PHOSPHORUS CONTROL ACTION PLAN

and Total Maximum Daily (Annual Phosphorus) Load Report

ANNABESSACOOK LAKE

Kennebec and Androscoggin Counties, Maine

Annabessacook Lake PCAP-TMDL Report

Maine DEPLW 2003 - 0627

Maine Department of Environmental Protection

COBBOSSEE WATERSHED DISTRICT and

Maine Association of Conservation Districts

Final EPA Review Document — May 6, 2004

ANNABESSACOOK LAKE Phosphorus Control Action Plan (PCAP)

Table of Contents

APPENDICES

ANNABESSACOOK LAKE

Total Maximum Daily (Annual Phosphorus) Load

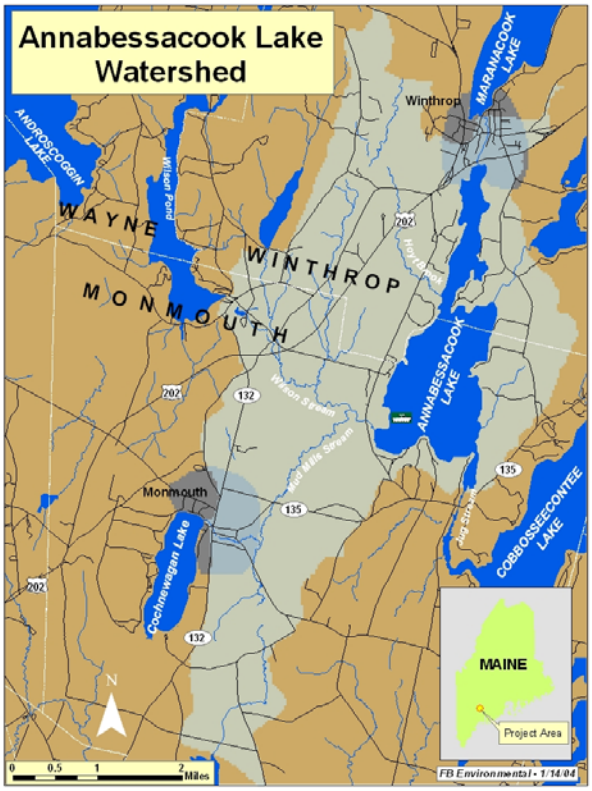
ACKNOWLEDGMENTS

In addition to Maine DEP and US-EPA Region I staff, the following individuals and groups were instrumental in the preparation of this Annabessacook Lake Phosphorus Control Action Plan-Total Maximum Daily (Annual Phosphorus) Load Report: Cobbossee Watershed District (Bill Monagle and Wendy Dennis); Maine Association of Conservation Districts staff (Jodi Michaud-Federle, Forrest Bell, and Tim Bennett); Towns of Monmouth and Winthrop (Office staff); Kennebec County Soil and Water Conservation District (Nate Sylvester and Dale Finseth); Natural Resources Conservation Service (Dick Ferland); Annabessacook Lake Improvement Association (Bob Turner and Doug Grant); VLMP Monitors (Mike Becker and Tom Hughes); Friends of the Cobbossee Watershed (Bob Moore); S. Elizabeth Young (Winthrop Code Enforcement Officer); Jan Healy (Winthrop Assessor), and fish biologists Jim Lucas and Bill Woodward (Maine Department of Inland Fish and Wildlife, Sidney).

Annabessacook Lake Phosphorus Control Action Plan - Summary Fact Sheet

Background

ANNABESSACOOK LAKE is a 1,391 acre water-body situated in the towns of Monmouth and Winthrop in Kennebec County, south-central Maine. Annabessacook Lake has a direct **watershed** (see map) area of 13,543 acres (21 square miles) and is located within the towns of Monmouth, Winthrop, and to a much lesser extent, Wales (Androscoggin County). This lake has a maximum depth of 47 feet, a mean depth of 17 feet; and a **flushing rate** of 3.7 times per year, more than twice the average for Maine lakes (1.5). The total Annabessacook Lake watershed, inclusive of four upstream lakes (Maranacook, Cochnewagon, Wilson and Lower Narrows), is 83.5 square miles.



Annabessacook Lake has a history of supporting excessive amounts of algae in the late summer, due in large part to the contribution of phosphorus in the form of nonpoint source pollution. Phosphorus is prevalent in area soils and has annually accumulated in the lake bottom sediments. Soil erosion in the Annabessacook Lake watershed can have far-reaching consequences, as soil particles effectively transport phosphorus, which serves to "fertilize" the lake and decreases water clarity. Excess phosphorus can also harm fish habitat and lead to nuisance algae blooms—floating mats of green scum (dead and dying algae). Studies show that as water clarity decreases, lakeshore property values also decline. Notably, the overall water quality of Annabessacook Lake has shown some gradual improvement in recent years.

Stakeholder Involvement

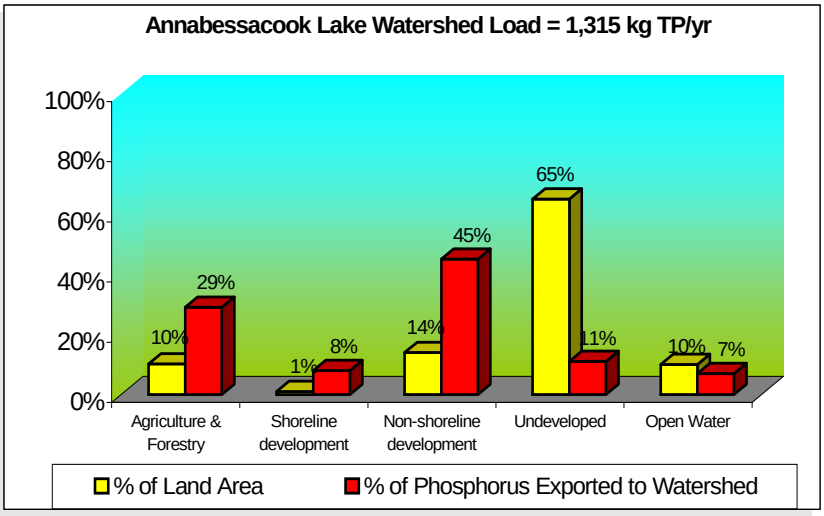
Federal, state, county, and local groups have been working together to effectively address this nonpoint source water pollution problem. In 2001, the Maine Department of Environmental Protection funded a project in cooperation with the Cobbossee Watershed District, the Maine Association of Conservation Districts, Kennebec County Soil and Water Conservation District, and the Annabessacook Lake Improvement Association, to identify and quantify the potential sources of phosphorus and identify the **Best Management Practices** needed to be installed in the watershed. A final report, completed in the spring of 2004, is entitled "Annabessacook Lake Phosphorus Control Action Plan" and doubles as a **TMDL** report, to be submitted to the United States Environmental Protection

View of Northern End of Lake from Route 202

Agency, New England Region, for their final review and approval.

What We Learned

A land use assessment was conducted for the Annabessacook Lake watershed to determine potential sources of phosphorus that may run off from land areas during storm events and springtime snow melting. This assessment utilized many resources, including generating and interpreting maps, inspecting aerial photos, and conducting field surveys.



An estimated 1,315 kilograms (kg) of phosphorus per year is exported to Annabessacook Lake from its direct watershed. The bar chart illustrates the land area for each land use relative to its total phosphorus export load. This information, which is detailed in the full report, will help Annabessacook Lake stakeholder groups to effectively prioritize future BMP projects for NPS pollution mitigation in the watershed.

Phosphorus Reduction Needed

Annabessacook Lake has a natural capacity to effectively process up to 2,485 kg of phosphorus annually without harming water quality. This amount of equates to an in-lake phosphorus concentration of 15 parts per billion (ppb). Annabessacook Lake's actual in-lake average annual total phosphorus (TP) concentration is 17 ppb, equal to 2,817 kg TP. Taking into account an 83 kg allocation for potential future watershed development, the total amount of phosphorus needed to be reduced to maintain water quality (bloom-free conditions) standards in Annabessacook Lake is estimated to be 415 kg.

What You Can Do To Help!

As a watershed resident, there are many things you can continue to do to protect the water quality of Annabessacook Lake. Lakeshore owners can use phosphorus-free fertilizers and maintain natural vegetation adjacent to the lake. Agricultural and commercial land users and watershed residents can consult the Cobbossee Watershed District, Kennebec County Soil and Water Conservation District or Maine DEP for information regarding Best Management Practices (BMPs) for reducing phosphorus loads. Watershed residents can become involved by volunteering to help the Annabessacook Lake Improvement Association and participating in events sponsored by the Friends of the Cobbossee Watershed. Lakeshore and watershed residents can learn more about their lake and the many resources available by reviewing the Annabessacook Lake Phosphorus Control Action Plan. Following final EPA approval, copies of this report, with recommendations for future NPS/BMP work, will be available online at www.state.me.us/dep/blwq/docmonitoring/tmdl2.htm, or can be viewed and/or copied (at cost) at the Maine DEP offices in Augusta.

Key Terms

- ***Watershed*** *is a drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.*
- ***Flushing rate*** *refers to how often the water in the entire lake is replaced on an annual basis..*
- ***Phosphorus*** *is one of the major nutrients needed for plant growth. It is naturally present in small amounts and limits the plant growth in lakes. Generally, as phosphorus increases, the amount of algae also increases.*
- ***Nonpoint source pollution*** *is polluted runoff that cannot be traced to a specific origin or starting point, but appears to flow from many different sources.*
- ***Best Management Practices*** *are techniques to reduce sources of polluted runoff and their impacts. BMP's are low cost, common sense approaches to reduce storm runoff and velocity to keep soil out of lakes and tributaries.*
- ***TMDL*** *is an acronym for Total Maximum Daily Load which represents the total amount of a pollutant (e.g., phosphorus) that a waterbody can receive on an annual basis and still meet water quality standards.*
- ***Epilimnetic*** *refers to the uppermost, warmest, well-mixed layer of a lake during summertime thermal stratification.*

Project Premise

This project, funded through a 319-grant from the United States Environmental Protection Agency (EPA), was directed and administered by the Maine Department of Environmental Protection (Maine DEP) under contract with the Cobbossee Watershed District (CWD) and the Maine Association of Conservation Districts (MACD), from summer 2001 through late spring of 2004.

The objectives of this project were twofold: First, a comprehensive land use inventory was undertaken to assist Maine DEP in developing a Phosphorus Control Action Plan (PCAP) and a Total Maximum Daily Load (TMDL) report for the Annabessacook Lake watershed. Simply stated, a TMDL is the total amount of phosphorus that a lake can receive without harming water quality. Maine DEP, with the assistance of CWD and MACD, will address and incorporate public comments before final submission to the U.S. EPA. *(For more information on the TMDL process and results, refer to the Appendices or contact Dave Halliwell at the Maine DEP Augusta office at 287-7649 or at David.Halliwell@maine.gov*).

Secondly, watershed survey work, including a shoreline survey evaluation, was conducted by CWD to assess **total phosphorus** reduction techniques that would benefit the Annabessacook Lake watershed. Watershed survey work included assessing direct drainage **nonpoint source (NPS) pollution** sites. The results of this assessment include recommendations for future conservation work in the watershed to help citizens, organizations, and agencies restore and protect Annabessacook Lake water quality.

Total Phosphorus (TP) - *is one of the major nutrients needed for plant growth. It is generally present in small amounts and limits the plant growth in lakes. Generally, as the amount of lake phosphorus increases, the amount of algae also increases.*

Nonpoint Source (NPS) Pollution *- is polluted runoff that cannot be traced to a specific origin or starting point, but appears to flow from many different sources.*

Note: *To protect the confidentiality of resident landowners in the Annabessacook Lake watershed, site-specific information has not been provided as part of this report.*

This Phosphorus Control Action Plan (PCAP) report compiles and refines land use data derived from various sources, including the CWD, the municipalities of Winthrop and Monmouth, the Annabessacook Lake Improvement Association, the Kennebec County Soil & Water Conservation District (SWCD), and the USDA Natural Resources Conservation Service (NRCS). Local citizens, watershed organizations, and conservation agencies should benefit from this compilation of data as well as the watershed assessment and the NPS Best Management Practice (BMP) recommendations. Above all, this document is intended to help Annabessacook Lake stakeholder groups to effectively prioritize future BMP work projects in order to obtain the funding resources necessary for NPS pollution mitigation work in their watershed.

Study Methodology

Annabessacook Lake background information was obtained using various methods, including a review of previous studies of the lake and watershed area, numerous phone conversations and personal interviews with municipal officials, regional organizations and state agencies, and several field tours of the watershed, including boat reconnaissance of the lake and shoreline.

Land use data were determined using several methods, including (1) **Geographic Information System (GIS)** map analysis, (2) analysis of topographic maps, (3) analysis of town property tax maps, tax data and building permit records, (4) a 1990 Annabessacook Lake Watershed Land Use/Land Cover analysis of aerial photographs, (5) a 1990 National Wetlands Inventory for Monmouth, and (6) field visits. Much of the undeveloped land use area (i.e., unmanaged forestland, scrub shrub, wetlands) was determined using GIS maps utilizing data from the Maine Gap Program/MLRC compiled by the Maine DEP. The developed land use areas were obtained using the best possible information available through analysis of methods 2 through 6 listed above. Necessary adjustments to the GIS data were made using best professional judgment.

> ***GIS**—or **geographic information system** combines layers of information about a place to give you a better understanding of that place. The information is often represented as computer generated maps.*

Roadway data were taken directly from previous Annabessacook Lake watershed reports (Dennis & McPhedran 1991) where roadway areas were determined using linear distances and average widths for each of the three main road types (state, town, camp/private).

