Lake Pocotopaug Nine Elements Watershed Based Plan

Prepared for:

Town of East Hampton

Lake Pocotopaug Lake Commission

Prepared by:

George Knoecklein

Hillary Kenyon

Northeast Aquatic Research

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Introduction

Purpose

This document incorporates results from prior studies, 1991-2009[1], and new lake and watershed data from 2014-2016 to develop a comprehensive US EPA Nine Elements Watershed-based Plan that identifies improvements necessary to allow Recreational Use to be Fully Supported in Lake Pocotopaug. This Nine Elements Plan characterizes the current condition of the Lake with regard to the CT DEEP Water Quality Standards and interprets changes needed to return the Lake to Fully Supported Recreation. This Plan delineates twenty-five high priority conveyance systems, or management zones, around the lake where Storm-water controls are needed to reduce nutrient and sediment runoff. Management zones are ranked in various ways to assist with prioritization schedule. Ranking includes; degree of impervious surface, anticipated water containment volume, linear feet of road surface, nutrient levels, and suitability of management measures. Steps necessary to achieve the long term goal of returning Fully Supported Recreation in Lake Pocotopaug are:

1) Modify existing lake and tributary monitoring program to resolve nutrient and sediments levels from identified conveyance systems. Confirm sample design can track changes as improvements are made.
2) Develop site plans detailing the selection and installation of storm-water filtering systems for all suitable conveyance systems.
3) Evaluate methods to control storm-water in conveyance systems not suitable for filtering alternatives.
4) Develop and implement Town maintenance program of existing storm-water conveyance.
5) Provide education to property owners on storm-water best management practices.
6) Inspect and diagnose the condition of lake shoreline.
7) Ensure undeveloped landscape retains integrity,
8) Systematically contract the construction of storm-water infrastructure projects.

[1] See Appendix 2 Document Review

Background

Lake Pocotopaug experienced unprecedented intense cyanobacteria blooms during the summers of 1988 and 1989, despite sewering of lakeside homes and businesses in 1983. The severity of the blooms triggered the first in a series of in-depth studies of the lake in 1991. These early studies focused on in-lake nutrient dynamics suggesting that internal loading of phosphorus from bottom sediments was the principal cause of excessive algae growth. Aluminum sulfate (Alum) was added to the lake in an effort to inactivate internal phosphorus release first in 2000, than again in 2001. Neither application rendered any change in either bottom phosphorus concentrations or algae growths with dominance of cyanobacteria in summer blooms virtually unchanged from years before the Alum treatments.

In 2002, after lack of success with Alum, nonpoint source pollution, especially storm-water, was considered to be the driving contributor to the poor water quality of the lake. Nutrient levels in runoff water were examined between 2001 and 2008. In 2006, State of Connecticut DEP listed Lake Pocotopaug as impaired because it did not support Recreational Use due to algae growth. In 2009, AECOM released a Lake Loading Response Model (LLRM) that used 8 years of watershed input data to estimate phosphorus and nitrogen loads from each of their 14 identified sub-basins. The model estimated lake response to different scenarios including full build-out and full use of management measures, showing that water clarity and bloom frequency would be improved with the use of storm-water retrofits, while overall lake condition would continue to decline with build-out and no management measures.

Existing Conditions

Consistency of monitoring at Lake Pocotopaug now provides a 15 year water quality record. Results of prior sampling (1991-2008) combined with recent field measurements (2014-2016) show the lake to have seasonally dependent water quality with best conditions in the spring and poorest conditions in the summer and fall. The long-term seasonal variations for three trophic metrics at Lake Pocotopaug are shown below with CT DEEP thresholds of impaired status. Lakes are classified by Trophic State with Eutrophic and Highly Eutrophic lakes designated as impaired **Table 1**. Lake condition summary is given in **Table 2** and the shown graphically in **Figures 1-3**.

- Total phosphorus concentration in the upper water of the lake has seasonal spread of values of between 10 µg/L and 35 µg/L, with values less than 10 µg/L becoming rare and values over 30 µg/L common (**Figure 1**),
- Secchi disk water clarity trends show annual eutrophic conditions (between 1 and 2 meters clarity) since records began in early 1990's. Readings show a steady loss of 3+ meter conditions and an increase in highly eutrophic (<1 meters) conditions (**Figure 2**).
- Total nitrogen concentration in upper water (**Figure 3**) show a wide seasonal range in values from low Mesotrophic levels in the spring to Highly Eutrophic levels in the fall.

Table 1 – CT DEEP classification parameters and defining ranges of lake trophic state

Trophic State Category	Trophic State Indicator[2]	Defining Range TP and TN Avg. spring and summer samples Unless otherwise noted
Oligotrophic	Total Phosphorus	0 – 10 µg/L
	Total Nitrogen	0 – 200 µg/L
	Secchi Disk Transparency	6 + meters *mid-summer*
	Chlorophyll-a	0 – 2 µg/L *mid-summer*
Mesotrophic	Total Phosphorus	10 – 30 µg/L
	Total Nitrogen	200 – 600 µg/L
	Secchi Disk Transparency	2 – 6 meters *mid-summer*
	Chlorophyll-*a*	2 – 15 µg/L *mid-summer*
Eutrophic	Total Phosphorus	30 – 50 µg/L
	Total Nitrogen	600 – 1000 µg/L
	Secchi Disk Transparency	1 – 2 meters *mid-summer*
	Chlorophyll-*a*	15 – 30 µg/L *mid-summer*
Highly Eutrophic	Total Phosphorus	50+ µg/L
	Total Nitrogen	1000+ µg/L
	Secchi Disk Transparency	0 – 1 meters *mid-summer*
	Chlorophyll-*a*	30 + µg/L *mid-summer*

