0%
tributary load	n/a			n/a			n/a		
Natural Sources / Background									
air deposition onto lake surface	0.3	0.1%	0%	0.4	0.04%	0%	0.5	0.1%	0%
groundwater							71	14%	0%
Other Allocations									
explicit Margin of Safety	180	34%	n/a	410	34%	n/a	170	34%	n/a

a Percent reductions shown for individual sources are necessary to achieve overall reductions in Table 9.

Table 14 TMDL calculations for each lake (annual loads and percent reductions[a], cont'd)

lake	Kirkwood Lake		%	Woodbury Lake		%	Imlaystown Lake		%
	kg TP/yr	% of IC	reduction	kg TP/yr	% of IC	reduction	kg TP/yr	% of IC	reduction
loading capacity (LC)	380	100%	n/a	350	100%	n/a	390	100%	n/a
Point Sources other than Stormwater									
minor municipal	n/a			n/a			n/a		
Nonpoint and Stormwater Sources									
medium / high density residential	79	21%	84%	95	27.5%	85%			
low density / rural residential	9.8	2.6%	84%	19	5.6%	85%	18	4.5%	0%
commercial	34	9.2%	84%	30	8.6%	85%			
industrial	4.4	1.2%	84%	6.7	1.9%	85%			
Mixed urban / other urban	23	6.0%	84%	20	5.7%	85%	13	3.3%	0%
agricultural	3.9	1.0%	84%	5.0	1.4%	85%	210	54%	0%
forest, wetland, water	57	15%	0%	38	10.9%	0%	16	4.0%	0%
barren land	37	9.9%	0%	15	4.2%	0%	2.2	0.6%	0%
septic systems									
waterfowl									
internal load									
tributary load	n/a			n/a			n/a		
Natural Sources / Background									
air deposition onto lake surface	0.7	0.2%	0%	1.3	0.4%	0%	0.5	0.1%	0%
groundwater									
Other Allocations									
explicit Margin of Safety	130	34%	n/a	120	34%	n/a	130	34%	n/a

a Percent reductions shown for individual sources are necessary to achieve overall reductions in Table 9.

Table 15 **TMDL calculations for each lake (annual loads and percent reductions[a], cont'd)**

lake	Spring Lake		%
	kg TP/yr	% of IC	reduction
loading capacity (LC)	11	100%	n/a
Point Sources other than Stormwater			
minor municipal	n/a		
Nonpoint and Stormwater Sources			
medium / high density residential			
low density / rural residential			
commercial			
industrial			
Mixed urban / other urban			
agricultural			
forest, wetland, water	3.8	35%	0%
barren land			
septic systems			
waterfowl			
internal load			
tributary load	n/a		
Natural Sources / Background			
air deposition onto lake surface	0.6	5.6%	0%
groundwater	2.8	26%	0%
Other Allocations			
explicit Margin of Safety	3.7	34%	n/a

a Percent reductions shown for individual sources are necessary to achieve overall reductions in Table 9.