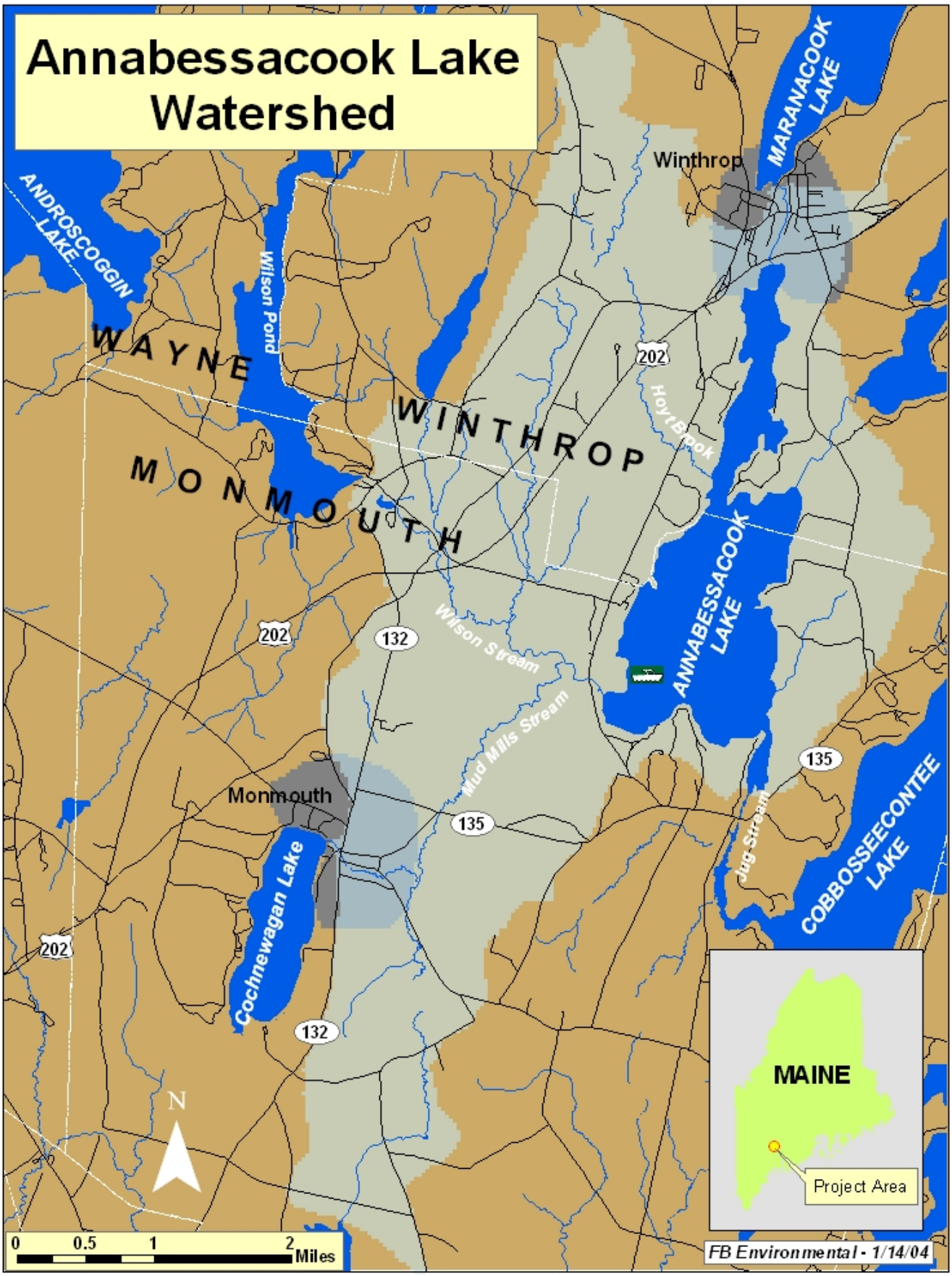
Additional land use data (i.e. non-shoreline residential, commercial) were determined using a combination of land use data from the past 1990-91 study, ground-truthing, and property tax maps. Also useful was the knowledge of new major subdivision and commercial developments as obtained by CWD as the primary review agent for the Monmouth and Winthrop planning boards, as well as building permit records from the towns of Monmouth and Winthrop for the 1991-2001 time period.

Agricultural information within the Annabessacook Lake watershed was generated by aerial photo interpretation (ASCS 1985 and 1990), consultation with the Kennebec County NRCS staff, CWD's working knowledge of the watershed, and by ground-truthing. Information regarding forest harvesting data were determined using GIS cover mapping.

Study Limitations

Land use data gathered for Annabessacook Lake and its surrounding watershed are as accurate as possible given available information and resources utilized. However, the final numbers for the land use analysis and phosphorus loading numbers are approximate at best, and should be viewed as carefully researched estimations only.

Figure 1. Map of Annabessacook Lake Direct Watershed



ANNABESSACOOK LAKE Phosphorus Control Action Plan

DESCRIPTION of WATERBODY (MIDAS Number 9961) and WATERSHED

ANNABESSACOOK LAKE is a 1,391 acre waterbody situated in the towns of Monmouth and Winthrop in Kennebec County, south-central Maine. Annabessacook Lake has a **direct watershed** (see map) area of 13,543 acres (21 square miles) and is located within the towns of Monmouth, Winthrop and to a much lesser extent, Wales (Androscoggin County). This lake has a maximum depth of 47 feet, a mean depth of 17 feet, and a **flushing rate** of 3.7 times per year. The total Annabessacook Lake watershed drainage area, inclusive of four upstream lakes (see below), is 83.5 square miles.

*The **direct watershed** refers to the land area that drains to the lake without first passing through another lake or pond.*

Drainage System – Annabessacook Lake receives drainage from four upstream lakes in addition to runoff from the direct watershed. Maranacook Lake to the north drains to Annabessacook Lake via Mill Stream (303d listed); Wilson Pond to the northwest drains to the lake via Wilson Stream; Cochnewagon Lake to the southwest drains to the lake via Mud Mills Stream (303d listed); and, Lower Narrows Pond to the northeast discharges via Holmes Brook. The lake outlets at its southeasterly end via Jug Stream, which flows southeasterly into Cobbossee Lake. The Town of Monmouth controls a dam at the outlet.

Water Quality Information

Annabessacook Lake is listed on the Maine DEP's 303(d) list of lakes that do not meet State water quality standards as well as the State's Nonpoint Source Priority Watersheds list; hence the need for preparation of a Phosphorus Control Action Plan (and TMDL report) which was developed, publicly reviewed, and completed in late spring 2004.

***Secchi Disk Transparency**—a measure of the transparency of water (the ability of light to penetrate water) obtained by lowering a black and white disk into water until it is no longer visible.*

Water quality data for Annabessacook Lake has been collected from the south deep hole station (01) and the north shallow basin (02) by CWD since 1975 (CWD). Based on monitored **Secchi disk transparencies,** measures of both total phosphorus (TP) and **chlorophyll-a**, the water quality of Annabessacook Lake is considered to be poor and the potential for nuisance summertime algae blooms is high (Maine DEP 2000). Together, these data document an historical trend of increasing **trophic state** in Annabessacook Lake, in direct violation of the Maine DEP Class GPA water quality criteria requiring a stable or decreasing trophic state. In recent years, the water quality of Annabessacook Lake has shown some improvement (CWD 2004).

***Chlorophyll-a** is a measurement of the green pigment found in all plants including microscopic plants such as algae. It is used as an estimate of algal biomass; the higher the Chl-a number, the higher the amount of algae in the lake.*

***Trophic state—**the degree of eutrophication of a lake. Transparency, chlorophyll-a levels, phosphorus concentrations, amount of macrophytes, and quantity of dissolved oxygen in the hypolimnion can be used to assess trophic state.*

Nonpoint source pollution is the main reason for declining water quality in Annabessacook Lake. During storm events, phosphorus - naturally occurring in soils - drains into the lake from the surrounding watershed by way of streams and overland flow.

Phosphorus is naturally limited in lakes and can be thought of as a fertilizer, a primary food for plants, including algae. When lakes receive excess phosphorus from NPS pollution, it "fertilizes" the lake by feeding the algae. Too much phosphorus can result in nuisance algae blooms, which can damage the ecology/aesthetics of a lake, as well as the economic well-being of the entire watershed community.

Principal Uses: The dominant human uses of the Annabessacook Lake shoreline are residential (both seasonal and year-round occupancy) and recreational—including boating, fishing, hunting, camping and swimming/beach use. A state operated public boat launch is located on the Waughan Road on the west side of the lake in the Town of Monmouth, adjacent to the lake's inlet from Wilson and Mud Mills streams.

Human Development: Annabessacook Lake is a moderately developed lake with 182 residential dwellings along the approximate 13-mile shoreline. A major portion of the southeastern shoreline remains relatively undeveloped. There is a single commercial campground located on the eastern shore of the lake in Winthrop with approximately 80 camp sites (personal communication, Town of Winthrop tax assessor).

Annabessacook Lake is on the State's **Nonpoint Source Priority Watersheds** list due primarily to algal blooms and associated dissolved oxygen declines below the thermocline (lower depths of the lake). In addition to NPS pollution, Annabessacook is also on the State's list of Lakes Most at Risk from Development due to perceived high population growth rates in the watershed. The estimated year-round populations of Monmouth and Winthrop are 3,905 and 6,302, respectively (KVCOG 2002). The Town of Monmouth is located about halfway between Augusta and Lewiston, two major commercial centers in Central Maine. Winthrop is an industrial and suburban center, located about 10 miles west of Augusta. Housing density estimates indicate that the majority of both towns reside within the watershed of Annabessacook Lake. Monmouth's summertime population and watershed/lake-related activity increases substantially during the summer months (Winthrop CEO and Monmouth Town Manager, personal communications).

*Waterbodies within designated **NPS priority watersheds** have significant value from a regional or statewide perspective and have water quality that is either impaired or threatened to some degree due to NPS water pollution. This list helps to identify watersheds where state and federal agency resources for NPS water pollution prevention or restoration should be targeted.*

Annabessacook Lake Fish Assemblage & Fisheries Status

Based on records provided by the Maine Department of Inland Fisheries and Wildlife (Maine DIFW) and a recent conversation with fish biologists Jim Lucas and Bill Woodward (Region B, Sidney DIFW office), **Annabessacook Lake** (towns of Monmouth and Winthrop, Jug Stream - Cobbosseecontee Lake/Stream - Kennebec River drainage) is currently managed as a warmwater (largemouth bass) fishery and was last surveyed in 1940 (revised 1953, 1974, and 2000). A total of **13** fish species are listed, including: **8** native indigenous fishes (American eel, golden shiner, white sucker, brown bullhead, chain pickerel, redbreast sunfish, pumpkinseed, and yellow perch); and **5** introduced fishes (white perch, rainbow smelt, smallmouth and largemouth bass, and illegally introduced northern pike). Transient catches of stocked brook and brown trout may occur, as dropdowns from nearby annually stocked Maranacook Lake (Maine DIFW). Principle warmwater fisheries, in addition to largemouth bass, include smallmouth bass, white perch, and chain pickerel. Apparently, there now exists a viable population of northern pike in Annabessacook Lake, which supports an active year-round fishery (Bill Woodward, Maine DIFW 2004).

Annabessacook Lake has historically been plagued with (annually occurring) severe summer-time nuisance algae blooms. Late summer dissolved oxygen levels in 2001 remained fairly low (0 to 4 ppm) with 50% of the water column at the deep hole (lower 6 meters) unsuitable for salmonid species (e.g., brown trout). Given the premise that reducing algal productivity will help restore/ maintain suitable water quality and fishery habitat conditions (reduce oxygen losses), a significant reduction (415 kg TP) in the external (watershed) loading of total phosphorus to Annabessacook Lake (1,315 kg TP) can lead to maintaining in-lake nutrient levels - within the assimilative capability of this lake (2,485 kg TP/year) to effectively process available total phosphorus and serve to further enhance and protect the existing warmwater fisheries.

Watershed Topography and Characteristic Soils (Source: USDA SCS 1978):

An estimated 85% of the shoreline is comprised of hydrologic soil groups "C" and "D" soil types. The types of soils series along the shoreline areas are predominantly Paxton, Hollis and Scantic. Hollis and Paxton soils have a high runoff potential (hydrologic soil group C) due to shallowness to bedrock and high water table conditions. Scantic soils (hydrologic soil group D) have a high runoff potential and a low infiltration rate of less than 2.54 cm/hour. Soil erodibility for these soil types is high. Given the slow infiltration rates and potential for high erodibility for these shoreline soils, it would seem likely that phosphorus transport via stormwater runoff would be a contributing factor to the phosphorus loading to Annabessacook Lake.

The western upland portion of the Annabessacook Lake Watershed is dominated by the **Buxton-Scio-Scantic soil association as well as the Scantic-Ridgebury-Buxton association**. These soils are characterized as deep, moderately well drained to poorly drained, nearly level to sloping, medium textured soils; in flat areas and near waterways. These associations are characterized by wetness and slow infiltration rates (hydrologic soil group C and D with infiltration rates less than 2.54 cm/hr). These soils have a very slow rate of water transmission and a high runoff potential. Soil erodibility is also high.

The eastern upland portion of the watershed is dominated by the **Hollis-Paxton-Charlton-Woodbridge soil association.** The major soils in this association were formed in glacial till. Hollis, Paxton, and Woodbridge soils have a high runoff potential (hydrologic soil group C) due to shallowness to bedrock and high water table conditions; Charlton soils have a moderate runoff potential (hydrologic soil group B). All soil types except Hollis have infiltration rates of less than 2.54 cm/hr. Soil erodibility is high.

Land Use Inventory

The results of the Annabessacook Lake watershed land use inventory are depicted in Table 1 (following page). Developed land areas comprise approximately 25% of the watershed, while the undeveloped land area - including the water surface area of Annabessacook Lake, comprise the remaining 75% of the watershed land area. These numbers may be used to help make future planning and conservation decisions relating to the Annabessacook Lake watershed. The information in Table 1 was also used as a basis for preparing the Total Maximum Daily (Annual Phosphorus) Load report (see Appendices).