Source: Regulation on Connecticut Water Quality Standards R-39 Rev. 03/2012

Table 2 – 1991-2016 measured values of trophic indicators in Lake Pocotopaug

Parameter	Value	
Water clarity	Persistent summer clarity less than 1 meter, many *mid-summer* readings less than 0.5 meters	Highly Eutrophic
Direct cell counts	Maximum cyanobacteria numbers over 300,000 cells/mL	Closure
Chlorophyll-*a*	Most summers 15µg/L, some summer maximum of 25µg/L	Eutrophic
Phosphorus concentrations	Consistently over 20µg/L, some summer maximum values over 30µg/L.	Meso- to Eutrophic
Nitrogen concentrations	Consistently over 600µg/L, some maximum summer values over 1,000µg/L	Eutrophic to Highly Eutrophic

[2] Trophic State also incorporates macrophyte growth and coverage but aquatic plants are sparse in Lake Pocotopaug

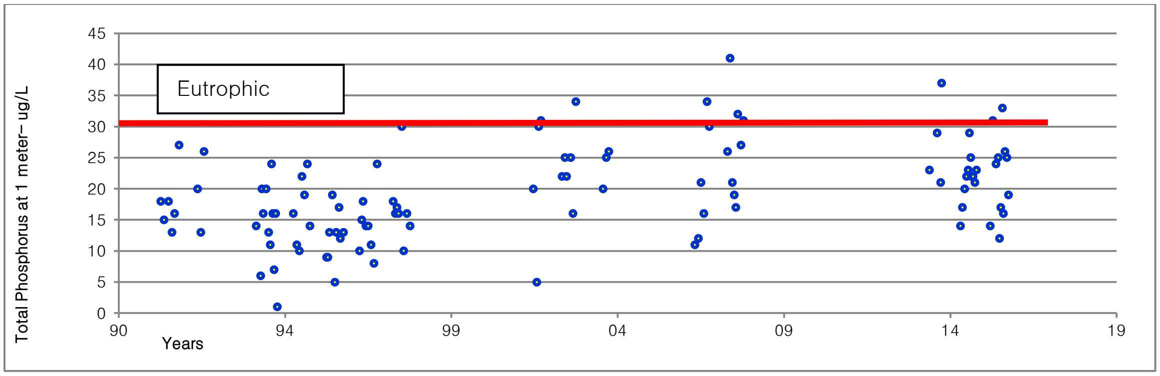


Figure 1 – Phosphorus concentrations in surface water of Lake Pocotopaug 1991-2016. Red line Eutrophic threshold at 30ppb

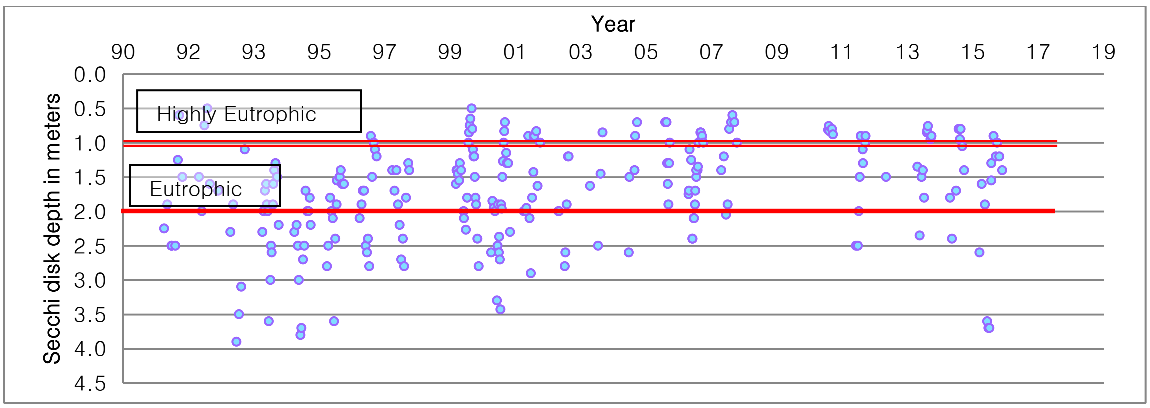


Figure 2 – Secchi disk water clarity in Lake Pocotopaug 1991-2016. Thresholds shown for Eutrophic-single red line at 2.0 meters and Highly Eutrophic-double red line at 1.0 meter

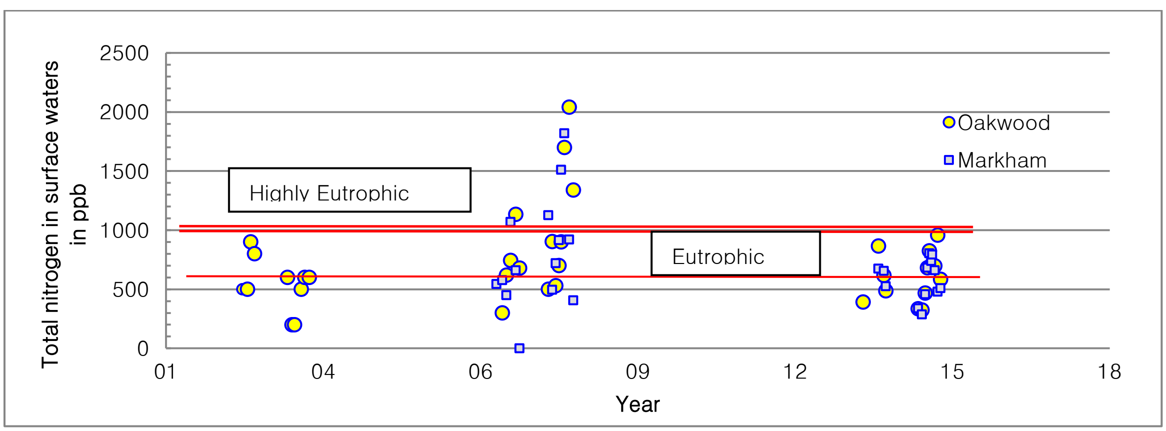


Figure 3 – Total nitrogen in upper waters of Lake Pocotopaug between 2002 and 2016. Thresholds shown for Eutrophic-single red line at 600 ppb, and Highly Eutrophic-double red line at 1000 ppb