Figure 28 **Phosphorus allocations for Burnt Mill Pond TMDL**

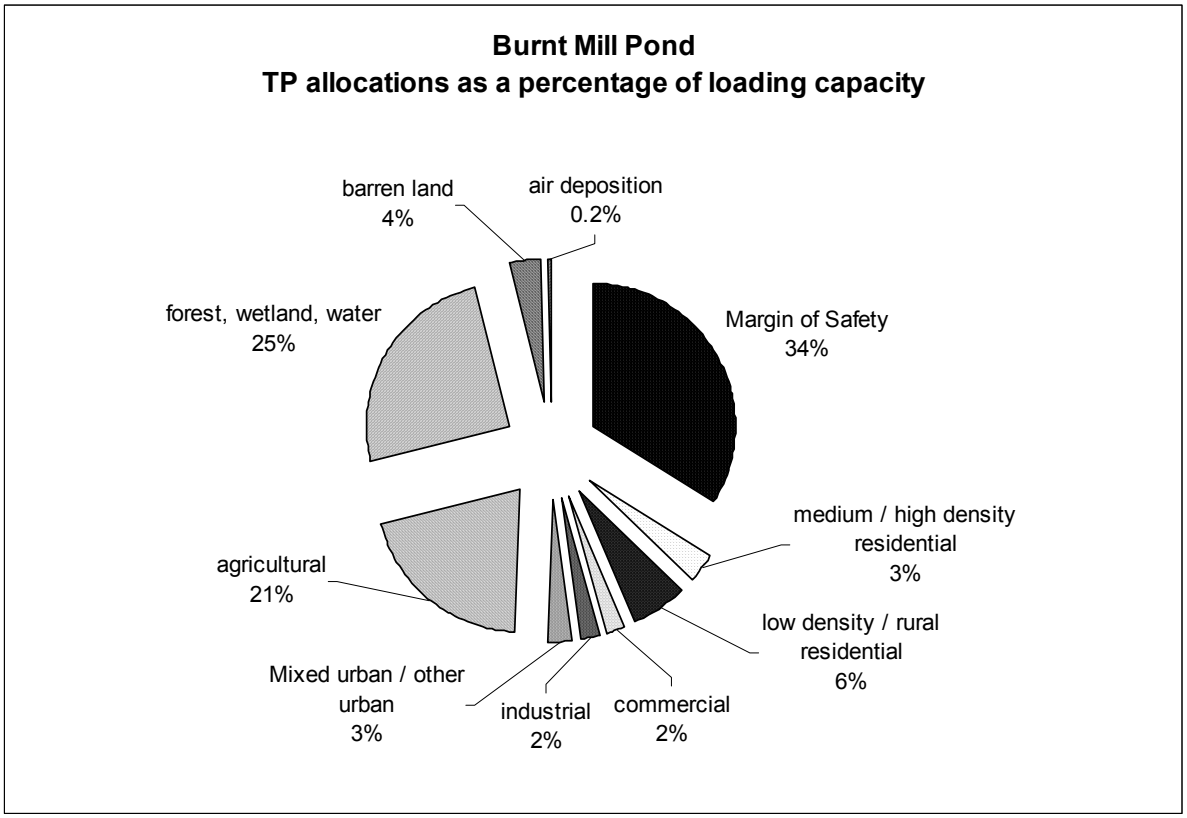


Figure 29 **Phosphorus allocations for Giampietro Lake**

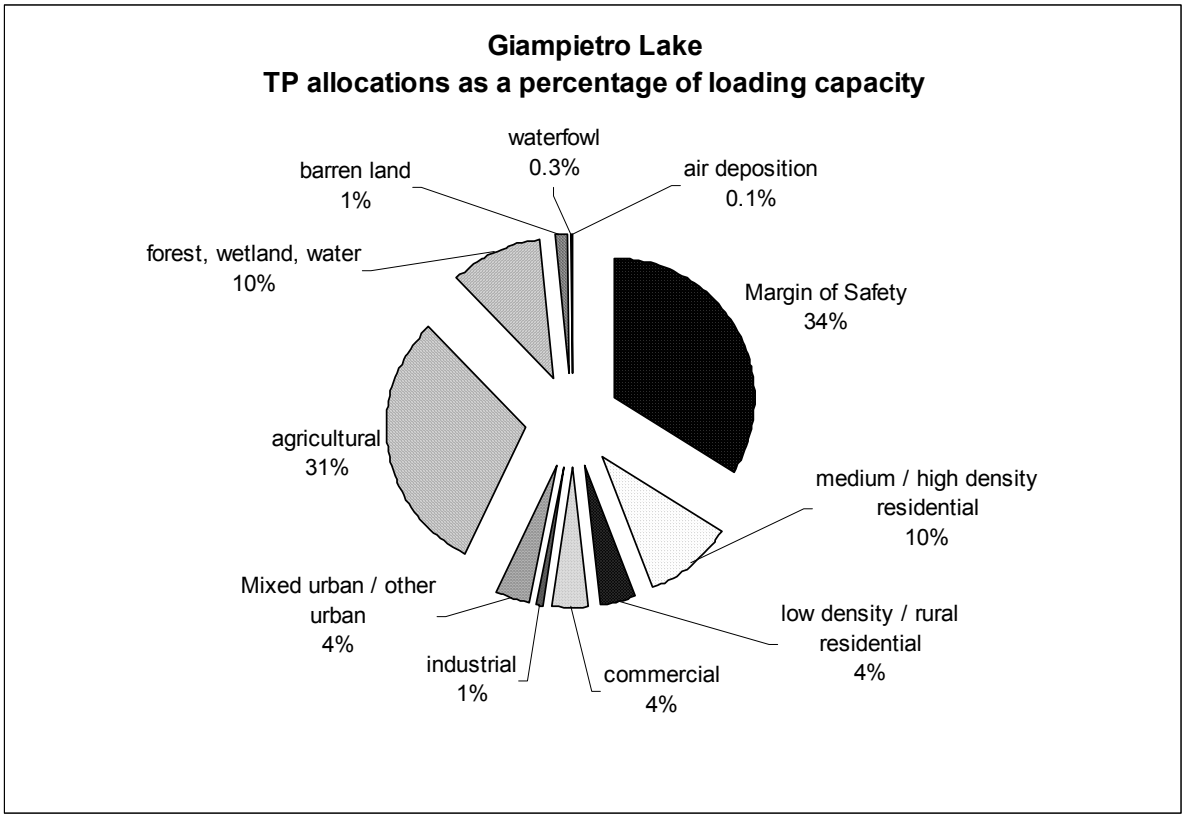