Descriptive Land Use and Phosphorus Export Estimates

Agriculture and Farming Practices: To determine the extent and types of agricultural land use in the watershed, the CWD project staff reviewed the earlier land use studies, particularly the 1991 Dennis and McPhedran study. The 1991 study involved the utilization of field surveys in the fall of 1990 and aerial photo interpretation, using 1985 photographs and 1990 slides available from the Natural Resources Conservation Service (formerly the Soil Conservation Service). In addition to the aerial photo interpretation and ground-truthing, the CWD staff conferred with NRCS staff to determine approximate acres of manured hayland, pasture land, cultivated land/row crops, and

Table 1. ANNABESSACOOK Lake Direct Watershed Land Use and P-Loads.

LAND USE CATEGORY	Total Land Area Acres	Total Land Area %	TP Export Total %
Agricultural & Forested Land		**Annabessacook Lake**	
Hayland (Manured)	36	0.3	1.4
Low-Intensity Hayland	1,080	8.0	21.3
Orchard	134	1.0	0.3
Pasture/Barnyard	123	0.9	3.1
Manure Storage	0.04	0.0	0.3
Operated Forest Land	118	0.9	1.5
Sub-Totals	**1,491**	**11%**	**28%**
Shoreline Development		**Annabessacook Lake**	
Low Impact Residential	5	0.0	0.2
Medium Impact Residential	12	0.1	0.6
High Impact Residential	25	0.2	1.3
Septic Systems	—	0.0	4.5
Camp and Private Roads	19	0.1	1.2
Recreational	10	0.1	0.4
Sub-Totals	**72**	**1%**	**8%**
Non-Shoreline Development		**Annabessacook Lake**	
State Roads	49	0.4	2.3
Town Roads	85	0.6	3.9
Low Density Residential	860	6.4	13.2
High Density Residential	410	3.0	12.4
Commercial Property	276	2.0	12.7
Cemeteries	17	0.1	0.1
Closed Landfill	20	0.1	0.4
Sand/Gravel Mining	102	0.8	0.0
Recreational	30	0.2	0.2
Sub-Totals	**1,849**	**14%**	**45%**
Total: DEVELOPED Land	**3,412**	**25%**	**82%**
Non-Developed Land		**Annabessacook Lake**	
Inactive/Passively Managed Forest	7,581	56	9.3
Wetlands	860	6.4	0.5
Scrub Shrub	299	2.2	0.9
Total: NON-DEVELOPED Land	**8,740**	**65%**	**11%**
Total: Surface Water (Atmospheric)	**1,391**	**10%**	**7%**
TOTAL: DIRECT WATERSHED	**13,543**	**100%**	**100%**

number of animals in the watershed. For this PCAP-TMDL study, the CWD project staff updated the earlier information through ground-truthing, personal communication with farmers, review of local and state permits, consultation with Dick Ferland (NRCS), Kennebec County Soil and Water Conservation Service, and the Maine Department of Agriculture (Augusta). The combination of the CWD's specific knowledge of farms in the watershed as well as with the aforementioned agencies provides excellent information on land use and practices in the Annabessacook Lake watershed.

Only two agricultural operations that involve livestock remain in the watershed. The Maine Department of Agriculture has regulatory jurisdiction over an egg farm under the nutrient management law and has approved the egg farm's nutrient management plan.

The amount of land used for agricultural purposes in the watershed is substantial when compared to other culturally-based land uses. The agricultural land area of the Annabessacook Lake drainage area currently comprises 10% of the total watershed area and 26% of the external phosphorus loading to the lake. Hayland is estimated to contribute the most phosphorus with pasture, orchard, and manure storage contributing the remaining agriculturally derived phosphorus load.

Forest Practices: Generally, poorly managed forestry operations have the potential to negatively impact a waterbody by erosion and sedimentation from logging sites. There are only a few forest harvesting operations in the Annabessacook Lake watershed. The major, well-known clear-cut area along Route 202 in Monmouth has been reviewed by the Maine Forest Service and appears to be in compliance of all standards (CWD 2003).

The operated forestland area within the watershed approximates 1% of the total land area and an estimated 1.5% of the total phosphorus load to Annabessacook Lake.

Shoreline Residential (House and Camp Lots): A shoreline survey was conducted in the summer and fall of 2001 by CWD project staff. This survey was conducted by boat and the results represent subjective determinations of potential NPS pollution impact ratings based on best professional judgment. The impact ratings range from 1 to 5, with 1 being very low impact (natural - best case scenario) and 5 being high impact (unnatural – worst case scenario). Lots receiving a rating of 1 have a full naturally vegetated buffer. Conversely, a lot given a score of 5 would have little or no vegetative buffer and support bare (eroding) soil, a visible source of phosphorus input to the lake. A grass covered mowed lawn leading down to a rip-rapped shoreline or beach would receive a rating of 4, but only if there was no evidence of bare soil, in which case a rating of 5 would be assigned.

In addition to the impact rating, project staff performed a residential structure tally along the immediate shoreline as well as estimated the residency status of each dwelling (seasonal vs. year-round). Of the 182 shoreline dwellings, it is estimated that 87 are year-round and 95 are seasonal. In order to estimate the NPS pollution severity impact, factors taken into consideration include the distance of the dwelling to the lake, the percent slope of the lot, the presence or lack of vegetated buffers, presence of bare soils, existing rip rap, and other notable features such as retaining walls or boat launches.

Table 2. Annabessacook Lake Shoreline Survey Results (2001)

NPS Pollution Potential Severity Score	Impact Rating Characterized by one or more of the following:	Number of shoreline sites identified within each category	% of sites within each category
1 = Low Impact	All natural vegetated buffer; good setback from the lake	19	10%
2	Good natural vegetation; good setback from the lake	17	9%
3 = Moderate Impact	Lack of adequate buffer; close to lake	31	17%
4	Lack of buffer; steep slopes; close to lake	102	56%
5 = High Impact	Total lack of buffer; steep slopes; close to lake; bare (eroding) soils	13	7%

Overall, 80% of the developed shoreline lots are rated as having a moderate to high NPS pollution impact due lack of adequate vegetated buffers, distance of the dwelling to the lake and presence of bare, eroding soils. Vegetative buffers help to decrease the amount and flow of run-off from the site. Many of the homes and cottages have mowed grass lawns that stretch down to the lake and do not serve as adequate vegetated buffers. There were about 15 linear feet of shoreline considered severely eroded and 335 feet considered moderate to severely eroded around the near 13-mile long shoreline.

To estimate phosphorus loading from shoreline residential land use, the shoreline survey data were condensed into three categories - low, medium and high impact categories. To estimate the phosphorus load to the lake from shoreline dwellings, each lot was subjectively assigned a phosphorus export coefficient corresponding to a residential lot with clearing limits of 10,000 square feet and situated on HSG-C soils as presented in PHOSPHORUS CONTROL IN LAKE WATERSHEDS: *A Technical Guide to Evaluating New Development* (Maine DEP 1992).

- *To convert kg of total phosphorus to pounds—multiply by 2.2046*
- *To convert kg/hectare to lbs/acre—multiply by .892*

Seasonal camp and year-round home lots on Annabessacook Lake comprise less than 1% of the land area and 27 kg of total phosphorus annually, which approximates 2.1% of the estimated total phosphorus load (Table 1).

Shoreline Septic Systems: It is important to consider the potential for phosphorus loading from septic systems in the immediate proximity of the lake. In order to estimate total phosphorus loading from shoreline septic systems, export coefficients and occupancy rates were taken from Dennis and McPhedran (1991) and applied to the recently completed shoreline survey. These include an estimate of 2.7 persons per household and export coefficients of 0.05 and 0.15 kg of phosphorus annually per capita for seasonal and year-round residences, respectively.

Estimated loading from residential septic systems on Annabessacook Lake is 48 kg total phosphorus per year. Estimated phosphorus loading from the single commercial campground septic system is 10.8 kg total phosphorus per year. Combined residential and commercial shoreline septic system loading approximates an average total watershed phosphorus export of 59 kg TP annually (Table 1).

Recreational (Shoreline): Included in this category are the public boat launch (approximately 1 acre) and the commercial campground located on the eastern shore of Annabessacook Lake. The campground facility has 80 campsites, encompassing about 10 acres (Winthrop CEO, personal communication). Estimates of loading from recreational (shoreline) development approximates a TP export of 5.5 kg of TP annually (Table 1).

Private/Camp Roadways: There are 18 private camp roads around Annabessacook Lake comprising an area of 19 acres. Total phosphorus loading from private camp roads comprises 0.1% of the land area and approximates 1.2% of the total watershed TP export annually (15 kg).

Overall, shoreline development comprises only 1% of the total watershed area however it contributes an average of 106 kg of total phosphorus annually which approximates 8% of the estimated phosphorus load (Table 1).

Other Development and Land Uses

Non-Shoreline Development refers to all watershed lands outside the immediate shoreline of Annabessacook Lake, including residential areas, commercial areas, state and town roadways and other land uses such as cemeteries, gravel pits, closed landfill, and recreational areas.

Residential Development: Data for non-shoreline residential areas in the watershed were taken from the 1991 study and updated by reviewing all building and land use permits in the towns of Winthrop and Monmouth from 1991 to 2002. To determine the degree of residential and commercial development in the watershed, CWD used a combination of ground-truthing, local familiarity, and knowledge of new major subdivision and commercial developments gained as the review agent for both planning boards in the towns of Winthrop and Monmouth. Additionally, building permit records and tax maps from the towns of Monmouth and Winthrop for the period 1991 to 2001 were reviewed to provide an estimate of increased watershed development not subject to planning board review processes.

The residential categories include low and high-density residential development. The non-shoreline residential land uses are estimated to contribute 337 kg of total phosphorus per year, or 25%, of the total phosphorus load to the lake (Table 1).

Public Roadways are divided into two categories - state public highway and town public roadway. There are approximately 10 miles of state highway and 35 miles of town roadways. The average road width for state highway is 40' and 20' for town roadway. There are 49 acres of state highway and 85 acres of town roadways. The total loading for public roadways is 81.4 kg TP or 6.2% of the total phosphorus load to Annabessacook Lake. Public roadways account for a much greater percentage of the phosphorus load (6.2%) versus its land area (1%) in the Annabessacook Lake watershed.

Commercial areas include stores, mills, manufacturing facilities and restaurants and comprise an area of about 276 acres. These combined commercial land uses are estimated to contribute 168 kg of total phosphorus per year or about 13% of the total annual phosphorus load to Annabessacook Lake.

Other Land Uses include several cemeteries, gravel pits, a closed landfill, and recreational areas. The total phosphorus loading from these other uses is estimated at 8.6 kg TP/yr, less than 1 percent of the total annual phosphorus loading to Annabessacook Lake.

Overall, non-shoreline development accounts for 14% of the total land area and contributes about 45% of the total phosphorus load to Annabessacook Lake.

Phosphorus Loading from Non-Developed Lands

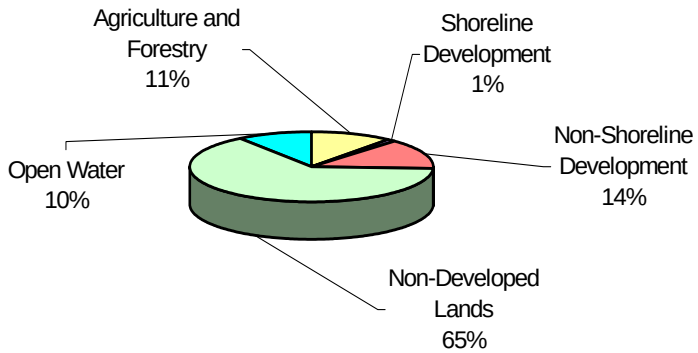
Forest (Inactive, passively managed): Of the total land area within the Annabessacook Lake watershed, 56% (7,581 acres) is forested, characterized by privately-owned non-managed deciduous and mixed forest plots (Maine DEP GIS cover mapping). About 9% (123 kg) of the phosphorus load is estimated to be derived from non-commercial forested areas within Annabessacook Lake's direct drainage area (Table 1).

Other Non-Developed Land Areas: Combined wetlands and old field scrub shrub account for the remaining 9% of the land area and 1.4% (19 kg) of the non-cultural total phosphorus export load.

Atmospheric Deposition (Open Water): Annabessacook Lake surface waters (1,391 acres) comprise 10% of the total watershed area (13,543 acres), representing 7% of the total phosphorus load entering Annabessacook Lake.

Figure 2 (right) depicts the percentage of total land area covered by each land use category within the Annabessacook Lake watershed.

Figure 2: Total Land Area - Annabessacook Lake Watershed



PHOSPHORUS LOADS – Watershed, Sediment and In-Lake Capacity

Supporting documentation for the phosphorus loading analysis includes the following: water quality monitoring data from CWD and the Volunteer Lake Monitoring Program, and the development of a phosphorus retention model (see Appendices for detailed information).

- Total phosphorus loadings to Annabessacook Lake originate from a combination of external (watershed) and internal (lake sediment) sources. External (direct) watershed TP sources approximating 1,315 kg annually have been identified & accounted for by land use (Tab. 3).

- Total phosphorus loading from the associated upstream lakes [Maranacook (369 kg) and Cochnewagon (60 kg) lakes and Wilson (282 kg) and Lower Narrows (27 kg) ponds] account for external loading from the indirect watershed of 738 kg annually, determined on the basis of *flushing rate x volume x TP concentration,* and typical area gauged streamflow calculations.

- The relative contribution of internal sources of total phosphorus within Annabessacook Lake - in terms of lake sediment total phosphorus recycling - approximate 465 kg/year (2001 phosphorus profile monitoring data, CWD and Maine DEP/MACD historical models).

- The load allocation (lake assimilative capacity) for all existing and future non-point pollution sources for Annabessacook Lake is 2,485 kg of total phosphorus per year, based on a target goal of 15 ppb.