Restoration of Recreation as Supported Use

The cause of impairment in Lake Pocotopaug has been listed as Chlorophyll-*a*, excess algae growth, and excess nutrient levels. These three causes of impairment have the same fundamental root-cause; excess nutrient levels in runoff from both Permitted and Non-permitted storm-water (**Table 3**)

Table 3 – Definition of designated use

Designated Use	Functional Definition	Cause	Potential
Recreation (human contact and non-contact)	Swimming, water skiing, surfing or other full body contact activities (primary contact), as well as boating, canoeing, kayaking, fishing, aesthetic appreciation or other activities that do not require full body contact (secondary contact).	Excess Algal Growth, Chlorophyll-*a*, Nutrient/Eutrophication Biological Indicators	Permitted and Non-permitted storm-water

Source = 2014 State of Connecticut's Integrated Water Quality Report to Congress

Existing conditions compared to Mesotrophic classification thresholds show changes required to bring the Lake from its current Eutrophic / Highly Eutrophic state to a Mesotrophic state **Table 4.** Based on DEEP ranges (**Table 2**), total phosphorus concentration needs to be less than <30 µg/L, water clarity needs to be better than 2 meters, chlorophyll-*a* needs to be less than 15 µg/L, and total nitrogen concentration less than 500 µg/L.

Table 4 – Changes required to restore Recreational Use in Lake Pocotopaug

Parameter	Existing Levels	Required levels	Change Required
Water clarity	Minimum = 0.5 meters	Minimum summer reading of 2 meters	0.5 meters increased to 2 meters
Direct cell counts	Maximum cyanobacteria = 300,000 cells/mL	Maximum cyanobacteria numbers <25,000 cells/mL	300,000 cells/mL decreased to 25,000 cells/mL
Chlorophyll-*a*	Summer maximums = 25 µg/L	Summer maximums <15 µg/L	25 µg/L decreased to <15 µg/L
Phosphorus concentrations	Maximum summer = 30 µg/L	Consistent summer <20 µg/L	30 µg/L decreased to <20 µg/L
Nitrogen concentrations	Maximum summer = 1,000 µg/L	Consistent summer <500 µg/L	1,000 µg/L decreased to <600 µg/L

Source = 2014 State of Connecticut Integrated Water Quality Report, October 2014 -- Connecticut Impaired Waters List (EPA Category 5)-Lake Pocotopaug CT4709-04-1- L1_01

Identified Causes of Impairment (element A)

Pollution Sources

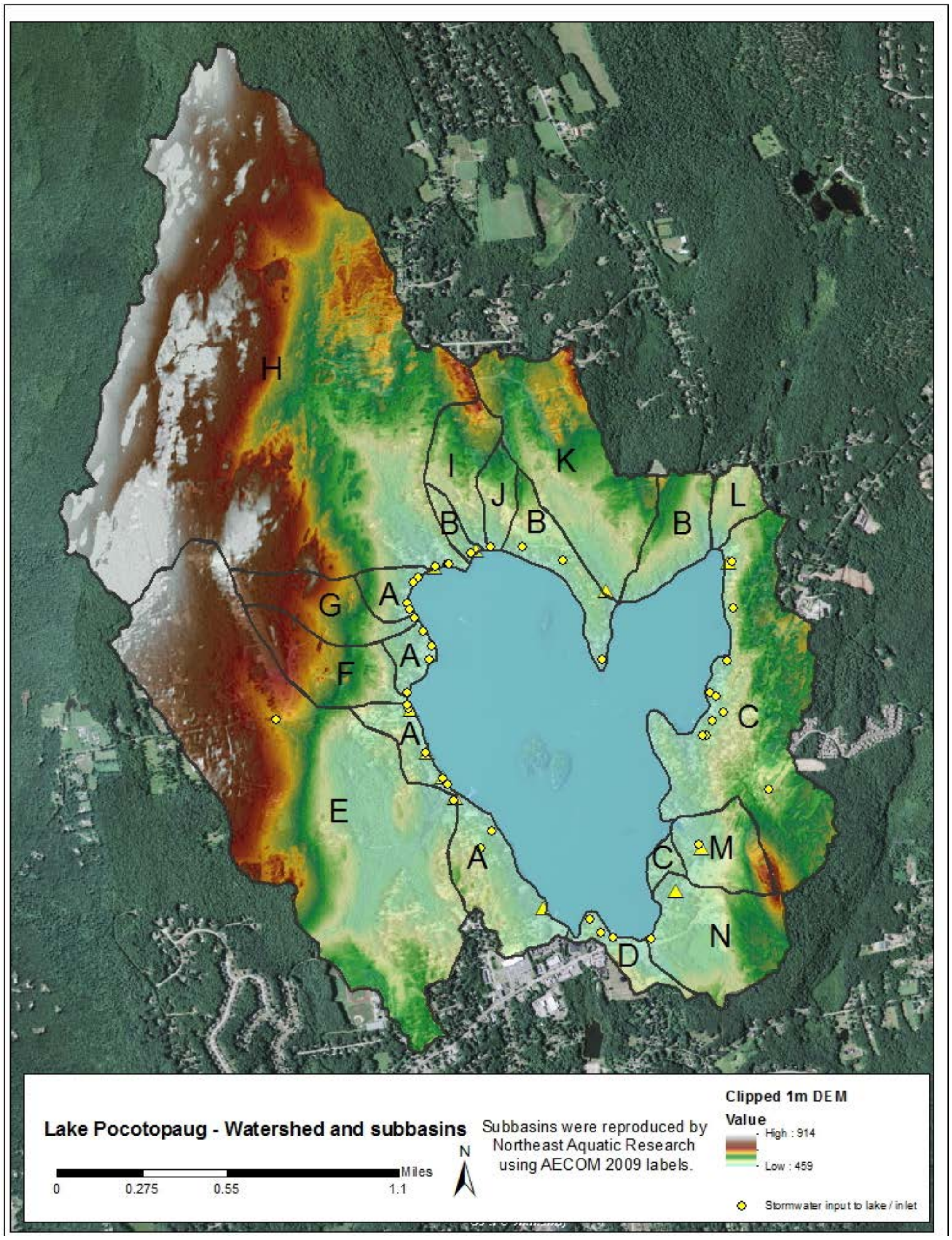
Watershed sub-basins

The AECOM 2009 report divided the Lake Pocotopaug watershed into fourteen sub-basins delineated by topography and conveyance **Map 1**. Sub-basins are smaller units of the drainage basin that individually supply water to a discharge point at the lake. The AECOM sub-basins are ranked by size of catchment in **Table 6** showing that the two largest basins, H & E, comprise 61% of the total area of the watershed. The remaining 39% is divided into 12 sub-basins each small <10%, or very small <5%, of the total lake watershed. The 12 smaller basins have high degrees of imperious surface with most runoff collected by catch basins and piped directly to the Lake.