Figure 30 **Phosphorus allocations for Mary Elmer Lake**

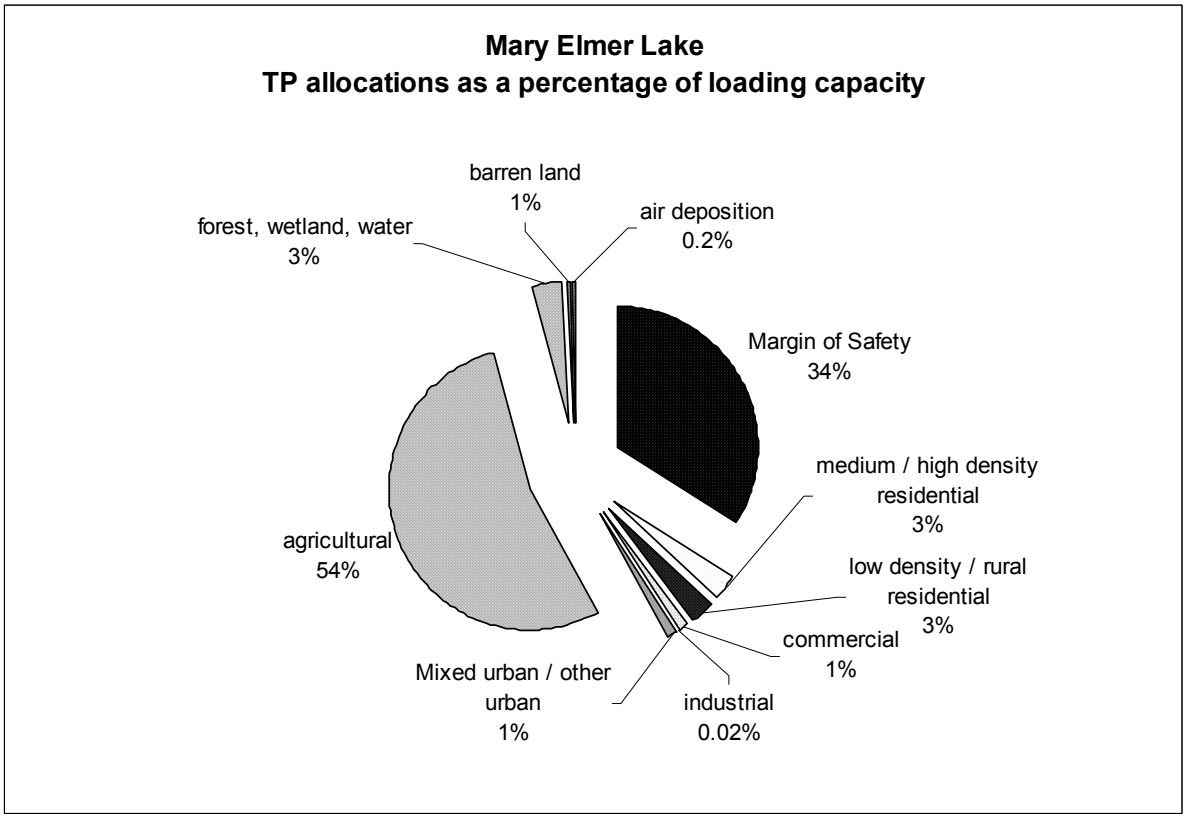


Figure 31 **Phosphorus allocations for Memorial Lake**

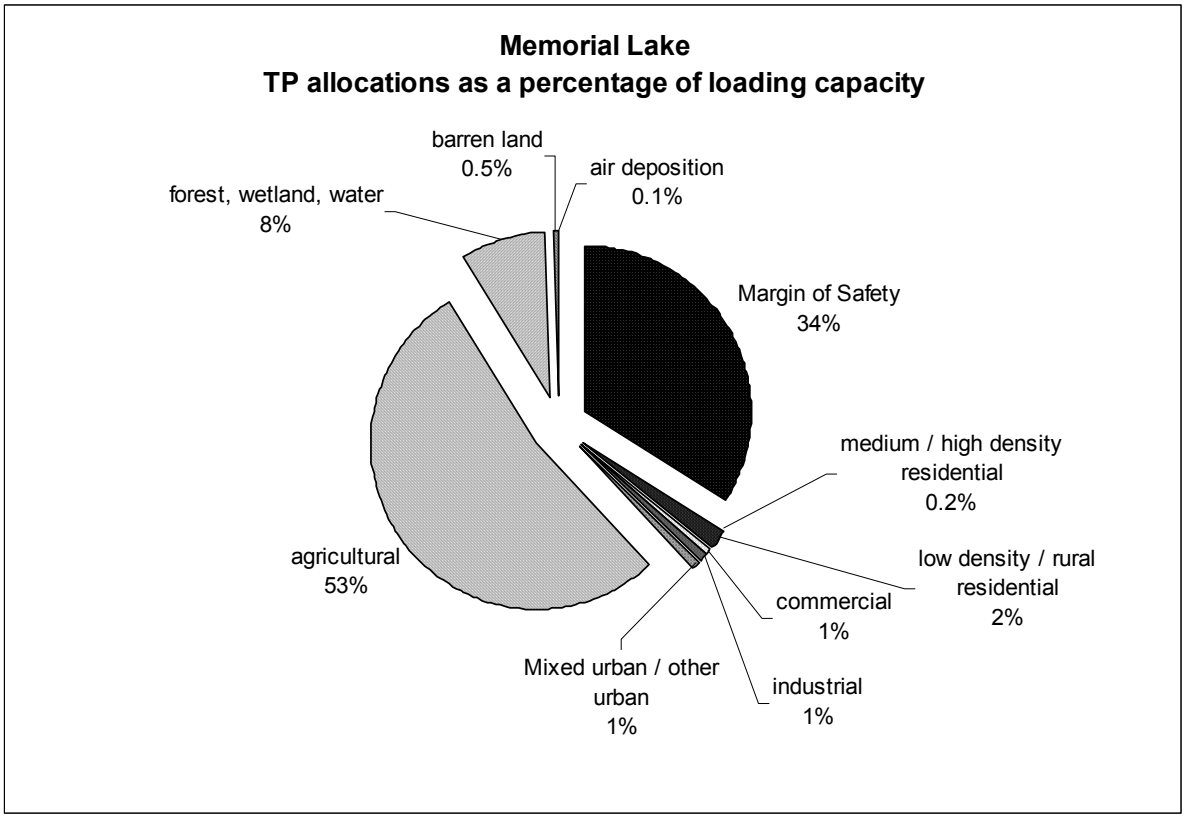