- A change of 1 ppb in phosphorus concentration in Annabessacook Lake is equivalent to 166 kg. The difference between the target goal of 15 ppb and the measured average annual epilimnetic phosphorus concentration (17 ppb) is 2 ppb (2 x 166), thus 332 kg. Given an 83 kg allocation for future development (0.5 x 166), the total amount of phosphorus needed to be reduced to maintain water quality standards in Annabessacook Lake approximates 415 kg.

Upstream Tributary Studies

Mill Stream, the major tributary to Annabessacook Lake, provides drainage from two upstream lakes, Maranacook Lake and Torsey Pond, as well as a 359-acre direct watershed comprised primarily of high density residential and commercial land in downtown Winthrop. Prior to 1972, the stream received point source discharges from domestic and industrial sewers. Since that time, all storm sewers have been redesigned for separate discharges. A 1977 study (Sage and Moran), estimated that the stream contributed 1,300 kg TP/yr to Annabessacook Lake with 700 ± 695 kg TP/yr attributed to the direct drainage of the stream. There was a high degree of uncertainty in the data, however, as a modeled load based on land use estimates suggested a figure closer to 150 kg TP/yr. Following the 1978 alum treatment project, CWD conducted bi-weekly phosphorus and stream flow monitoring in Mill Stream in 1978-1979. Included in this study were five tributaries, and the outlet stream, Jug Stream. The results indicated that the estimated annual load for the five streams (and upstream lakes) remained 9 percent greater than that needed to prevent algae blooms from occurring (Wendy Dennis 1982).

As part of the most recent 205j project, in addition to updating watershed land use and land cover, the CWD monitored the Mill Stream during dry and wet weather periods from March 1989 to November 1990. Samples were analyzed for total phosphorus and were augmented with stream flow measurements via automated recording gages operated by the USGS through a cooperative agreement with the CWD. Samples were collected at the outlet of Maranacook Lake and at Route 202 at the point of discharge to Annabessacook Lake. This approach provided an estimate of the total load from the Mill Stream as well as the net contribution from the direct watershed (i.e., downtown Winthrop). Total phosphorus concentrations at Route 202 ranged from 9 ppb to 163 ppb. The range reflected varying precipitation as well as watershed conditions (e.g., soil saturation, land disturbance). The Mill Stream was found to contribute between 320 kg TP/yr and 438 kg TP/ yr to Annabessacook Lake, with approximately 27 percent (116 and 157 kg TP/yr, respectively) attributable to the direct watershed of the stream. Runoff from the direct watershed, however, was found to comprise only 2 percent of the annual water load in the Mill Stream.

In 1986, upstream Cochnewagon Lake was the beneficiary of an alum treatment to reduce in-lake internal phosphorus recycling. As part of a post-restoration evaluation, the outlet of the lake and Mud Mills Stream downstream, which receives this discharge prior to entering Annabessacook Lake, were monitored for total phosphorus and stream flow in 1991 and 1992 (Dennis and McPhedran 1993). Mud Mills Stream was estimated to contribute between 355 kg TP/yr and 462 kg TP/yr to Annabessacook Lake. Of this total, 85 to 88 percent was attributed to the direct drainage of Mud Mills Stream and the small stream connecting Cochnewagon Lake to Mud Mills Stream. The watershed of Mud Mill Stream proper was comprised of primarily agricultural and forested land use/cover. The small outlet stream from Cochnewagon Lake receives direct runoff from the downtown area of Monmouth.

Recent and Current NPS/BMP Efforts

Annabessacook Lake began displaying a severe decline in clarity in the 1940's when the first formal complaints of algae blooms on the lake were recorded (USEPA 1980). The principle cause of the decline was the discharge of municipal and industrial waste to the lake from the towns of Winthrop and Monmouth. Nonpoint source phosphorus pollution from various land use types in the watershed served to exacerbate the municipal and industrial point sources. Early efforts to control the blooms included copper sulfate applications in the 1960's and early 1970's with declining results with each year. It had been estimated that the industrial and municipal discharges accounted for 93% of the annual phosphorus load, which at that time was estimated at 13,600 kilograms per year. The eventual connection to the Augusta Sanitary District's trunkline sewer by Winthrop (1972) and Monmouth (1976) directed all discharges to the wastewater treatment plant in Augusta, thereby eliminating all point source discharges to the lake. Water quality showed some improvement, but the lake continued to sustain nuisance algae blooms.

As part of a Section 208 water quality management plan for Southern Kennebec Valley region, the CWD conducted a land use/water quality study of Annabessacook Lake in 1977 to determine phosphorus sources to the lake and strategies for phosphorus reduction (Sage and Moran, 1977). The study revealed that in-lake sources of phosphorus as well as land based (primarily agriculture) sources must be reduced in order to achieve water quality goals. Mill Stream, which flows through downtown Winthrop before discharging to the north end of the lake, was found to contribute a greater portion of the annual phosphorus load than would be expected based on land use estimates alone.

In 1977, the CWD was awarded a Clean Lakes Program (Section 314) grant to support lake restoration efforts, with implementation to begin in 1978. The program included an alum treatment to reduce the internally recycled component of the annual phosphorus load to the lake and to reduce phosphorus export from agricultural lands through improved animal waste management.

Annabessacook Lake (Direct) Watershed Survey

A study funded under the Clean Water Act was conducted by the CWD in 1991 to update land use in the direct watershed of Annabessacook Lake and evaluate their significance in terms of potential phosphorus export to the lake. This study was an attempt to update 1974 land use estimates as determined in an earlier land use study (SKVRPC 1976; Sage and Moran, 1977).

The Annabessacook Lake Improvement Association (ALIA), using trained volunteers, performed a survey of all camp roads accessing shorefront properties on Annabessacook Lake in 1992 and 1993. The survey identified 18 potential NPS sites, the majority (16) related to improperly designed or eroding/unstable roads or driveways (2). Following the survey, the CWD conducted follow-up inspections and offered recommendations to property owners to improve drainage related problems.

In 1995, the CWD applied funds from a Section 319 grant (#95-10, Cobbossee Lake Watershed Project) for Cobbossee Lake immediately downstream to the most severe of these NPS sites (Piney Heights Road) and demonstrated the remedial measures to watershed residents. Subsequent to that demonstration, other watershed residents sought technical advice. The CWD has and will continue to make available to local camp road associations technical advice on proper road design and maintenance. Recommendations generally include the installation of typical roadside BMPs such as reshaping of ditches, culvert maintenance, proper crowning of roads, and installing plunge pools and turnouts.

The CWD has worked cooperatively with the Maine Department of Transportation (MDOT) on a large-scale roadside BMP project on US Route 202 in Winthrop. The 1994 project included the application of extensive amounts of rock-lining to deep gullies lining both sides of Route 202. The gullies on both sides of the highway carried stormwater and eroded soil directly to Annabessacook Lake. Prior to this work, cloudy sediment plumes would be observed in the lake during rain events. Following the work, these visible discharges have ceased. The CWD maintains a cooperative working relationship with the MDOT on road repair-related projects throughout the CWD.

In the summer 2002, CWD began a coordinated effort with the newly formed non-profit organization, Friends of the Cobbossee Watershed (*Friends*), to expand current education and outreach to lakeshore owners and boaters. The *Friends'* mission is to support programs and projects offered by CWD and related lake associations within the Cobbossee watershed, as well as to promote public awareness and to educate about water quality issues. In 2002 the *Friends* launched the E/V (education vessel) Otter on several of the lakes of the CWD to disseminate lake education material and to educate citizens about vegetated buffers, proper camp road maintenance and erosion control. During the summer of 2003, the *Friends* hired an AmeriCorps team to mitigate NPS pollution sources within the Cobbosee watershed. The *Friends* plan to continue to facilitate this type of conservation work within the Cobbossee watershed, which includes Annabessacook Lake, in future years.

Urban Centers of Winthrop, Monmouth and North Monmouth – The three densely developed town centers are traversed by significant tributaries to Annabessacook Lake. From visual observation, in-town roads tend to accumulate a significant amount of road sand as well as soil material from other sources. The Town of Winthrop had contracted to have the town roads swept once per year (town manager, personal communication). More frequent sweeping of in-town roads was recommended by CWD to eliminate a substantial amount of sediment-borne phosphorus from being washed into the tributary streams, and hence, Annabessacook Lake .

Based on a proposal by the CWD and the Town of Winthrop, a grant was awarded by the Maine DEP in 2003 under the Stormwater Compensation Fund for the purchase of a high-tech regenerative air street sweeper. The street sweeper, although owned by Winthrop, is being shared with the Town of Monmouth. Both towns operate the sweeper throughout the year, keeping fine sediment and its attached phosphorus off of the streets and out of stormwater runoff.

Recommendations for Future Work

With the elimination of point source discharges in the early 1970's, Annabessacook Lake is largely impacted by nonpoint sources of phosphorus pollution. Specific recommendations regarding Best Management Practices (BMPs) and actions to reduce external watershed total phosphorus loadings in order to improve the water quality conditions in Annabessacook Lake are as follows:

Watershed Management: Since the 1970's the Cobbossee Watershed District (CWD) has taken an active role in documenting and mitigating nonpoint source (NPS) pollution sites throughout the Annabessacook Lake watershed. The last documented survey was performed in 1991 and ongoing documentation and mitigation of NPS pollution sites continues to take place by the CWD (see above). The Annabessacook Lake Improvement Association (ALIA), all watershed residents, municipal officials and the Maine DEP should support the CWD and the *Friends* in their continued efforts to facilitate implementation of BMPs and other education and outreach efforts in order to reduce NPS pollution within the Annabessacook Lake watershed. The Annabessacook Lake stakeholders should coordinate lake improvement efforts by forming a leadership team that meets at least once a year in order to inform all interested parties about various water quality related activities that are taking place in the watershed.

Action Item # 1: Coordinate Existing Watershed Management Efforts		
Activity	**Participants**	**Schedule & Cost**
Develop an Annabessacook Lake Leadership Team	ALIA, CWD, *Friends*, Maine DEP, municipalities, local business, watershed citizens	Annual Roundtable Meetings beginning in 2003—**minimal cost**

Agriculture/Farm Practices: The 1990 watershed survey did not list any single source in the agricultural community as being a major problem. Hayland was the major agricultural land use then as it is now. It remains a recommendation that the fields that are known to be non-manured be further researched to determine what, if any, other source of fertilizer is being applied. Those determined to be using chemical fertilizers should be urged to adhere to the proper timing and application rate schedule for the specific fertilizer product.

A farmland erosion survey would be beneficial to identify areas in need of BMPs for sediment and phosphorus control. Because hayland is such a large component, area-wise, of the agricultural land, it should be a priority. Barnyards and cattle holding areas, although small in

Action Item # 2: Continue to work with Watershed Farmers		
Activity	**Participants**	**Schedule & Cost**
Work with watershed farmers to complete an erosion survey and to encourage installation and updating of phosphorus control measures	CWD, KC-SWCD/NRCS and agriculture community	Annually beginning in 2004 **$1,000/yr**

relative area, are high erosion sources and would be rated a medium priority.

Shoreline Residential areas have the greatest potential to negatively impact water quality of Annabessacook Lake. In order to mitigate phosphorus export from shoreline residential lots, shoreline landowners should be encouraged to implement BMPs. The CWD will continue to encourage these practices at annual meetings of the ALIA. Beginning in summer 2002, the CWD coordinated with the newly formed non-profit organization, Friends of the Cobbossee Watershed *(Friends)* to expand current outreach to lakeshore owners and boaters. The *Friends* operates their E/V (education vessel) Otter on several lakes of the Cobbossee Watershed, including Annabessacook Lake, to disseminate lake protective education material and educate citizens about such BMPs as vegetated buffers, proper camp road maintenance and erosion control.

Action Item # 3: Implement a Buffer Awareness and Planting Campaign		
Activity	**Participants**	**Schedule & Cost**
Develop a Buffer Awareness Campaign for Watershed Citizens	ALIA, *Friends*, CWD, KC-SWCD, Maine DEP, watershed citizens, local nurseries	Annually beginning in 2004 **$5,000/yr**

Private/Camp Roads - Few camp roads are designed and maintained properly and can be a major source of erosion and sedimentation to the lake. For free technical assistance on proper road maintenance, the formation of a road association and/or potential cost-sharing on NPS BMP projects, contact CWD (377-2234) or KC-SWCD (622-7847 ext 3).

Public Roadways – The municipalities of Monmouth and Winthrop have cooperated with the CWD in the past on town road-related problems as they become apparent. The CWD will continue to seek this cooperation when erosion or drainage related problems arise on town roads in the watershed.

Action Item # 4: Implement Roadway Best Management Practices		
Activity	**Participants**	**Schedule & Cost**
Continue to Implement Roadside BMPs watershed-wide	CWD, KC-SWCD, ALIA, Maine DEP, watershed road associations	Annually beginning in 2004 **$10,000/yr**

Non-Shoreline areas must be considered as potential NPS pollution problem areas, especially since they contribute a large percentage of the phosphorus loading to Annabessacook Lake.

The educational campaign conducted by CWD and *Friends* (see above) should be expanded to include a watershed-wide outreach program. Commercial areas should be included in education and outreach efforts as well since many of them benefit directly from the continued health of Annabessacook Lake. The CWD offers technical assistance to the planning boards of Monmouth and Winthrop regarding the review of proposed subdivisions and commercial uses. This assistance has resulted in a deceleration of phosphorus export from these land use types and has facilitated the gradual improvement of Annabessacook Lake.

Special attention should be given to areas near watershed brooks and streams. These areas

are especially vulnerable since they provide a direct link for NPS pollution to enter the lake.