Table 5 – Watershed AECOM sub-basins of Lake Pocotopaug ranked by size

Code	Name	Type	Acres	% Area
H	Hales Brook	Stream	890	39
E	Christopher Brook	Stream	496	22
C	*Storm-water*	Direct	208	9
K	Fawn Brook	Stream	144	6
A	*Storm-water*	Direct	122	5
B	*Storm-water*	Direct	94	4
N	Days Brook	Brook	81	4
F	Clark Hill *Storm-water*	Stream	61	3
G	*Storm-water*	Direct	50	2
M	O'Neill Brook	Stream	46	2
I	Candlewood *Storm-water*	Steam	44	2
D	*Storm-water*	Direct	34	1
J	*Storm-water*	Direct	22	1
L	Hazen Brook	Steam	13	0.6
	Total Drainage Area		2,305	100

Map 1 – Lake Pocotopaug watershed with color enhanced elevation, boundaries delineating each of the 14 AECOM sub-basins, and yellow circles showing water sample collection stations



Land Use

Historical aerial images (**Map 2**) are available from the CT DEEP and UCONN MAGIC GIS clearinghouse. The images demonstrate that the immediate shore areas of Lake Pocotopaug were heavily developed throughout recent years, large areas of open earth construction in 2005. The visibly green water is a product of cyanobacteria blooms occurring in the lake at the time of the photograph, July 2005.

Map 2 – Aerial images of Lake Pocotopaug Watershed in 1934 and 2005

Recent Updates and Current Land-Use

The AECOM 2009 LLRM differentiated the drainage basin of Lake Pocotopaug using fourteen land-use types--nine of which are applicable to the Lake Pocotopaug basin (**Table 6**). The most recent GIS data available for the Lake Pocotopaug watershed is from 2006 and served as the base for updated 2009 land cover data used in the LLRM (AECOM 2009). Because there are inherent errors in using satellite and aerial imagery calculations to create large land cover GIS files, ground field data becomes incredibly important as supplementary information for more accurate land-use estimates when modeling watershed runoff and estimating nutrient loading. The directly downloaded 2006 GIS data contains possible flaws; NEAR confirmed that AECOM was able to appropriately reclassify raster pixels.

Table 6 – Land-use areas (acres) for each land-use category in each sub-basin

	AECOM Sub-basins														
LAND USE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	TOTAL
Urban 1 Light DR	74	49	108	17	117	27	5	79	17	11	45	1	21	17	587
Urban 2 Medium DR/Hwy	9	6	14	2	15	3	1	10	2	1	6		3	2	73
Urban 3 High DR/Com	9	6	14	2	15	3	1	10	2	1	6		3	2	73
Agric 1 Cvr Crop					2										2
Forest 1 Upland	19	27	68	8	281	22	38	747	23	8	83	11	14	52	1,401
Forest 2 Wetland					36			15			5			7	63
Open 1 Wetland/Lake	6	4	1	1				8							22
Open 2 Meadow	5	1	3	4	25	5	5	17				2	3	1	73
Open 3 Excavation					6			4							11
TOTALS=	122	94	209	34	496	61	50	890	43	22	144	13	46	81	2,305
Zeros left blank															

Nutrient Loading Estimates

Several attempts were made between 1993 and 2009 to estimate nutrient loads to Lake Pocotopaug **Table 7**. The AECOM 2009 report presented the Lake Loading Response Model (LLRM) as the culmination of several years of data collection and watershed analysis. The LLRM estimates of phosphorus and nitrogen loads to Lake Pocotopaug are given in **Table 7** (shown in gray) alongside prior modeling results, also shown graphically in **Figure 4**. The LLRM estimated that 65-70% of total phosphorus and nitrogen loads are from the storm-water runoff from the watershed indicating that management measures can be used to control about 265 kg P/yr. phosphorus, and 5,662 kg N/yr. The remaining 30%, 19% internal recycling, 10% atmospheric deposition, and about 1% water-foul cannot be controlled by watershed measures so are not covered by this Plan.

Table 7 – Loading model results

	TP Load (kg/yr.)						TN Load (kg/yr.)	
Source	Fugro 1993	LAC 1995	ENSR 2002	ENSR 2007	AECOM 2009 Model	AECOM 2009 Expected Range	AECOM 2009 Model	AECOM 2009 Expected Range
Atmospheric	574	207	25-50	74	41	33-49	1,242	1,201-1,283
Wildlife		20	20-40	20	4	4-40	19	19-190
Direct Groundwater			5-18	12	265	242-408	5,662	4,701-6,013
Watershed		360	280-720	318-364				
Internal	500	?	62	16	72	50-100	1,790	1,400-2,000
Total	1,074	587+ internal	392-890	441-487	382	329-597	8,713	7,321-9,486