Figure 32 **Phosphorus allocations for Sunset Lake**

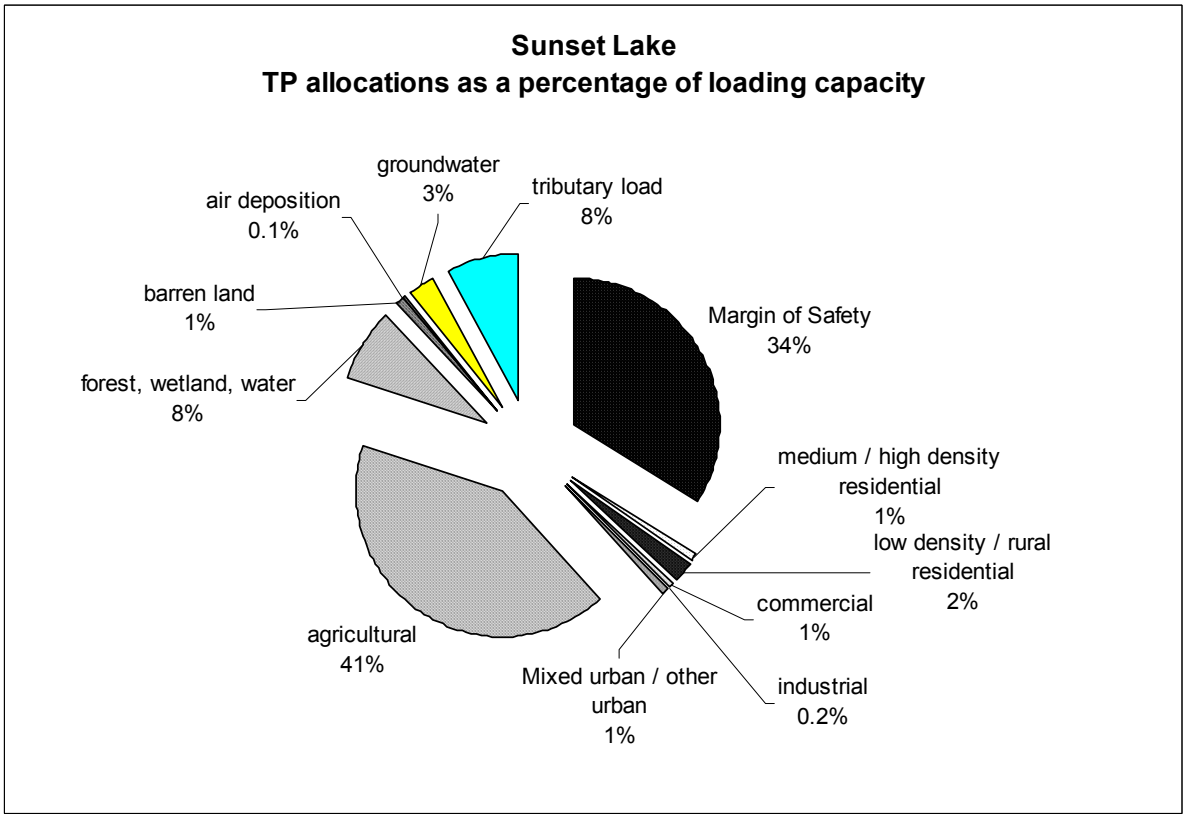


Figure 33 **Phosphorus allocations for Bell Lake**

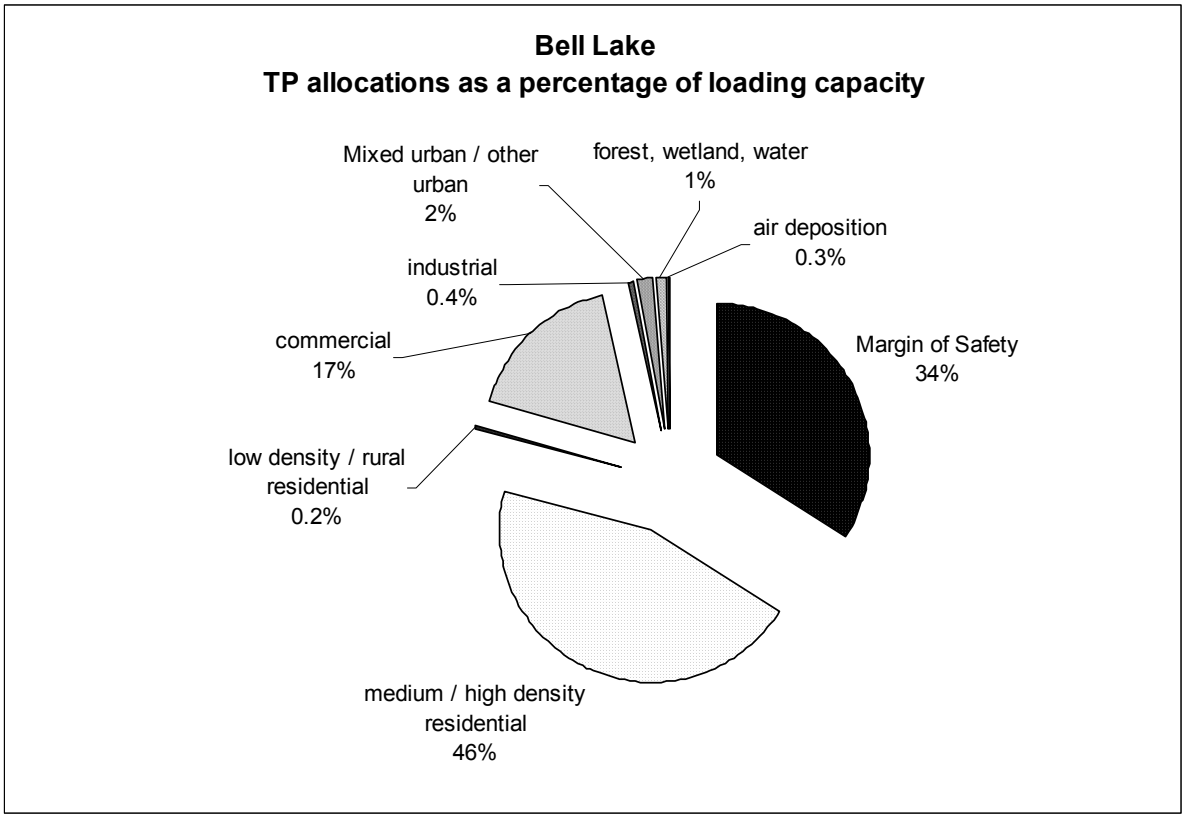