Action Item # 5: Homeowner Education and Technical Assistance Programs		
Activity	**Participants**	**Schedule & Cost**
Expand outreach and education efforts to watershed citizens including technical assistance to landowners	*Friends*, CWD, KC-SWCD, ALIA	Annually beginning in 2004 **$1,500/yr includes printing of educational materials**

Action Item # 6: Develop Stewardship Initiatives for Annabess. Lake Tributaries		
Activity	**Participants**	**Schedule & Cost**
"Adopt" local streams to promote stewardship efforts including education and water quality monitoring	ALIA, CWD, *Friends*, KC-SWCD, Maine DEP Stream Team, local schools and watershed citizens	Annually beginning in 2003 **$500/yr**

Septic Systems – Antiquated and/or poorly designed and installed septic systems within the shoreland zone may contribute to the annual total phosphorus load to adjacent lake water, adding to the cumulative phosphorus load to Annabessacook Lake. While Annabessacook Lake septic systems – when properly sited, constructed, maintained, and set back from the water – should have a minimal effect on lake water quality, systems that do not meet all of these criteria have the potential to contribute phosphorus and other contaminants to lake water. Systems around Annabessacook Lake which are sited in coarse, sandy soils with minimal filtering capacity, and which are situated in zones where groundwater in-seepage is significant, are especially likely to contribute nutrients to lake waters. This is particularly true for old systems which pre-date Maine's 1974 Plumbing Code.

Available options for reducing septic system-related phosphorus loading to Annabessacook Lake include seeking the replacement of pre-plumbing code septic systems and other poorly functioning systems within the shoreland zone of Annabessacook Lake. Identification of potential problem systems can be accomplished through a combination of shorefront property owner questionnaire surveys and/or formal sanitary surveys. Educational efforts should make residents aware of impending problems and possible cost-effective solutions.

Action Item # 7: Update old and failing shoreline septic systems		
Activity	**Participants**	**Schedule & Cost**
Increase education efforts to watershed citizens re: septic system maintenance and potential funding sources	ALIA, *Friends*, CWD, Maine DEP, watershed municipalities	Beginning in 2004 - **$1,500/yr includes printing of educational materials**

Other Recommendations

Forestry: Landowners, loggers and foresters working within the watershed should contact the Maine Forest Service (1-800-367-0223) for a copy of Forestry BMP guidelines and other forest management assistance. Special attention should be given to forest access roads and proper erosion control measures should be utilized.

Individual Actions for all watershed residents should include the use of non-phosphate cleaning detergents, establishing or maintaining vegetated buffer strips down-gradient of developed areas, changing lawn care practices to include the use of phosphorus-free fertilizer, and practicing proper erosion control during any construction activities, however minor.

In-Lake Nutrient Inactivation – Internal total phosphorus release from Annabessacook Lake sediments during periods of **thermal stratification** and **hypolimnetic anoxia** continue to appear to be substantial. In 2001, the total phosphorus released from the sediments represents 16 percent of the estimated total for that year. Also, it continues to represent the single most significant source of phosphorus to Annabessacook Lake. However, based on 2001 in-lake monitoring data and review of past water quality data, it appears that the magnitude of **internal recycling** may be in decline.

Thermal stratification *is the seasonal layering of warm water over colder water.*

Hypolimnetic anoxia *is a condition of no oxygen in the bottom waters of the lake.*

Internal phosphorus cycling *is the transformation of phosphorus from biological to inorganic forms through decomposition, occurring within the lake itself.*

It is possible that the significant internal stores of phosphorus are being depleted following repeated annual release/flushing cycles. Because the cost of a second alum treatment in Annabessacook Lake would be significant, probably on the order of hundreds of thousands of dollars, and that the cost-benefit ratio is uncertain, more frequent and detailed in-lake monitoring would be necessary before prescribing this technique. Because of the relative importance of this source to the total annual phosphorus load to Annabessacook Lake, however, a second inactivation project should not be ruled out as a future possibility.

Upstream Lakes - Collectively, the four upstream lakes, Maranacook and Cochnewagon lakes and Wilson and Upper Narrows ponds contribute approximately 738 kg TP annually to Annabessacook Lake.

Upstream lakes *refers to the lakes that eventually drain into this waterbody*

On an annual basis, Maranacook Lake contributes the greatest share of this total, 369 kg TP. The CWD continues to monitor Maranacook Lake and provides technical assistance to residents in the watershed as well as the Readfield and Winthrop Planning Boards to assist them in evaluating new development applications in the watershed. It is doubtful that reductions in the annual load from Maranacook Lake could be realized, as the average total phosphorus concentration in the south basin of the lake has remained steady at or below 10 ppb.

The CWD will continue to monitor closely Cochnewagon Lake and Wilson Pond, not only out of concern for Annabessacook Lake water quality, but because those two lakes have also been exhibiting general decline in the past several years. Cochnewagon Lake was the subject of a 1988 nutrient inactivation treatment (alum) and watershed (primarily agricultural) BMP implementation.

Nutrient inactivation treatments, however, have a finite lifetime of effectiveness and the CWD must maintain close watch to determine if internal recycling of phosphorus is again a threat to lake water quality. Annabessacook Lake has been exhibiting episodes of increased algal biomass and reduced SDT in recent years. Wilson Pond has also been exhibiting a general decline in clarity over the past decade. The CWD will continue to monitor these lakes and provide technical assistance to private property owners and municipal planning boards in the respective watersheds.

WATER QUALITY MONITORING PLAN

Historically, the water quality of Annabessacook Lake has been monitored monthly during open water periods by the CWD since 1975. The water quality monitoring program has been augmented through the effort of local volunteers who provide frequent Secchi disk lake water transparency data (CWD, Maine DEP and VLMP). Continued long-term water quality monitoring within the two basins of Annabessacook Lake will be conducted, between the months of May to October, through the continued efforts of the CWD. Under this planned, post-TMDL water quality-monitoring scenario, sufficient data will be acquired to adequately track seasonal and inter-annual variation and long-term trends in water quality in Annabessacook Lake.

PCAP CLOSING STATEMENT

The Cobbossee Watershed District (CWD), along with the Annabessacook Lake Improvement Association (ALIA), has worked diligently since the early to mid-1970's addressing nonpoint source pollution in the watershed and inactivating sediment based phosphorus in the deep portions of Annabessacook Lake. Technical assistance by the CWD is available to all District town planning boards to mitigate phosphorus export from existing NPS pollution sources and the prevention of excess loading from future sources. The Towns of Monmouth and Winthrop have long recognized the link between their water resources and the local economy and provide strong support to lake restoration and protection efforts. As such, the Towns of Monmouth and Winthrop should be commended for their cooperation with the CWD in the pursuit of lake protection and improvement.

The CWD has also worked closely with the newly-formed Friends of the Cobbossee Watershed, a watershed made up of 28 waterbodies, of which Annabessacook Lake is but one. This regional watershed group is taking an aggressive and innovative approach to water quality education and outreach, which includes a newsletter, an interactive web site, an Education Vessel, educational workshops for kids and a conservation corps. The CWD also works closely with the Natural Resources Conservation Service to collaboratively address agricultural based nutrient loading. The Kennebec County Soil and Water Conservation District regularly joins forces with the CWD to identify NPS pollution sites and develop effective mitigation strategies.

Based on this collaborative approach to water quality restoration demonstrated over the past 30 years, there is a very high probability that lake restoration and enhancement efforts will continue to benefit Annabessacook Lake well into the future and that water quality conditions will continue to improve in the years to come.

APPENDICES

ANNABESSACOOK LAKE

Total Maximum Daily (Annual Phosphorus) Load

Introduction to Maine Lake TMDLs and Phosphorus Control Action Plans (PCAPs)

You may be wondering what the acronym 'TMDL' represents and what it is all about. TMDL is actually short for 'Total Maximum Daily Load.' This information, no doubt, does little to clarify TMDLs in most people's minds. However, when we think of this as an annual phosphorus load (*Annual Total Phosphorus Load),* it begins to make more sense.

Simply stated, excess nutrients or phosphorus in lakes promote nuisance algae growth/blooms - resulting in the violation of water quality standards as measured by water clarity depths of less than 2 meters. A lake TMDL is prepared to estimate the total amount of total phosphorus that a lake can accept on an annual basis without harming water quality. Historically, development of TMDLs was first mandated by the Clean Water Act in 1972, and was applied primarily to *point sources* of water pollution. As a result of public pressure to further clean up water bodies, lake and stream TMDLs are now being prepared for watershed-generated *Non-Point Sources* (NPS) of pollution.

Nutrient enrichment of lakes through excess total phosphorus originating from watershed soil erosion has been generally recognized as the primary source of NPS pollution. Major land use activities contributing to the external phosphorus load in lakes include residential-commercial developments, roadways, agriculture, and commercial forestry. Statewide, there are 32 lakes in Maine which do not meet water quality standards due to excessive amounts of in-lake total phosphorus - the great majority of which are located in south-central Maine (Kennebec County).

The first Maine lake TMDL was developed (1995) for Cobbossee Lake by the Cobbossee Watershed District (CWD) - under contract with Maine DEP and US-EPA. TMDLs have been approved by US-EPA for Madawaska Lake (Aroostook County), Sebasticook Lake, East Pond (Belgrade Lakes), China Lake, Webber, Threemile and Threecornered ponds (Kennebec County), and Mousam and Highland lakes in southern Maine. PCAP-TMDLs are presently being prepared by Maine DEP, with assistance from the Maine Association of Conservation Districts (MACD) and County Soil and Water Conservation Districts (SWCDs) - for Pleasant Pond and Annabessacook Lake (under contract with CWD), Sabattus, Unity, and Toothaker ponds, and Highland Lake (Bridgton - with assistance from Lakes Environmental Association). PCAP-TMDL studies have also been initiated for Togus and Lovejoy ponds, Little Cobbossee Lake and Upper Narrows Pond (under contract with CWD) and Long Lake (Bridgton - with assistance from LEA). Duckpuddle and Lily ponds in Knox-Lincoln County SWCD will be studied next, along with Herman and Hammond ponds, and the remaining seven 303(d) listed PCAP-TMDL waterbodies in Aroostook County.

Lake PCAP-TMDL reports are based in part on available water quality data, including seasonal measures of total phosphorus, chlorophyll-a, Secchi disk transparencies, and dissolved oxygen-water temperature profiles. Actual reports include: a lake description; watershed GIS assessment and estimation of NPS pollutant sources; selection of a total phosphorus target goal (acceptable amount); allocation of watershed/land-use phosphorus loadings, and a public participation component to allow for stakeholder review.

PCAP-TMDLs are important tools for maintaining and protecting acceptable lake water quality and are designed to 'get a handle' on the magnitude of the NPS pollution problem and to develop plans for implementing Best Management Practices (BMPs) to effectively address the lake's water pollution problem. Landowners and watershed groups are eligible to receive technical and financial assistance from state and federal natural resource agencies to reduce watershed total phosphorus loadings to the lake. **Note:** for non-stormwater regulated lake watersheds, the *development of phosphorus-based lake PCAP-TMDLs are not generally intended by Maine DEP to be used for regulatory purposes*.

For further information, contact Dave Halliwell, Maine Department of Environmental Protection, Lakes PCAP-TMDL Program Manager, SHS #17, Augusta, ME 04333 (287-7649).

Water Quality Monitoring: (Source: CWD & VLMP 2002) Water quality data for Annabessacook Lake has been collected by the CWD since 1975. Sampling is performed primarily on a monthly basis during ice-free conditions (May – Oct) at both a deep station (1) in the southern portion of the lake and a shallower station (2) in the north. This water quality assessment is based on 27 years of Secchi disk transparency (SDT) measures (taken bi-weekly), combined with 5-7 years of epilimnion core phosphorus (TP) data, and over 20 years of chlorophyll-a and associated water chemistry monitoring data.

Water Quality Measures: (Source: CWD and VLMP 2002) Annabessacook Lake has a range of SDT measures from 0.4 to 6.9 meters, with an average of 3.3 m, an epilimnion core TP range of 19 to 31 with an average of 24 parts per billion (ppb), and chlorophyll-a measures ranging from 2 to 74, with an average of 13.8 ppb. In 1977, prior to the 1978 lake restoration program, mean in-lake total phosphorus concentration during open-water season was 41 ppb. Following the alum treatment in 1978, the mean phosphorus concentration in the lake ranged from 22 to 28 ppb, with the exception of 1984 (32 ppb). In 2001, the volume-weighted epilimnetic (TP) ranged from 10 ppb to 29 ppb. Recent dissolved oxygen (DO) profiles indicate low levels of DO in deep areas of the lake (below 6 meters). The potential for total phosphorus to leave the bottom sediments and become available to algae in the water column (internal loading) is high (Maine DEP 2000). Notably, in spite of observed anoxic hypolimnia, the overall water quality of Annabessacook Lake has shown some improvement in recent years (CWD 2004).

Priority Ranking, Pollutant of Concern and Algae Bloom History: Annabessacook Lake is listed on the State's 1998 303(d) list of waters in non-attainment of Maine state water quality standards and was moved up in the priority development order due to stakeholder interest and need to complete an accelerated approach to lakes TMDL development. The Annabessacook Lake TMDL has been developed for total phosphorus, the major limiting nutrient to algae growth in freshwater lakes in Maine.

Natural Environmental Background Levels for Annabessacook Lake were not separated from the total nonpoint source load because of the limited and general nature of available information. Without more and detailed site-specific information on nonpoint source loading, it is very difficult to separate natural background from the total nonpoint source load (US-EPA 1999). Currently, there are no known point sources of pollutants to Annabessacook Lake.

WATER QUALITY STANDARDS & TARGET GOALS

Maine State Water Quality Standard for nutrients which are narrative, are as follows *(July 1994 Maine Revised Statutes Title 38, Article 4-A*): "Great Ponds Class A (GPA) waters shall have a stable or decreasing trophic state (based on appropriate measures, e.g., total phosphorus, chlorophyll a, Secchi disk transparency) subject only to natural fluctuations, and be free of culturally induced algae blooms which impair their potential use and enjoyment."