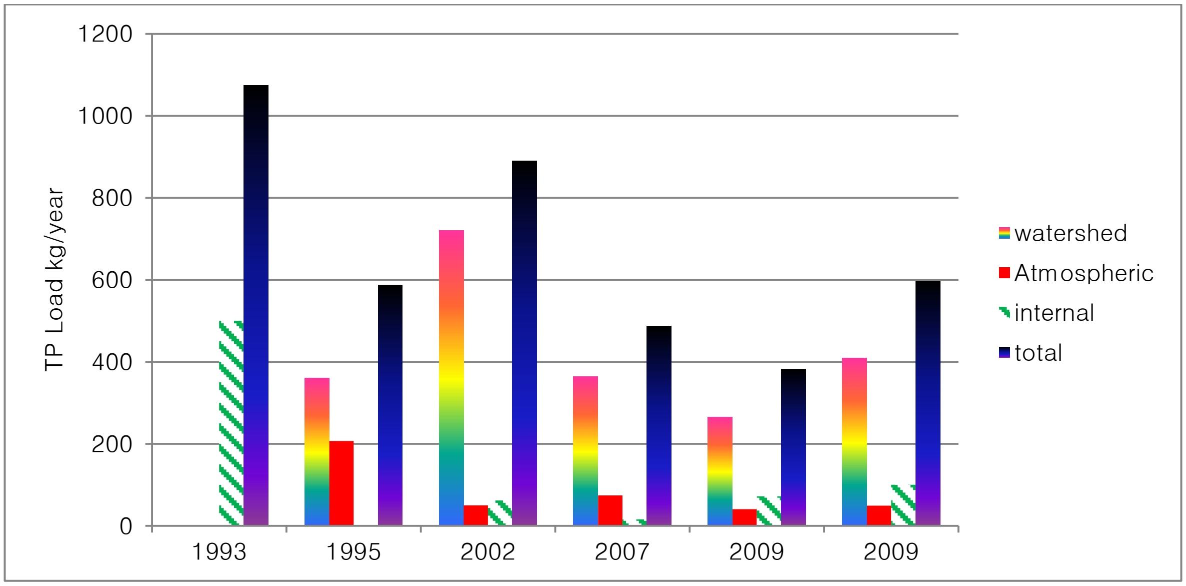


Figure 4 – Range in phosphorus loading estimates from different models

Sub-basin level nutrient loading

The AECOM 2009 Lake Loading Response Model (LLRM) estimated total annual water, phosphorus, and nitrogen exports from each of their 14 delineated sub-basins **Table 8**. Total annual phosphorus and nitrogen loading for each sub-basin follows size with largest basins contributing the majority of the nutrient load and the smallest basins contributing minor amounts (**Figure 5**). However, loading rates per unit area (kg/ha/yr.) were highest in small near shore sub-basins and lowest from the larger sub-basins **Figure 6**. The magnitude of phosphorus loading rates follows the percent development with highest rates coming from sub-basins with more than 50% impervious land (**Figure 7**).

Table 8 – Nutrient loading estimates by sub-basin

Basin Code and Name	Watershed size %	Phosphorus (kg/yr.)	Phosphorus kg/ha/yr.	Nitrogen (kg/yr.)	Nitrogen kg/ha/yr.
H – Hales Brook	39	64.7	0.18	1,608.6	4.5
E – Christopher Brook	22	48.3	0.24	962.3	4.8
C – Storm-water=East	9	39.0	0.46	878.3	10.5
A – Storm-water=West	6	24.9	0.50	564.5	9.7

K – Fawn Brook	5	20.3	0.35	317.5	6.4
B – Storm-water=North	4	17.6	0.46	397.3	10.5
F – Clark Hill Road Storm-water	4	10.2	0.42	231.1	7.0
N – Days Brook	3	9.4	0.29	148.0	5.9
M – O'Neil Brook	2	8.0	0.43	126.7	6.3
I – Candlewood Brook	2	6.8	0.39	106.6	5.6
D – Storm-water=South	2	6.0	0.43	136.3	7.6
G – Ola Brook	1	4.7	0.24	104.4	7.5
J – Raymond Brook	1	4.0	0.46	63.5	7.1
L – Hazen Brook	0.6	1.1	0.21	17.3	3.5
TOTAL		265.1		5,662.2	

Source = AECOM 2009

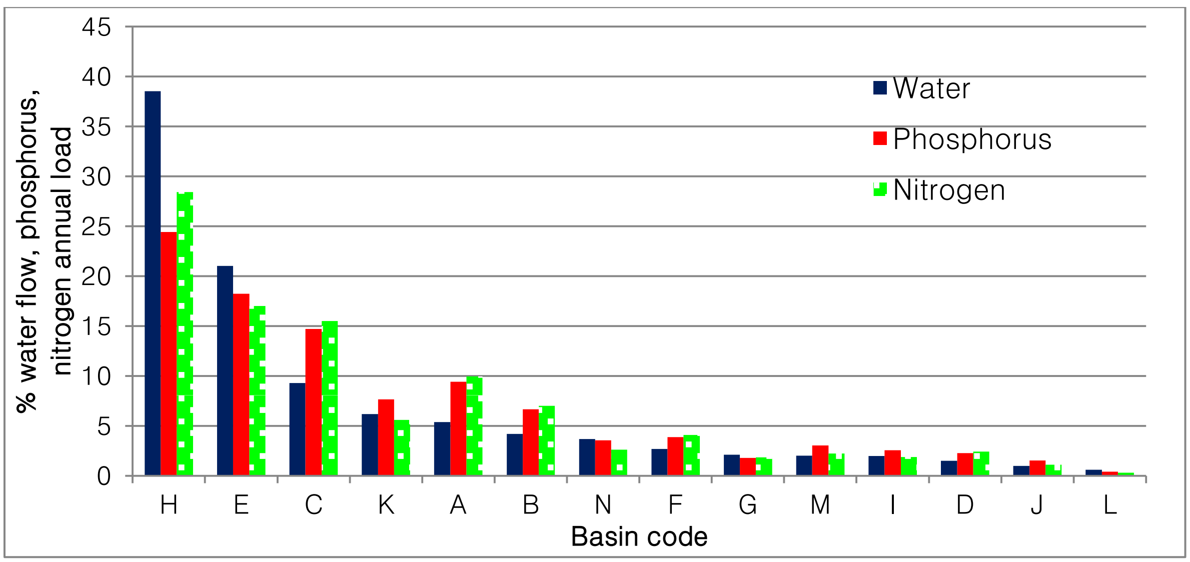


Figure 5 – Estimated % loads of water, phosphorus, and nitrogen from each sub-basin