Figure 34 **Phosphorus allocations for Bethel Lake**

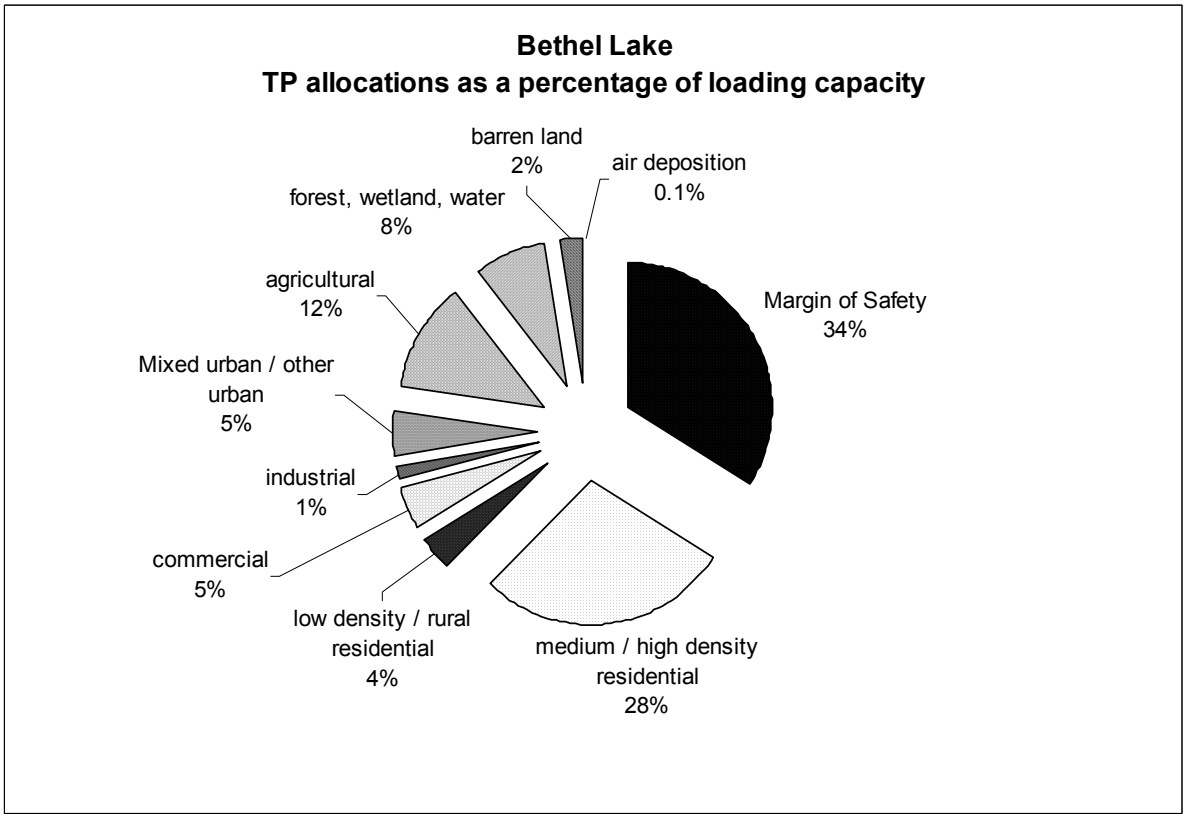


Figure 35 **Phosphorus allocations for Blackwood Lake**

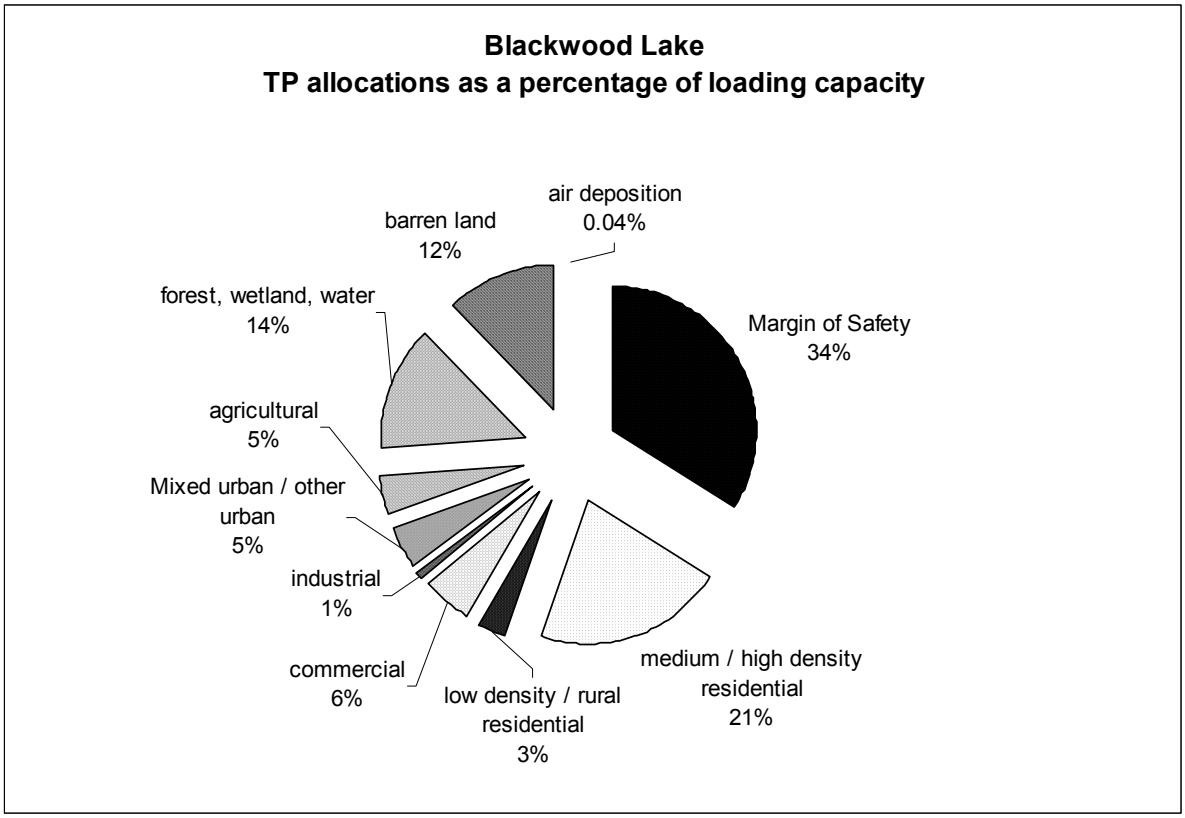


Figure 36 **Phosphorus allocations for Harrisonville Lake**