Maine DEP's functional definition of nuisance algae blooms include episodic occurrence of Secchi disk transparencies (SDTs) < 2 meters for lakes with low levels of apparent color (<26 SPU) and for higher color lakes where low SDT readings are accompanied by elevated chlorophyll a levels. Annabessacook Lake is a non-colored waterbody (average color 22 SPU), with an average SDT of 3.3 m (10.5 feet), in association with elevated average chlorophyll a levels of 13 ppb (1976 - 2002). Currently, Annabessacook Lake does not meet water quality standards due to annual summertime nuisance algae blooms, hence a continued trend of increasing trophic state. This water quality assessment uses historic documented conditions as the basis for comparison. Given the context of "impaired use and enjoyment," along with a realistic interpretation of Maine's goal-oriented Water Quality Standards (WQS), Maine DEP has determined that episodic, non-cyanobacteria based algae blooms (e.g. diatoms), limited to the fall or spring periods only, are in WQS attainment for GPA waters.

Designated Uses and Antidegradation Policy: Annabessacook Lake is designated as a GPA (Great Pond Class A) water in the Maine DEP state water quality regulations. Designated uses for GPA waters in general include: water supply; primary/secondary contact recreation (swimming and fishing); hydro-electric power generation; navigation; and fish and wildlife habitat. No change of land use in the watershed of a Class GPA water body may, by itself or in combination with other activities, cause water quality degradation that would impair designated uses of downstream GPA waters or cause an increase in their trophic state. Maine's anti-degradation policy requires that "existing in-stream water uses, and the level of water quality necessary to sustain those uses, must be maintained and protected."

Numeric Water Quality Target: The numeric (in-lake) water quality target for Annabessacook Lake is set at 15 ppb total phosphorus (2,485 kg TP/yr). Since numeric criteria for phosphorus currently do not exist in Maine's sate water quality regulations – and would be less accurate targets than those derived form this study – we employed best professional judgment to select a target in-lake phosphorus concentration that would attain the narrative water quality standard. Springtime total phosphorus levels in Annabessacook Lake averaged 12 to 15 ppb during 2001. The volume-weighted in-lake total phosphorus profile measures during summer and fall periods ranged from 10 to 29 ppb (nuisance bloom conditions). Average annual epilimnetic phosphorus concentrations averaged 17 ppb for Annabessacook Lake, based on 1998-2001 water quality data (Maine DEP).

In summary, the numeric water quality target goal of 15 ppb for total phosphorus in Annabessacook Lake was based on available data corresponding to non-bloom conditions, as reflected in suitable (water quality attainment) measures of both Secchi disk transparency (>2.0 m) and chlorophyll-a (<8.0 ppb).

ESTIMATED PHOSPHORUS EXPORT BY LAND USE CLASS

Table 3 details the numerical data used to determine external phosphorus loading for the Annabessacook Lake watershed. The key below explains the columns and the narrative that follows the table (pages 32-33) relative to each of the representative land use classes.

Key for Columns in Table 3

Land Use Class: The land use category that was analyzed for this report

Land Area in Acres: The area of each land use as determined by GIS mapping, aerial photography, Delorme Topo USA software, and field reconnaissance.

Land Area %: The percentage of the watershed covered by the land use.

TP Coeff. Range kg TP/ha: The range of the total phosphorus coefficient values listed in the literature associated with the corresponding land use.

TP Coeff. Value kg TP/ha: The selected coefficient for each land use category. The total phosphorus coefficient is determined from previous research – usually the median value, if listed by the author. The coefficient is often adjusted using best professional judgment based on conditions including soil type, slope, and best management practices (BMPs) installed.

Land Area in Hectares: Conversion, 1.0 acre = 0.404 hectares

TP Export Load kg P: Total hectares x applicable total phosphorus coefficient

TP Export Total %: The percentage of estimated phosphorus exported by the land use.

Table 3. ANNABESSACOOK Lake Direct Watershed Phosphorus Export by Land Use Class

LAND USE CLASS	Land Area Acres	Land Area %	TP Coeff. Range kg TP/ha	TP Coeff. Value kg TP/ha	Land Area Hectares	TP Export Load kg TP	TP Export Total %
Agricultural and Forested Land			**Annabess**	**Lake**			
Hayland (Manured)	36	0.3%	0.65 - 1.81	1.24	15	18.1	1.4%
Low Intensity Hayland	1080	8.0%	0.35 - 1.35	0.64	437	279.7	21.3%
Orchard	134	1.0%	0.06 - 0.75	0.40	54	21.7	0.3%
Pasture	123	0.9%	0.14 - 4.90	0.81	50	40.3	3.1%
Manure Storage	0.04	0.0%	21 - 795	224	0	3.6	0.3%
Operated Forest Land	118	0.9%	0.20 - 0.60	0.40	48	19.1	1.5%
Sub-Totals	**1,491**	**11%**	**Annabess**	**Lake**	**603**	**383**	**28%**
Shoreline Development							
Low Impact Residential	5	0.0%	0.25 - 1.75	1.24	2	2.4	0.2%
Medium Impact Residential	12	0.1%	0.40 - 2.20	1.50	5	7.3	0.6%
High Impact Residential	25	0.2%	0.56 - 2.70	1.66	10	16.8	1.3%
Septic Systems	**Annabess**	0.0%	**Lake**	**Septic**	**Model**	59.0	4.5%
Camp and Private Roads	19	0.1%	0.60 - 10.0	2.00	8	15.4	1.2%
Recreational	11	0.1%	0.25 - 1.75	1.24	4	5.5	0.4%
Sub-Totals	**72**	**1%**	**Annabess**	**Lake**	**29**	**106**	**8%**
Non-Shoreline Development							
State Roads	49	0.4%	0.60 - 10.0	1.50	19.9	29.8	2.3%
Town Roads	85	0.6%	0.60 - 10.0	1.50	34.4	51.6	3.9%
Low Density Residential	860	6.4%	0.25 - 1.75	0.50	348.0	174.0	13.2%
High Density Residential	410	3.0%	0.56 - 2.70	0.98	165.9	162.6	12.4%
Commercial	276	2.0%	0.77 - 4.18	1.50	111.7	167.5	12.7%
Cemeteries	17	0.1%	0.14 - 4.90	0.14	6.9	1.0	0.1%
Closed Landfill	20	0.1%	0.14 - 4.90	0.57	8.1	4.6	0.4%
Sand/Gravel Mining	102	0.8%	0.00 - 0.00	0.00	41.3	0.0	0.0%
Recreational	30	0.2%	0.25 - 1.75	0.25	12.1	3.0	0.2%
Sub-Totals	**1,849**	**14%**	**Annabess**	**Lake**	**748**	**594**	**45%**
Total: DEVELOPED LAND	**3,412**	**25%**	**Annabess**	**Lake**	**1381**	**1,083**	**82%**
Non-Developed Land							
Inactive/Passively Managed Forest	7,581	56.0%	0.01 - 0.04	0.04	3068	122.7	9.3%
Wetlands	860	6.4%	0.00 - 0.05	0.02	348	7.0	0.5%
Scrub Shrub	299	2.2%	0.10 - 0.20	0.10	121	12.1	0.9%
Total: NON-DEVELOPED Land	**8,740**	**65%**	**Annabess**	**Lake**	**3,537**	**142**	**11%**
Total: Surface Water (Atmospheric)	**1,391**	**10%**	0.11 - 0.21	0.16	**563**	**90**	**7%**
TOTAL: DIRECT WATERSHED	**13,543**	**100%**	**Annabess**	**Lake**	**5,481**	**1,315**	**100%**

Total Phosphorus Land Use Loads

Estimates of total phosphorus export from different land uses found in the Annabessacook Lake direct watershed are presented in Table 3 representing the extent of current external phosphorus loading to the lake. Total phosphorus loading from the associated upstream lakes (738 kg TP/yr) accounts for loading from the indirect watershed, determined on the basis of *flushing rate x volume x TP concentration,* and typical area gauged streamflow calculations.

Total phosphorus loading measures are provided as a range of values to reflect the degree of uncertainty generally associated with such relative estimates (Walker 2000). The watershed total phosphorus loadings were primarily determined using published literature and locally-derived export coefficients as found in Schroeder (1979), Reckhow et al. (1980), Dennis (1986), Dennis et al. (1992), and Bouchard et al. (1995) for residential properties, roadways, agriculture and other types of land uses (e.g., recreational, commercial).

In some cases (primarily roads and residential) selected phosphorus loading coefficients were reduced (from total P values) to account for the estimated bioavailability of the soil runoff sources according to available literature (Lee et al. 1980 and Sonzogni et al. 1982) and to better account for algal available-P export values as reflected in Dennis et al. (1992) - realizing that direct delivery of phosphorus to the lake is not occurring in most cases. These adjustments accounted not only for the readily available SRP (soluble-reactive-phosphorus) in the runoff, but also a substantial portion of the particulate inorganic component, particularly the P which is weakly adsorbed on the surface of soil particles (relative to discussion in Chapra 1997, pg. 524). **Note:** *These adjustments in P-load coefficients did not effectively alter the overall conclusions and final recommendations of the Annabessacook Lake PCAP-TMDL report regarding identified needs and NPS/BMP implementation plans for the Annabessacook Lake watershed.*

Agricultural and Forest Operational Lands: Phosphorus loading coefficients as applied to agricultural land uses were adopted, in part, from Reckhow et. al. 1980: manured hayland 1.24 kg TP/ha, pasture 0.81 kg TP/ha; and Dennis and Sage 1981: low-intensity hayland 0.64 kg TP/ha; The phosphorus loading coefficient applied to operated forestlands (0.40 kg TP/ha) was derived (best estimate) from the original Cobbossee Lake TMDL report (Monagle 1995).

Shoreline Residential Lots (House and Camp): The range of phosphorus loading coefficients used (0.25 – 2.70 kg ha/yr) were developed using information on residential lot stormwater export of algal available phosphorus as derived from Dennis et al (1992) .

Private Camp Roads: The total phosphorus loading coefficient for private camp roads (2.00 kg/ha) was chosen, in part, from previous studies of rural Maine highways (Dudley et al. 1997), as well as best professional judgment (Jeff Dennis, Maine DEP).

Non-Shoreline Development

Residential: Non-shoreline residential areas in the watershed are best characterized as low density and high density residential - reflected in the 0.50 and 0.98 TP loading coefficients, respectively.

Public Roadways: Town and state roadways (54 ha) were assigned a total phosphorus loading rate of 1.50 kg per hectare per year. This coefficient was chosen, in part, from previous studies of rural Maine highways (Dudley et al. 1997).

Total Developmental Phosphorus Loading: A total of 82% (1,083 kg) of the total phosphorus loading to Annabessacook Lake is estimated to have been derived from the cumulative effect of the preceding cultural land use classes: agriculture and forestry (29% - 383 kg); non-shoreline development (45% - 594 kg) and shoreline development (8% - 106 kg), including septic systems (4.5% - 59 kg) and camp/private roads (1.2% - 15.4 kg) – as depicted in Table 3.

Non-Developmental Phosphorus Loading: The phosphorus export coefficient for forested land (0.04) is based on a New England regional study (Likens et al 1977). The lower total phosphorus loading coefficient chosen for atmospheric deposition (0.16 kg TP/ha) is similar to that used for the China Lake TMDL (Kennebec County), while the upper range (0.21 kg TP/ha) generally reflects a watershed that is 50 percent forested, combined with agricultural areas interspersed with urban/ suburban land uses (Reckhow et al. 1980). Other Non-Cultural Land Uses: Combined wetlands and old field scrub shrub account for the remaining 1.4% (19.1 kg) of the total non-cultural or non-developed land total phosphorus export load of 142 kg (Table 3).

Atmospheric Deposition (Open Water): Annabessacook Lake surface waters (563 ha) comprise 10% of the total watershed area (5,481 ha) and account for an estimated 90 kg of total phosphorus, representing 7% of the total phosphorus load entering Annabessacook Lake.

Phosphorus Load Summary

It is our professional opinion that the selected landuse export coefficients are appropriate for the Annabessacook Lake watershed. Results of the land use analysis indicate that a best estimate of the present phosphorus loading from external (watershed generated) nonpoint source pollution approximates 1,315 kg TP/yr. Given the estimated phosphorus loading contributions from indirect tributary drainages (738 kg) and internal sediment P-accumulations (465 kg), this annual external watershed generated loading to Annabessacook Lake equates to a direct total phosphorus loading modeled at 22 to 23 ppb (2,518 kg TP/year).

LINKING WATER QUALITY and POLLUTANT SOURCES

Assimilative Loading Capacity: The Annabessacook Lake TMDL is expressed as an annual load as opposed to a daily load. As specified in 40 C.F.R. 130.2(i), TMDLs may be expressed in terms of either mass per unit time, toxicity, or other appropriate measures. It is thought appropriate and justifiable to express the Annabessacook Lake TMDL as an annual load— even though the lake basin has an annual flushing rate of 3.7, more than twice the average Maine flushing rate of 1.50, but well below the flushing rate of 6.0, which distinguishes lakes from rivers (Maine DEP 2002).

The Annabessacook Lake basin lake assimilative capacity is capped at 2,485 kg TP/yr, as derived from the empirical phosphorus retention model based on a target goal of 15 ppb. This value reflects the modeled annual phosphorus loading responsible for current trophic state conditions, based on a long term goal of maintaining average total phosphorus concentrations at or below 15 ppb. **Future Development:** The Maine DEP water quality goal of maintaining a stable trophic state includes a reduction of current P-loading which accounts for both recent P-loading as well as potential future development in the watershed. The methods used by Maine DEP to estimate future growth (Dennis et al. 1992) are inherently conservative, as they provide for relatively high-end regional growth estimates and largely non-mitigated P-export from new development. This provides an additional non-quantified margin of safety to ensure the attainment of state water quality goals. Previously unaccounted phosphorus loading from anticipated future development on the Annabessacook Lake watershed approximates 83 kg annually (0.5 x 1 ppb change in trophic state = 166 kg). No doubt, human population growth will continue to occur in the Annabessacook Lake watershed, contributing new sources of phosphorus to the lake. Hence, total phosphorus source loads must be reduced to allow for these anticipated new sources of phosphorus.