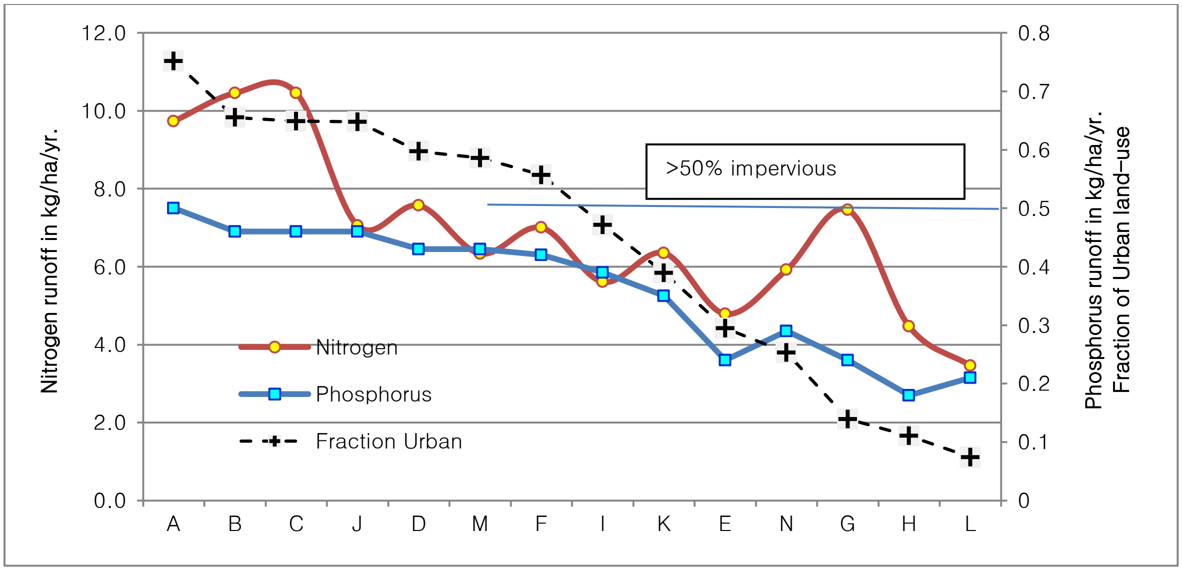


Figure 6 – Ranked unit export rates for phosphorus and nitrogen against fraction of urban land-use from 14 sub-basins

Pollutant Loading Reduction (element B)

Needed Load Reductions to Restore Supported Recreational Use

Recent measurement show seasonal ranges for phosphorus concentration of between 10 and 35 µg/L (**Figure 1**), and Secchi disk depth of between 0.5 meters and 2.5 meters (**Figure 2**). Relationship between phosphorus and water clarity for Lake Pocotopaug shown in **Figure 7**, indicates that water clarity greater than 1.5 meters is unlikely when phosphorus exceeds 25 µg/L. However, water clarity can be poor with phosphorus concentrations as low as 15 µg/L. Although a target phosphorus concentration of 25 µg/L makes it possible to have water clarity of >2 meters it doesn't guarantee it, suggesting phosphorus not the only factor affecting water clarity.

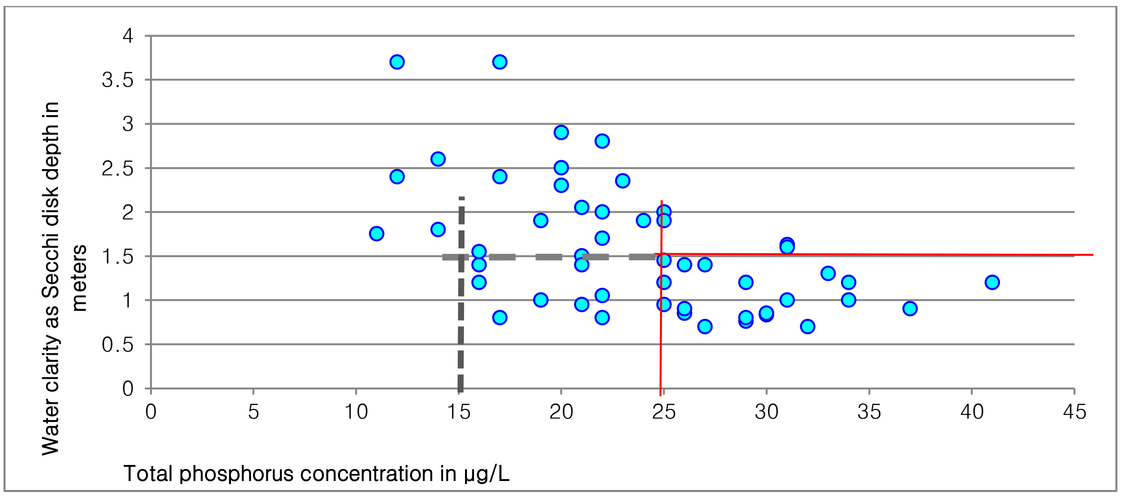


Figure 7 – Total phosphorus and water clarity in Lake Pocotopaug

The relationship between in-lake epilimnion phosphorus concentration and total P mass is about 8 kg for each 1 µg P/L (**Figure 8**). Slight variation in the relationship is due to influence of deeper strata of water. Total mass increases by about 80 kg between 15µg/L and 25µg/L, and another 40 kg between 25 µg/L and 30 µg/L, indicating phosphorus controlling concentration in the lake will require managing about 120 kg phosphorus load to the lake. AECOM estimates of total P load to the lake from sub-basins, given in **Table 8**, suggest about half the total load of phosphorus needs to be controlled. Recent phosphorus runoff measurements (2014-2016), show average concentration of phosphorus in runoff from highly impervious sub-basins exceeds the in-lake target P concentration of 25 µg/L (**Figure 9**).