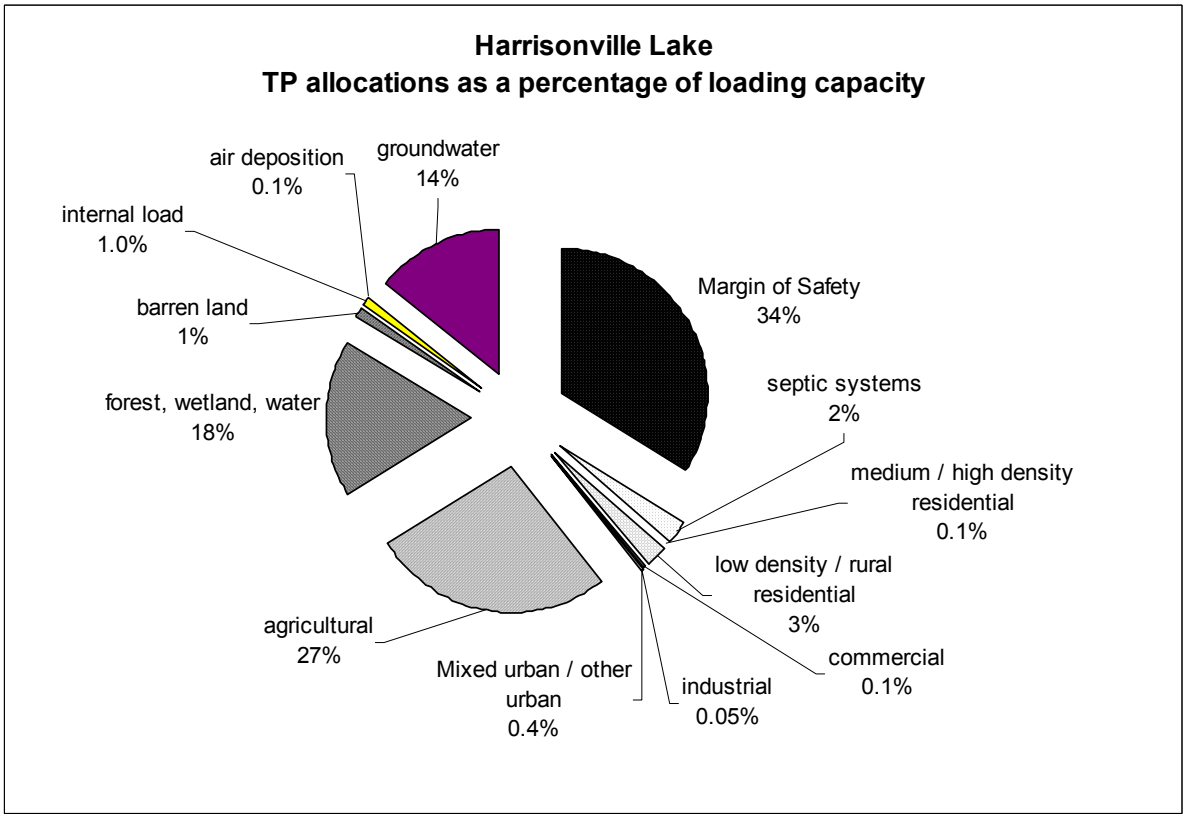


Figure 37 **Phosphorus allocations for Kirkwood Lake**

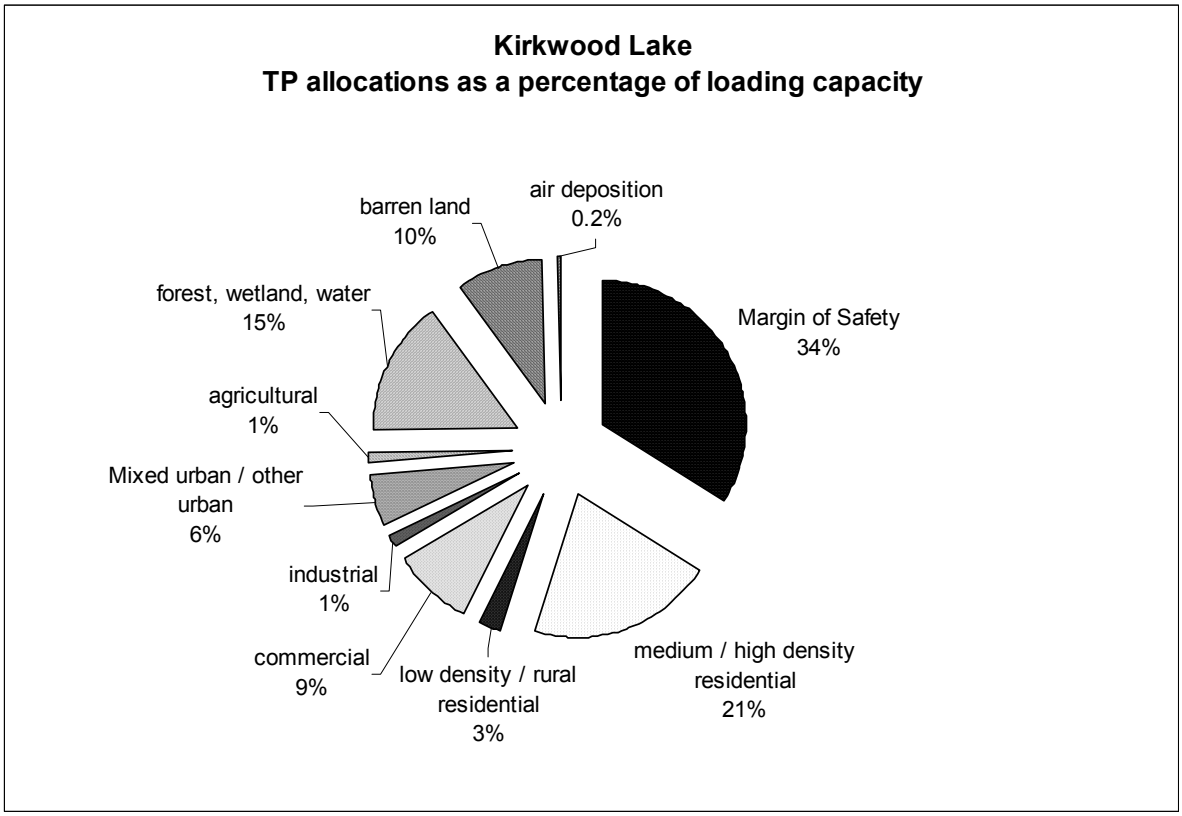


Figure 38 **Phosphorus allocations for Woodbury Lake**