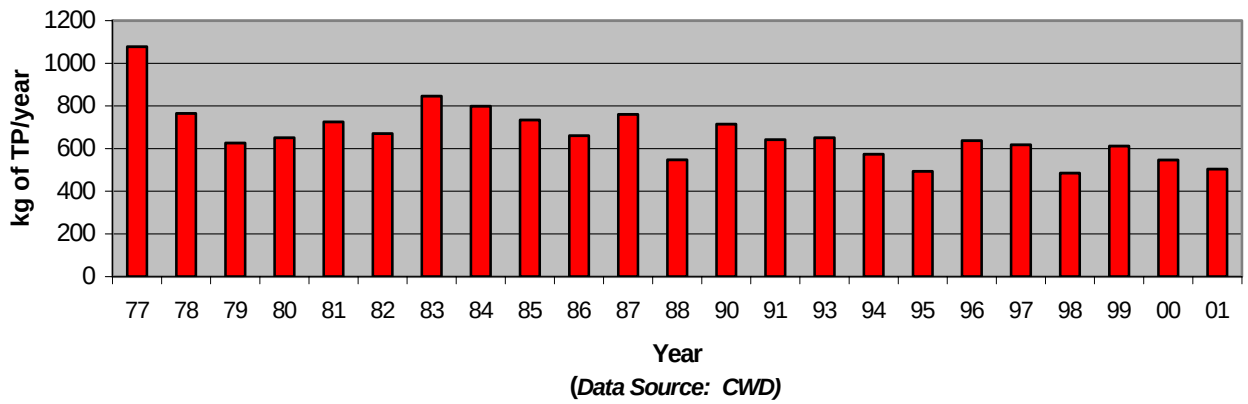
Overall, the presence of nuisance algae blooms in Annabessacook Lake may be mitigated, along with halting the trend of increasing trophic state, if the existing combined phosphorus loading is further reduced by approximately 415 kg TP. Reductions already underway in nonpoint source total phosphorus loadings are expected from the continued implementation of best management practices - primarily from improvements to roadways and residential shoreline buffer plantings of natural vegetation (see NPS/BMP implementation plan and PCAP report summary).

Internal Lake Sediment Phosphorus Mass: The relative contribution of internal sources of total phosphorus within Annabessacook Lake - in terms of sediment TP recycling - were analyzed (using lake volume-weighted mass differences between early and late summer) and estimated to approximate 465 kg, on the basis of water column TP data from 2001. Historic internal sediment loadings for the past two decades (1977-2001) were modeled and are depicted in Figure 4.

In summary, Annabessacook Lake combined internal (sediment) and external (watershed) phosphorus loads approximate 2,518 kg annually. Based on the 2 ppb difference between the 15 ppb target goal and the 17 ppb average annual epilimnetic P-concentration (332 kg), and inclusive of 83 kg allocated for future development, approximately 415 kg TP needs to be reduced to maintain suitable water quality standards. This reduction in total phosphorus may be attained over time given continued reductions in external watershed phosphorus loads leading to further reductions in internal sediment phosphorus loads via annual flushing in Annabessacook Lake.

Linking Pollutant Loading to a Numeric Target: the basin loading capacity for Annabessacook Lake was set at 2,485 kg/yr of total phosphorus to meet the numeric water quality target of 15 ppb of total phosphorus. A phosphorus retention model, calibrated to in-lake phosphorus data, was used to link phosphorus loading to the numeric target.

Figure 3: Annabessacook Lake Internal Load Sediment TP



Supporting Documentation for the Annabessacook Lake TMDL Analysis includes the following: CWD and VLMP water quality monitoring data; watershed/land use maps created by the CWD in 1991 and updated in 2001 – 2002; literature derived export coefficients; and specification of a phosphorus retention model – including both empirical models and retention coefficients.

Total Phosphorus Retention Model (after Dillon and Rigler 1974 and others)

L = P (A z p) / (1-R) where,

2,485 = **L** = external total phosphorus load capacity (kg TP/year)

15.0 = **P** = spring overturn total phosphorus concentration (ppb)
5.60 = **A** = lake basin surface area (km^2)
5.20 = **z** = mean depth of lake basin (m) **A z p = 107.7**
3.70 = **p** = annual flushing rate (flushes/year)
0.65 = **1- R** = phosphorus retention coefficient, where:
0.35 = **R = 1 / (1+ sq.rt. p)** (Larsen and Mercier 1976)

Previous use of the Vollenwieder (Dillon and Rigler 1974) type empirical model for Maine lakes, e.g., Cobbossee, Madawaska, Sebasticook, East Pond, China Lake, Mousam, and Highland lake TMDLs (Maine DEP 2000-2003) have shown this approach to be effective in linking watershed total phosphorus (external) loadings to existing in-lake total phosphorus concentrations.

Strengths and Weaknesses in the Overall TMDL Analytical Process: The Annabessacook Lake TMDL was developed using existing lake water quality monitoring data, derived watershed export coefficients (Reckhow et al. 1980, Maine DEP 1981 and 1989, Dennis 1986, Dennis et al. 1992, Bouchard et al. 1995, Soranno et al. 1996, and Mattson and Isaac 1999) and a phosphorus retention model which incorporates both empirically derived and observed retention coefficients (Vollenwieder 1969, Dillon 1974, Dillon and Rigler 1974 a and b, and 1975, Kirchner and Dillon 1975). Use of the Larsen and Mercier (1976) total phosphorus retention term, based on localized data (northeast and north-central U.S.) from 20 lakes in the US-EPA National Eutrophication Survey (US-EPA-New England) provides a more accurate model for northeastern regional lakes.

Strengths:

- Approach is commonly accepted practice in lake management
- Makes best use of available water quality monitoring data
- Based upon experience with other lakes in the northeastern U.S. region, the empirical phosphorus retention model was determined to be appropriate for the application lake.

Weaknesses:

- Inherent uncertainty of TP load estimates (Reckhow 1979, Walker 2000) and associated variability and generality of TP loading coefficients.

Critical Conditions - Occur in Annabessacook Lake during the summertime, when the potential (both occurrence and frequency) of nuisance algae blooms are greatest. The loading capacity of 15 ppb of total phosphorus was set to achieve desired water quality standards during this critical time period, and will also provide adequate protection throughout the year (see Seasonal Variation).

LOAD ALLOCATIONS (LA's) The load allocation (lake capacity) for all existing and future nonpoint pollution sources for Annabessacook Lake is 2,485 kg TP/yr, as derived from the empirical phosphorus retention model based on a target goal of 15 ppb (see Loading Capacity discussion). Reductions in nonpoint source phosphorus loadings are expected from the continued implementation of best management practices for camp roads and town roads (including in-town streets), as well as improved agricultural practices (see BMP Implementation Plan summary). As previously mentioned, it was not possible to separate natural background from nonpoint pollution sources in this watershed because of the limited and general nature of available information. As in other Maine 303(d) listed TMDL lakes, in-lake nutrient loadings in Annabessacook Lake originate from a combination of external and internal sources of total phosphorus. External TP sources, approximating 1,315 kg have been identified and accounted for in the land use breakdown portrayed in the land use table (3).

WASTE LOAD ALLOCATIONS (WLA's): There are no known existing point sources of pollution (including regulated storm-water sources) in the Annabessacook Lake watershed, hence, the waste load allocation for all existing and future point sources is set at 0 (zero) kg/year of total phosphorus.

MARGIN OF SAFETY (MOS): An implicit margin of safety was included in the Annabessacook Lake TMDL through the conservative selection of the numeric water quality target, as well as the selection of relatively conservative phosphorus export loading coefficients for cultural pollution sources (Table 3). Based on both the Annabessacook Lake historical records and a summary of statewide Maine lakes water quality data for non-colored (< 26 SPU) lakes - the target of 15 ppb

(2,485 kg TP/yr in Annabessacook Lake) represents a fairly conservative goal to assure attainment of Maine DEP water quality goals of non-sustained and non-repeated blue-green summer-time algae blooms due to NPS pollution or cultural eutrophication and stable or decreasing trophic state. The statewide data base for uncolored Maine lakes indicate that summer nuisance algae blooms (growth of algae which causes Secchi disk transparency to be less than 2 meters) are more likely to occur at 18 ppb or above. The 332 kg difference between the in-lake target of 15 ppb (2,485 kg) and 17 ppb (2,817) represents a 12% [(2,817-2,485)/2,817] implicit margin of safety (nuisance algal blooms unlikely) for Annabessacook Lake.

SEASONAL VARIATION: The Annabessacook Lake TMDL is protective of all seasons, as the allowable annual load was developed to be protective of the most sensitive time of year – during the summer and early fall, when conditions most favor the growth of algae & aquatic macrophytes. With an average of 3.7 flushes/year, the average annual phosphorus loading is most critical to the water quality in Annabessacook Lake. Generally, Maine DEP lake biologists use more than six flushes annually (bi-monthly) as the cutoff for considering seasonal variation as a major factor (to distinguish lakes vs. rivers) in the evaluation of total phosphorus loadings in aquatic environments. Nonpoint source best management practices (BMPs) proposed for the Annabessacook Lake watershed have been designed to address total phosphorus loading during all seasons.

PUBLIC PARTICIPATION: Adequate ('full and meaningful') public participation in the Annabessacook Lake TMDL development process was ensured - including land use and phosphorus load reduction discussions - through the following avenues:

1. CWD Project Manager, Bill Monagle**,** explained the Annabessacook Lake TMDL to the CWD Board of Trustees on February 20, 2001. The CWD Board of Trustees has two municipally appointed members from each of the two Towns on Annabessacook Lake, Monmouth and Winthrop. The monthly meeting of the CWD was publicly noticed and was attended by Doug Grant, vice-president of Annabessacook Lake Improvement Association.
2. On March 28, 2001, CWD Project Manager, Bill Monagle provided the Monmouth Planning Board with an overview of CWD's guidelines for controlling phosphorus from new developments. At this meeting, Mr. Monagle informed the Board of the pending TMDL for Annabessacook Lake, describing the features of the project and the general TMDL process.
3. CWD Project Manager, Bill Monagle, was the guest speaker at the annual meeting of the Annabessacook Lake Improvement Association (ALIA) on August 18, 2001. Mr. Monagle addressed a number of lake-related topics. He disseminated a written description of the TMDL process to the near-100 attendees, and how the TMDL specifically relates to the future of Annabessacook Lake.
4. During the winter of 2001 – 2002, CWD Project staff met on a number of occasions with an engineer from Wright-Pierce (Topsham), a consulting firm working with the Town of Monmouth to assist them with a downtown revitalization, or Smart Growth grant, awarded to the Town by the State Planning Office. On these occasions, the status of the current TMDL and potential recommendations generated from the TMDL were conveyed to the Town for consideration in their project.
5. On February 12, 2003, CWD Project Manager, Bill Monagle, addressed the Monmouth Board of Selectmen to update them on the status of the TMDL and to explain a prospective program of urban street sweeping to be jointly implemented with the Town of Winthrop.
6. On April 7, 2003, CWD Project Manager, Bill Monagle, addressed the Winthrop Town Council to update the Council on the TMDL, among other matters, and the prospective urban street sweeping program to be conducted jointly with the Town of Monmouth.

STAKEHOLDER REVIEW COMMENTS

A preliminary stakeholder review draft Annabessacook Lake PCAP-TMDL report was provided to 15 interested individuals who received electronic or hard copy versions of the report on March 4, 2004, and were requested to comment by the end of the day on March 18 (two-week review period). Some minor edits were made to the stakeholder review document and one comment was received, as appears below:

Single Stakeholder Review Comment (Annabessacook Lake Improvement Association):

Date: 15 March 2004
David Halliwell
State of Maine

Re**: Comments on Phosphorous Control Plan**

Dear Mr. Halliwell,

The Annabessacook Lake Improvement Association (ALIA), is a nonprofit corporation, made up of interested lakeside owners, incorporated for more than 50 years, with a goal of maintaining and improving the quality of water, and the quality of life on Lake Annabessacook. We have seen and reviewed the Plan recently published, and we are grateful to have an opportunity to present comments and to show our interest.

The plan properly identifies ALIA as a stakeholder, and invites us to be a participant in future discussions policy development to protect the lake. This invitation to become a participant is appreciated, as ALIA works hard to have contact with all relevant entities whose work can affect Lake Annabesacook. We have and plan to continue good working relationships with the Cobbossee Watershed District, the towns of Monmouth and Winthrop, DEP, Kennebec County Soil and Water Conservation District, VLMP and LEA to help us in our effort to improve the quality of water in the lake. We now have a new partner, Friends of the Cobbossee Watershed, to help us educate the public on the importance of taking care of our lakes and streams and how to improve the quality of water for everyone.

We, therefore accept the invitation. ALIA wants to proactively participate on Annabessacook Lake Leadership Team. For over 50 years ALIA has taken a leadership role in the coordination of efforts to improve the quality of water in Annabessacook Lake. We have done this by eliminating the point source phosphorus pollutants and reducing the non-point source of phosphorus pollutants using the Best Management Practices available. ALIA is ready to work with the Leadership Team on the list of recommendations that can lower non-point sources of phosphorus pollutants.

We thank you for the invitation and are looking forward to working with you as a part of the Leadership Team in the future. The threat of polluting our lake is greater than ever before, and the collective effort of all is needed to make sure the threat does not become a reality.

We look forward to the work ahead. We trust we will be included and added to any relevant mailing list.

We thank you.

Sincerely yours,

ALIA
Douglas Grant, President
Michael J. Levey, Secretary

PUBLIC REVIEW COMMENTS

The Annabessacook Lake public review draft PCAP-TMDL report was advertised in weekend editions of three newspapers (*Kennebec Journal, Lewiston Sun Record,* and the *Brunswick Times Record*) over two weekends, and the (Winthrop) *Community Advertiser* - for a month long review period (March 26 to April 23) and was also posted on the Maine DEP website. During this time period, only minor US-EPA New England region I formal comments were received and were fully addressed in the final submission (May 10, 2004).

LITERATURE

Lake Specific References

Dennis, W.L. 1982. Cobbossee Watershed lakes restoration: Hypolimnetic treatment and agricultural waste management. Final Rep. To U.S. EPA (Grant #S001391010). Cobbossee Watershed District, Winthrop, ME.