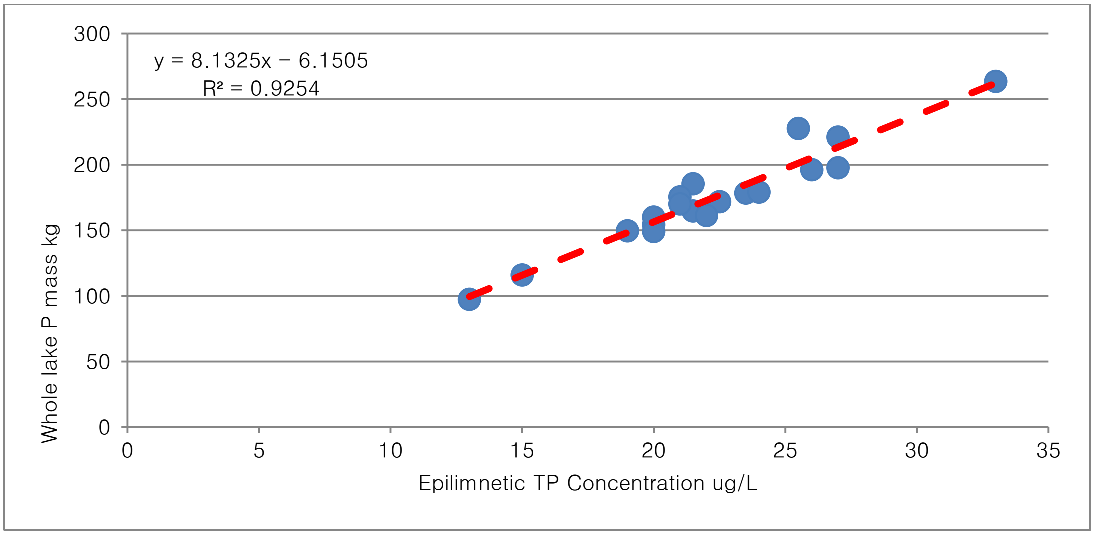


Figure 8 – Total in-lake phosphorus concentration and P mass 2014-2016

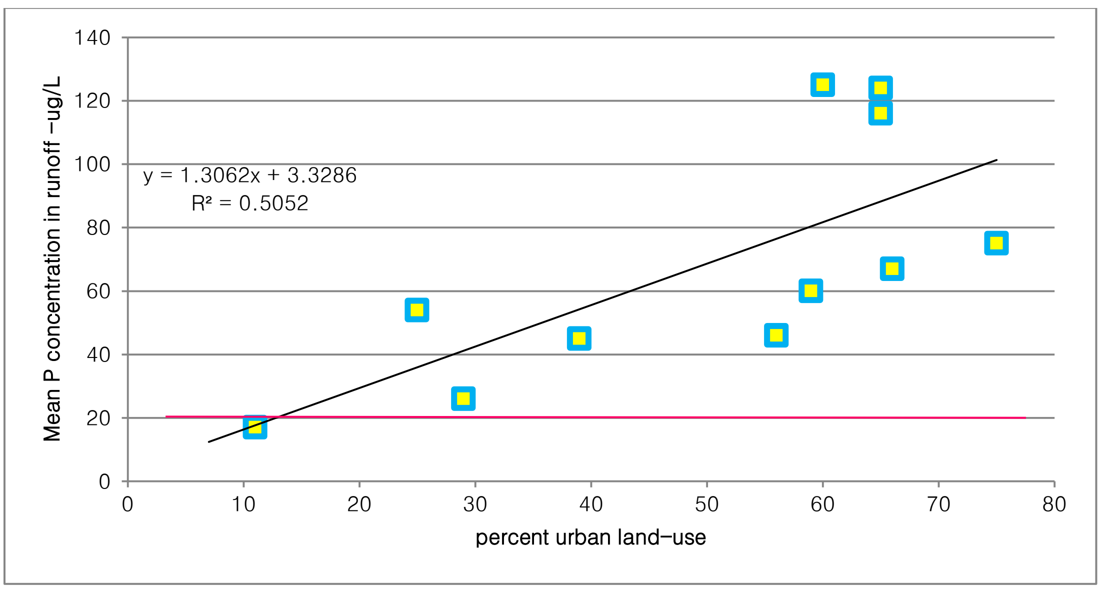


Figure 9 – Mean phosphorus concentration as a function of percent urban land-use

Total nitrogen loads have been estimated to be between 2,185 and 5,662 kg/yr. (see **Table 7**). There is a strong relationship between increasing in-lake nitrogen mass and decreasing water clarity (**Figure 10**). Water clarity of less than 1.0 meter usually occurs when in-lake total nitrogen exceeds 4,000 kg. Preliminary analysis of cyanobacteria and nitrogen shows a possible relationships between increasing total nitrogen concentration cyanobacteria numbers (**Figure 11**).