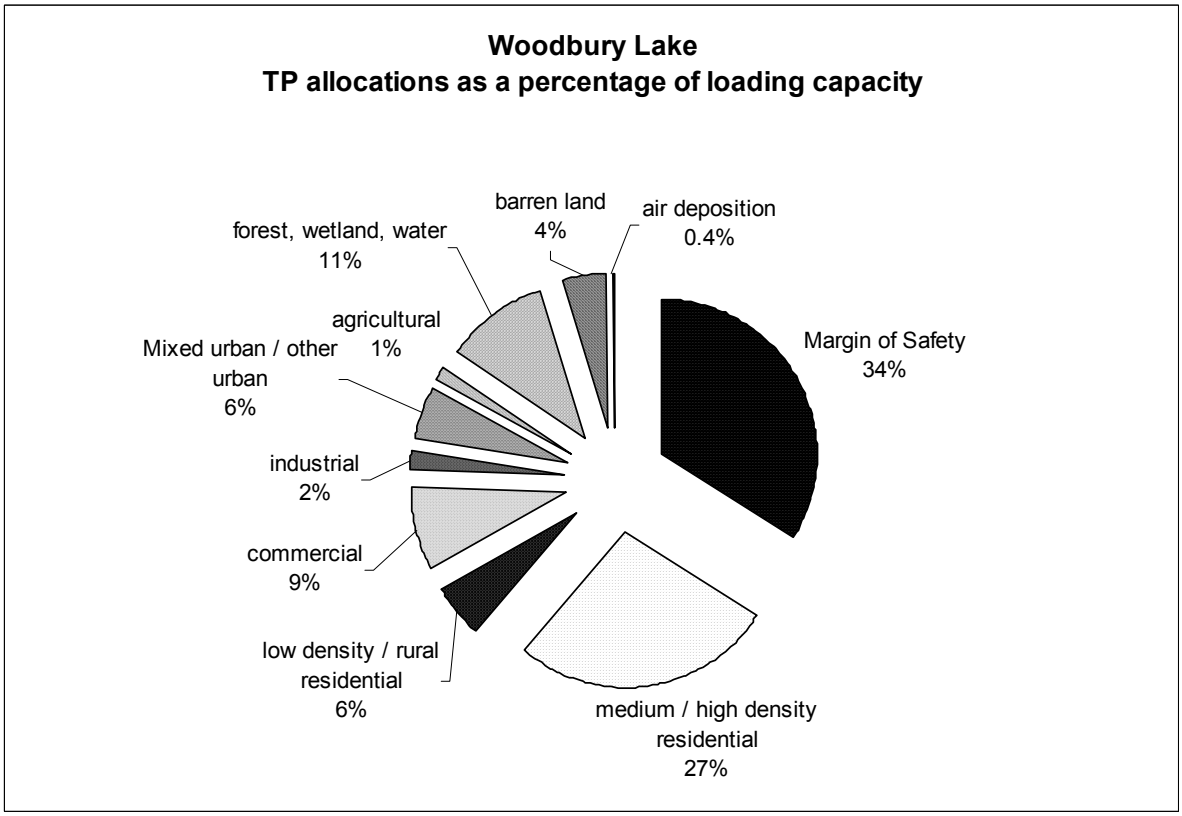


Figure 39 **Phosphorus allocations for Imlaystown Lake TMDL**

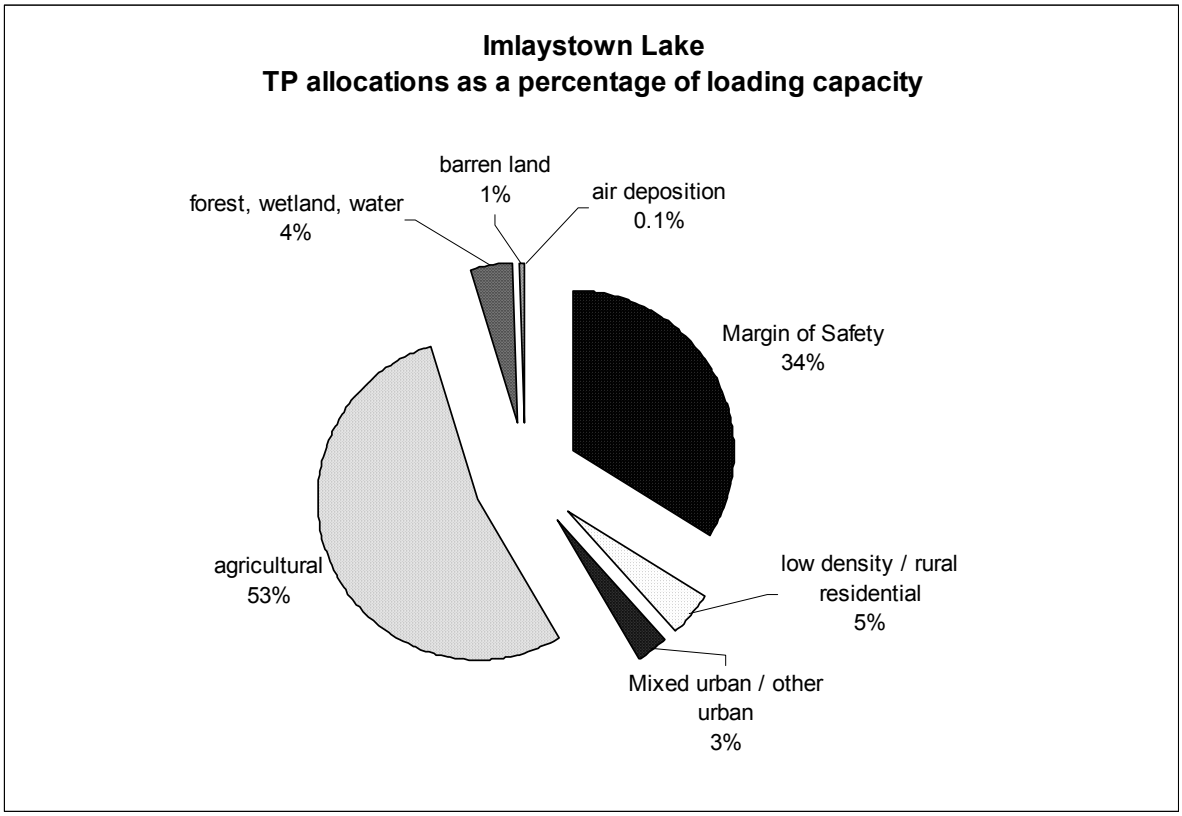
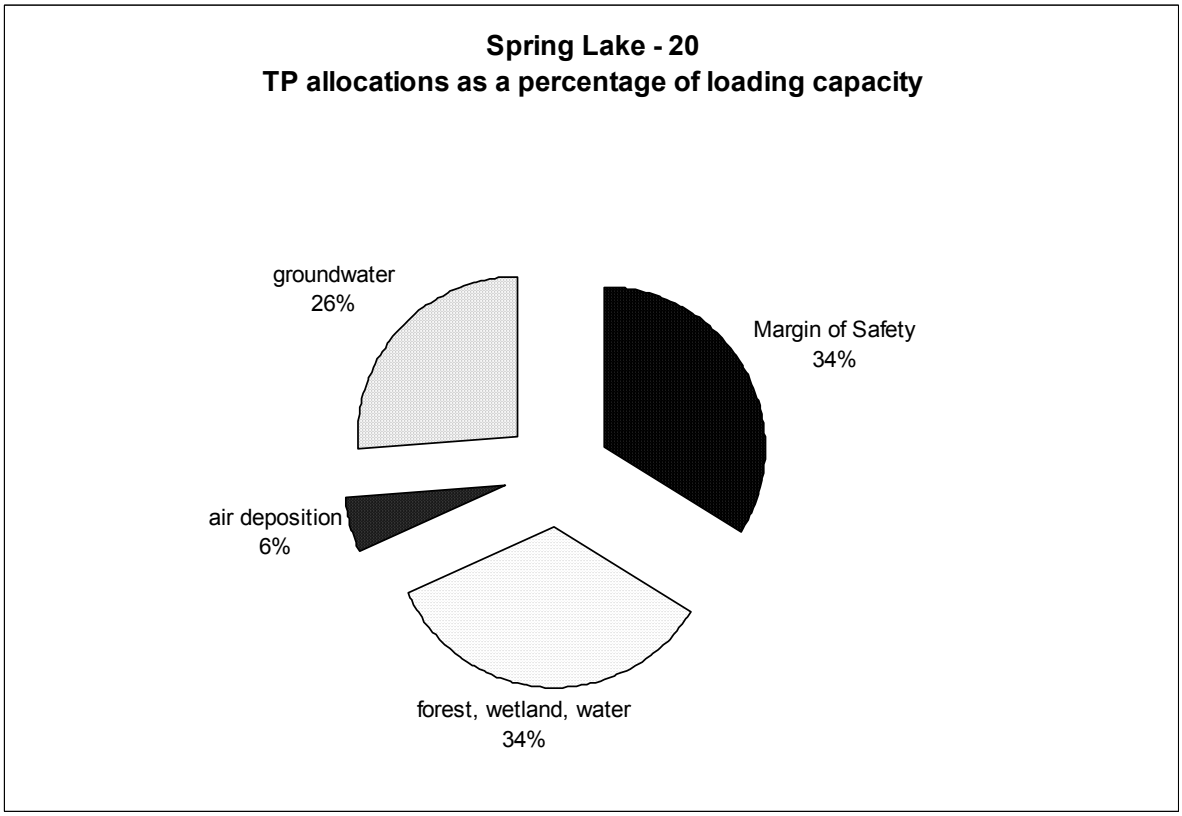