Dennis, W.L. and J.H. McPhedran. 1991. Annabessacook Lake Watershed: 1990 Land Use Evaluation and Mill Stream Monitoring. Cobbossee Watershed District, Winthrop, ME.

Dennis, W.L and J.H. McPhedran. 1993. Cochnewagon Lake post-restoration evaluation of alum treatment effectiveness. Progress Report #3 to U.S. EPA (Grant #S001227-01-0). Cobbossee Watershed District, Winthrop, ME.

Cole, H.S., Ph.D., Director, Clean Water Fund, Technical Assistance Center. Recommendations for the Cleanup of the Winthrop Superfund Site in Winthrop, ME. August, 1991.

Hall, M.W., Ph.D. Cultural eutrophication of Lake Annabessacook; causes, consequences, correction. Environmental Engineering Services, Inc., Orono, Maine. April 6, 1972.

Hall, M.W., Ph.D. Artificial mixing experiment and water quality monitoring program. Lake Annabessacook, Maine. June 6, 1973.

Maine Department of Environmental Protection. 1989. Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development. Augusta, ME.

Maine Department of Environmental Protection, Division of Lakes and Biological Studies. 1977. Annabessacook Lake evaluation proposal—draft. May 13, 1977.

Maine Department of Environmental Protection. 1992. Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development. Augusta, ME.

Maine Water Improvement Commission. Technical Report. Annabessacook Lake Study. Eutrophication and fertilization. Augusta, Maine. September, 1967.

Millen, R.R. Introductory survey of Annabessacook's limnological algacidal needs. October 6, 1971.

Sage, K.J. and E. Moran. 1977. Annabessacook Lake study. Cobbossee Watershed District, Winthrop, ME.

Smith, R.H. and S.C. DeWick. Classification Violation Report. Mill Stream, Annabessacook Lake, Winthrop, Maine. State of Maine Water Improvement Commission. Fall, 1965.

Southern Kennebec Valley Regional Planning Commission. 1976. Land Use Trends and Projections. Augusta, ME.

United States Environmental Protection Agency. 1980. Capsule Report: Lake Restoration in Cobbossee Watershed. EPA-625/2-80-027. U.S.EPA, Washington, DC.

U.S. Environmental Protection Agency. 1999. Regional Guidance on Submittal Requirements for Lake and Reservoir Nutrient TMDLs. US-EPA Office of Ecosystem Protection, New England region, Boston, MA.

General References

Barko, J.W., W.F. James, and W.D. Taylor. 1990. Effects of alum treatment on phosphorus and phytoplankton dynamics in a north-temperate reservoir: a synopsis. *Lake and Reservoir Management* 6:1-8.

Basile, A.A. and M.J. Vorhees. 1999. A practical approach for lake phosphorus Total Maximum Daily Load (TMDL) development. *US-EPA Region I*, Office of Ecosystem Protection, Boston, MA (July 1999).

Bostrom, B., G. Persson, and B. Broberg. 1988. Bioavailability of different phosphorus forms in freshwater systems. *Hydrobiologia* 170:133-155.

Bouchard, R., M. Higgins, and C. Rock. 1995. Using constructed wetland-pond systems to treat agricultural runoff: a watershed perspective. *Lake and Reservoir Management* 11(1):29-36.

Butkus, S.R., E.B. Welch, R.R. Horner, and D.E. Spyridakis. 1988. Lake response modeling using biologically available phosphorus. *Journal of Water Pollution Control Federation* 60:1663-69.

Carlton, R.G. and R.G. Wetzel. 1988. Phosphorus flux from lake sediments: effect of epipelic algal oxygen production. *Limnology and Oceanography* 33(4):562-570.

Chapra, S.C. 1997. Surface Water-Quality Modeling. McGraw-Hill Companies, Inc.

Correll, D.L., T.L. Wu, E.S. Friebele, and J. Miklas. 1978. Nutrient discharge from Rhode Island watersheds and their relationships to land use patterns. In: *Watershed Research in Eastern North America: A workshop to compare results*. Volume 1, February 28 - March 3, 1977. (mixed pine/hardwoods)

Dennis, W.K. and K.J. Sage. 1981. Phosphorus loading from agricultural runoff in Jock Stream, tributary to Cobbossee Lake, Maine: 1977-1980. *Cobbossee Watershed District*, Winthrop.

Dennis, J. 1986. Phosphorus export from a low-density residential watershed and an adjacent forested watershed. *Lake and Reservoir Management* 2:401-407.

Dennis, J., J. Noel, D. Miller, C. Elliot, M.E. Dennis, and C. Kuhns. 1992. Phosphorus Control in Lake Watersheds: A Technical Guide to Evaluating New Development. *Maine Department of Environmental Protection*, Augusta, Maine.

Dillon, P.J. 1974. A critical review of Vollenweider's nutrient budget model and other related models. *Water Resources Bulletin* 10:969-989.

Dillon, P.J. and F.H. Rigler. 1974a. The phosphorus-chlorophyll relationship for lakes. *Limnology and Oceanography* 19:767-773.

Dillon, P.J. and F.H. Rigler. 1974b. A test of a simple nutrient budget model predicting the phosphorus concentration in lake water. *Journal of the Fisheries Research Board of Canada* 31:1771-1778.

Dillon, P.J. and F.H. Rigler. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. *Journal of the Fisheries Research Board of Canada* 32:1519-1531.

Dudley, R.W., S.A. Olson, and M. Handley. 1997. A preliminary study of runoff of selected contaminants from rural Maine highways. U.S. Geological Survey, Water-Resources Investigations Report 97-4041 (DOT, DEP, WRI), 18 pages.

Gasith, Avital and Sarig Gafny. 1990. Effects of water level fluctuation on the structure and function of the littoral zone. Pages 156-171 (Chapter 8) in: M.M. Tilzer and C. Serruya (eds.), *Large Lakes: Ecological Structure and Function*, Springer-Verlag, NY.

Heidtke, T.M. and M.T. Auer. 1992. Partitioning phosphorus loads: implications for lake restoration. *Journal of Water Resources Plan. Mgt.* 118(5):562-579.

James, W.F., R.H. Kennedy, and R.F. Gaubush. 1990. Effects of large-scale metalimnetic migrations on phosphorus dynamics in a north-temperate reservoir. *Canadian Journal of Fisheries and Aquatic Sciences* 47:156-162.

James, W.F. and J.W. Barko. 1991. Estimation of phosphorus exchange between littoral and pelagic zones during nighttime convective circulation. *Limnology and Oceanography* 36 (1):179-187.

Jemison, J.M. Jr., M.H. Wiedenhoeft, E.B. Mallory, A. Hartke, and T. Timms. 1997. A Survey of Best Management Practices on Maine Potato and Dairy Farms: Final Report. University of Maine Agricultural and Forest Experiment Station, Misc. Publ. 737, Orono, Maine.

Kallqvist, Torsten and Dag Berge. 1990. Biological availability of phosphorus in agricultural runoff compared to other phosphorus sources. *Verh. Internat. Verein. Limnol.* 24:214-217.

Kirchner, W.B. and P.J. Dillon. 1975. An empirical method of estimating the retention of phosphorus in lakes. *Water Resources Research* 11:182-183.

Larsen, D.P. and H.T. Mercier. 1976. Phosphorus retention capacity of lakes. *Journal of the Fisheries Research Board of Canada* 33:1742-1750.

Lee, G.F., R.A. Jones, and W. Rast. 1980. Availability of phosphorus to phytoplankton and its implications for phosphorus management strategies. Pages 259-308 (Ch.11) in: *Phosphorus Management Strategies for Lakes*, Ann Arbor Science Publishers, Inc.

Likens, G.E., F.H. Bormann, R.S. Pierce, J.S. Eaton, and N.M. Johnson. 1977. Bio-Geochemistry of a Forested Ecosystem. Springer-Verlag, Inc. New York, 146 pages.

Maine Department of Environmental Protection. 1999. Cobbossee Lake (Kennebec County, Maine) Final TMDL Addendum (to Monagle 1995). *Maine Department of Environmental Protection*, Augusta, Maine.

Marsden, Martin, W. 1989. Lake restoration by reducing external phosphorus loading: the influence of sediment phosphorus release (Special Review). *Freshwater Biology* 21(2):139-162.

Martin, T.A., N.A. Johnson, M.R. Penn & S.W. Effler. 1993. Measurement and verification of rates of sediment phosphorus release for a hypereutrophic urban lake. *Hydrobiologia* 253:301-309.

Mattson, M.D. and R.A. Isaac. 1999. Calibration of phosphorus export coefficients for total maximum daily loads of Massachusetts lakes. *Journal of Lake and Reservoir Management* 15 (3):209-219.

Michigan Department of Environmental Quality. 1999. Pollutant Controlled Calculation and Documentation for Section 319 Watersheds *Training Manual*. Michigan DEQ, Surface Water Quality Division, Nonpoint Source Unit.

Monagle, W.J. 1995. Cobbossee Lake Total Maximum Daily Load (TMDL): Restoration of Cobbossee Lake through reduction of non-point sources of phosphorus. *Prepared for ME-DEP by Cobbossee Watershed District.*

Nurnberg, G.K. 1984. The prediction of internal phosphorus load in lakes with anoxic hypolimnia. *Limnology and Oceanography* 29:111-124.

Nurnberg, G.K. 1987. A comparison of internal phosphorus loads in-lakes with anoxic hypolimnia: Laboratory incubation versus in situ hypolimnetic phosphorus accumulation. *Limnology and Oceanography* 32(5):1160-1164.

Nurnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. *Canadian Journal of Fisheries and Aquatic Sciences* 45:453-462.

Nurnberg, G.K. 1995. Quantifying anoxia in lakes. *Limnology and Oceanography* 40(6):1100-11.

Reckhow, K.H. 1979. Uncertainty analysis applied to Vollenweider's phosphorus loading criteria. *Journal of the Water Pollution Control Federation* 51(8):2123-2128.

Reckhow, K.H., M.N. Beaulac, and J.T. Simpson. 1980. Modeling phosphorus loading and lake response under uncertainty: a manual and compilation of export coefficients. EPA 440/5-80-011, *US-EPA*, Washington, D.C.

Reckhow, K.H., J.T. Clemens, and R.C. Dodd. 1990. Statistical evaluation of mechanistic water-quality models. *Journal Environmental Engineering* 116:250-265.

Riley, E.T. and E.E. Prepas. 1985. Comparison of phosphorus-chlorophyll relationships in mixed and stratified lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 42:831-835.

Rippey, B., N.J. Anderson, and R.H. Foy. 1997. Accuracy of diatom-inferred total phosphorus concentrations and the accelerated eutrophication of a lake due to reduced flushing and increased internal loading. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2637-2646.

Schroeder, D.C. 1979. Phosphorus Export From Rural Maine Watersheds. *Land and Water Resources Center, University of Maine*, Orono, Completion Report.

Singer, M.J. and R.H. Rust. 1975. Phosphorus in surface runoff from a (northeastern United States) deciduous forest. *Journal of Environmental Quality* 4(3):307-311.

Sonzogni, W.C., S.C. Chapra, D.E. Armstrong, and T.J. Logan. 1982. Bioavailability of phosphorus inputs to lakes. *Journal of Environmental Quality* 11(4):555-562.

Soranno, P.A., S.L. Hubler, S.R. Carpenter, and R.C. Lathrop. 1996. Phosphorus loads to surface waters: a simple model to account for spatial pattern. *Ecological Applications* 6(3):865-878.

Sparks, C.J. 1990. Lawn care chemical programs for phosphorus: information, education, and regulation. U.S. Environmental Protection Agency, Enhancing States' Lake Management Programs, pages 43-54. [Golf course application]

Stefan, H.G., G.M. Horsch, and J.W. Barko. 1989. A model for the estimation of convective exchange in the littoral region of a shallow lake during cooling. *Hydrobiologia* 174:225-234.

Tietjen, Elaine. 1986. Avoiding the China Lake Syndrome. Reprinted from *Habitat* - Journal of the Maine Audubon Society, 4 pages.

U.S. Environmental Protection Agency. 1999. Regional Guidance on Submittal Requirements for Lake and Reservoir Nutrient TMDLs. *US-EPA Office of Ecosystem Protection*, New England Region, Boston, MA.

U.S. Environmental Protection Agency. 2000a. Cobbossee Lake TMDL Final Approval Documentation. US-EPA/NES, January 26, 2000.

U.S. Environmental Protection Agency. 2000b. Madawaska Lake TMDL Final Approval Documentation. US-EPA/NES, July 24, 2000.

U.S. Environmental Protection Agency. 2001a. Sebasticook Lake TMDL Final Approval Documentation. US-EPA/NES, March 8, 2001.

U.S. Environmental Protection Agency. 2001b. East Pond TMDL Final Approval Documentation. US-EPA/NES, October 9, 2001.

U.S. Environmental Protection Agency. 2001c. China Lake TMDL Final Approval Documentation. US-EPA/NES, November 5, 2001.

U.S. Environmental Protection Agency. 2003a. Highland (Duck) Lake TMDL Final Approval Documentation. US-EPA/NES, June 18, 2003.

U.S. Environmental Protection Agency. 2003b. Webber Pond TMDL Final Approval Documentation. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003c. Threemile Pond TMDL Final Approval Documentation. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003d. Threecornered Pond TMDL Final Approval Documentation. US-EPA/NES, September 10, 2003.

U.S. Environmental Protection Agency. 2003e. Mousam Lake TMDL Final Approval Documentation. US-EPA/NES, September 29, 2003.

Vollenweider, R.A. 1969. Possibility and limits of elementary models concerning the budget of substances in lakes. *Arch. Hydrobiol.* 66:1-36.

Walker, W.W., Jr. 2000. Quantifying Uncertainty in Phosphorus TMDL's for Lakes. March 8, 2001 *Draft* Prepared for NEIWPCC and EPA Region

---