Figure 40 **Phosphorus allocations for Spring Lake TMDL**



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 next steps toward implementation are preparation of lake characterizations and lake restoration plans, where they have not already been developed. In the development of these plans, the loads by source will be revised, as necessary, to reflect refinements in source contributions. It will be on the basis of refined source estimates that specific strategies for reduction will be developed. These will consider issues such as cost and feasibility when specifying the reduction target for any source or source type. As appropriate, WLAs or other measures to be applied to traditional or stormwater point sources through NJPDES permits will be adopted by the Department as amendments to the applicable areawide Water Quality Management Plan.

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 of these lakes are shallow lakes, as defined by having a mean depth less than 3 meters. For a lake to be shallow means 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 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. The Lake Restoration Plans for each lake will need to consider the ecological nuances of shallow and deep 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.

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 Lower Delaware 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, public 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.

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.

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

Additional monitoring may be performed in order to develop the Lake Restoration Plans to implement these TMDLs. The level of characterization necessary to plan restoration will be specific to individual lakes depending on the remedial options being considered. During at least one or two summer trips, the following information may be collected as necessary.

- 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 16.

Table 16 Implementation Schedule

Lake	Lake Characterization	Lake Restoration Plan
Burnt Mill Pond[a]	Summer 2008	Spring 2009
Giampietro Lake[a]	Summer 2009	Spring 2010
Mary Elmer Lake	Summer 2004	Spring 2005
Memorial Lake	Summer 2006	Spring 2007
Sunset Lake	Summer 2004	Spring 2005
Alcyon Lake	Summer 2005	Spring 2006
Bell Lake[a]	Summer 2009	Spring 2010
Bethel Lake	Summer 2006	Spring 2007
Blackwood Lake[a]	Summer 2008	Spring 2009
Grenloch Lake	Summer 2005	Spring 2006
Harrisonville Lake[b]	Completed 2002	Completed March 2003
Kirkwood Lake	Summer 2006	Spring 2007
Woodbury Lake	Summer 2007	Spring 2008
Allentown Lake	Summer 2005	Spring 2006
Imlaystown Lake[c]	Summer 2007	Spring 2008
Spring Lake[c]	Summer 2007	Spring 2008

a The Diagnostic / Feasibility studies for these lakes (F.X. Browne; 1993, 1989, 1989, 1992) provide some of the Lake Characterization information necessary to develop the Lake Restoration Plan. This schedule provides for additional biological monitoring and evaluation in order to restore a clear-water condition in the lake.

b The Diagnostic / Feasibility study of Harrisonville Lake (Princeton Hydro, 2003) fulfills the TMDL requirements for lake characterization and lake restoration planning.

c Nutrient reductions are not required for these lakes. However, this schedule provides for additional biological monitoring and evaluation in order to restore a clear-water condition in the lake.

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 16. 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 require 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. Further, the Department shall propose each TMDL as an amendment to the appropriate areawide water quality management plan in accordance with procedures at N.J.A.C. 7:15-3.4(g). As part of the public participation process for the development and implementation of the TMDLs for phosphorus to address eutrophic lakes in the Lower Delaware Water Region, the Department 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 includes a comprehensive stakeholder process that includes of members from major stakeholder groups, (agricultural, business and industry, academia, county and municipal officials, commerce and industry, purveyors and dischargers, and environmental groups). As part of this watershed management planning process, Public Advisory Committees (PACs) and Technical Advisory Committees (TACs) were created in all 20 WMAs. The PACs serve in an advisory capacity to the Department, examining and commenting on a myriad of issues in the watersheds. The TACs are focused on scientific, ecological, and engineering issues relevant to the issues of the watershed, including water quality impairments and management responses to address them.

Through a series of presentations and discussions the Department engaged the WMA 17, 18, 19 and 20 PACs and TACs in a process that culminated in the development of 13 phosphorus TMDLs for eutrpohic Lakes in the Lower Delaware Water Region. One or two meetings, as specified below, were held in each WMA. At the PAC meetings, the expedited eutrhopic lake TMDL protocols and the executed Memorandum of Agreement between the Department and EPA Region 2 were described, including the associated schedule for completing TMDLs. The PACs were asked to review the list of lakes and provide local insight. Maps with aerial photography and topography of the lakes were provided to facilitate the conversation. In most cases, a second meeting was held with the TAC and/or a smaller working group to identify areas of concern based on their local knowledge. TAC members were encouraged to provide any additional source information through the formal comment period after advertisement of the TMDL proposal in the New Jersey Register. The dates of the meetings were as follows:

WMA	PAC Meeting	TAC Meeting
17	December 10, 2002	January 22, 2003
18	December 3, 2002	December 3, 2002
19	November 13, 2002	December 10, 2002
20	November 13, 2002	December 3, 2002

Additional input was received through the NJ EcoComplex (NJEC). The Department contracted with NJEC in July 2001. The NJEC consists of a review panel of New Jersey University professors whose role is to provide comments on the Department's technical approaches for development of TMDLs and management strategies. The New Jersey Statewide Protocol for Developing Fecal TMDLs was presented to NJEC on August 7, 2002 and was subsequently reviewed and approved. The protocol was also presented at the SETAC Fall Workshop on September 13, 2002 and met with approval.

Appendix A: References

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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:

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