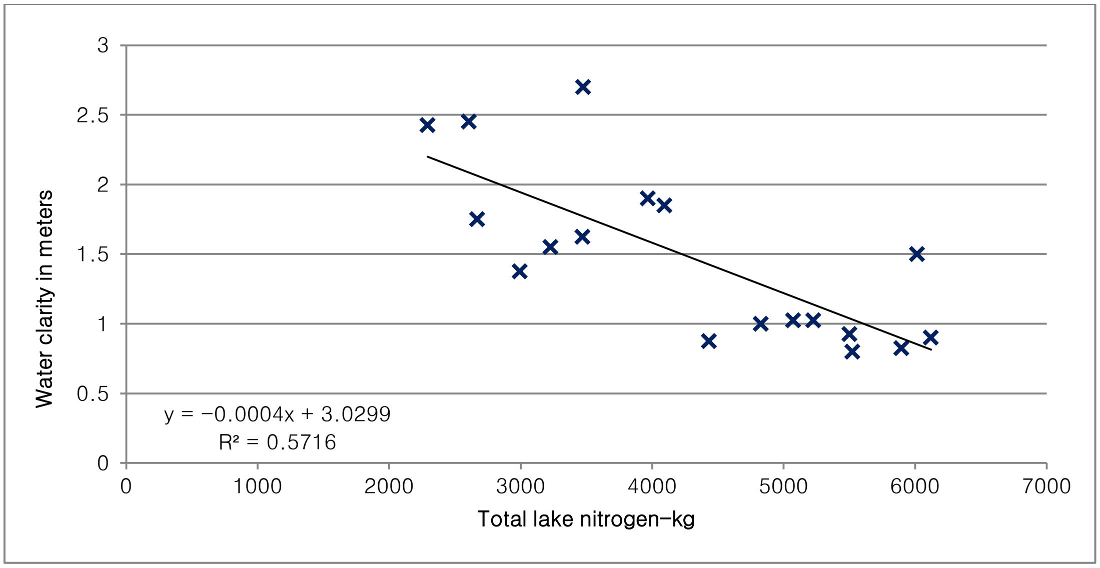


Figure 10 – Total in-lake nitrogen mass and water clarity

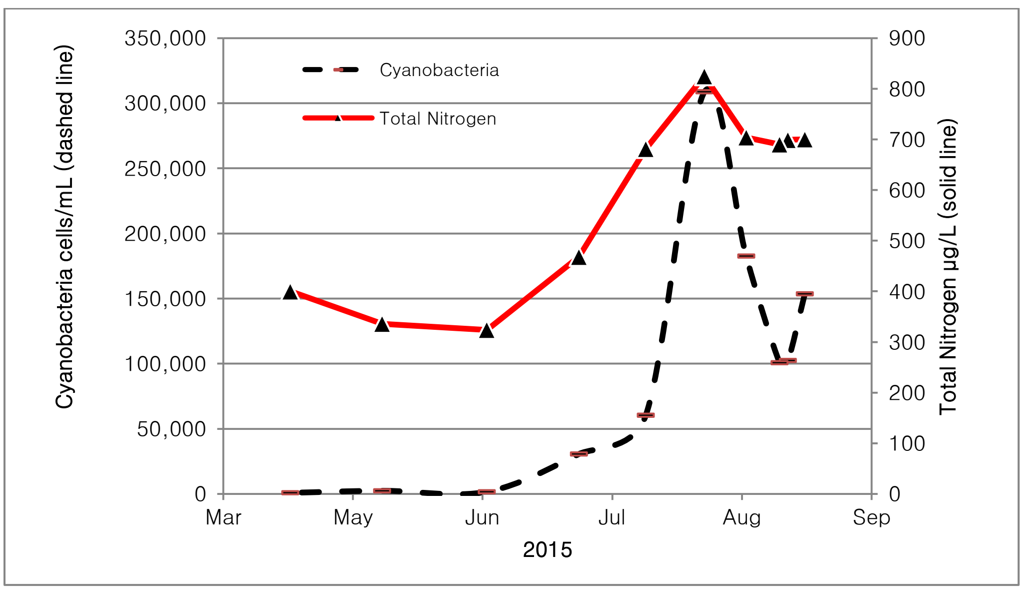


Figure 11 – Total in-lake nitrogen and cyanobacteria numbers

Critical Areas Requiring Nonpoint Management Measures (element C)

Critical Areas Requiring Management Measures

The lake Pocotopaug watershed as designated by AECOM, **Map 1 (pg14),** consists of three large drainage basins; Hale (H), Christopher (E), and Fawn Brooks (K), and 11 smaller basins that encircle the Lake (A, B, C, D, F, G, I, J, L, M, and N).

For purposes of this 9 Elements Plan the Lake drainage basin is prioritized into three general management tiers. Highest priority Tier 1 includes the 11 smaller basins because of high degree of impervious cover and high nutrient loading rates. Tier 1 includes most land within 1500 feet of the Lake. Tier 2 areas are of moderate priority and include development occurring within the three large drainage basins. Remaining areas of Hale, Christopher, and Fawn Brooks are undeveloped so have low priority and are classified as Tier 3.

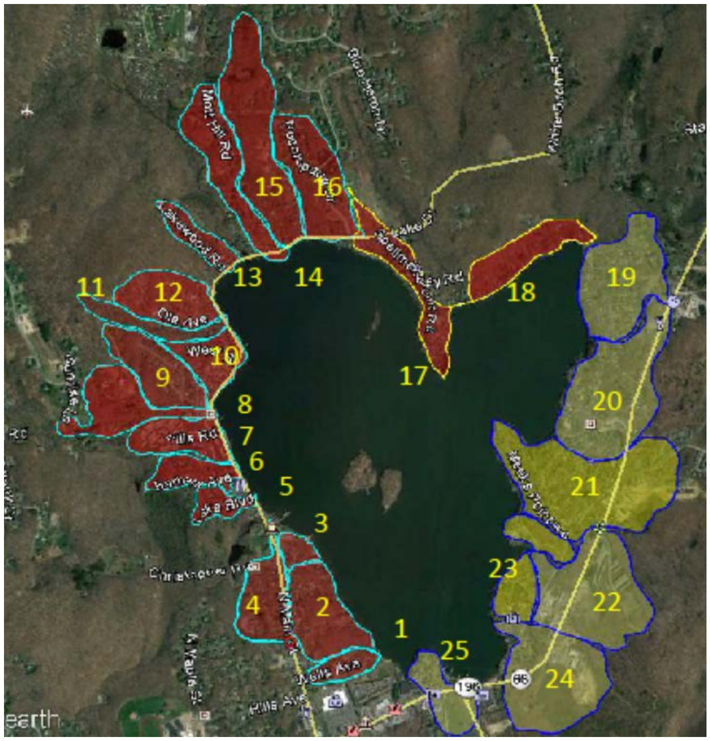
Tier 1 – Management Zones

The 11 smaller sub-basins have been further divided into twenty-five single drainage systems shown in **Map 3.** This was done by separating A into 10 smaller systems, and C, into 4 smaller drainages, each with an individual discharge point. Assessment of conveyance on each of these sub-basins shows each is an individual drainage supply area with a common catch-basin / culvert array that services a set of roads with a unique drain to the lake. Each area typically has runoff from rooftops, parking lots, driveways, lawns, and other impervious surfaces directed either intentionally and/or unintentionally to the road surfaces and into catch basins and directly to the Lake

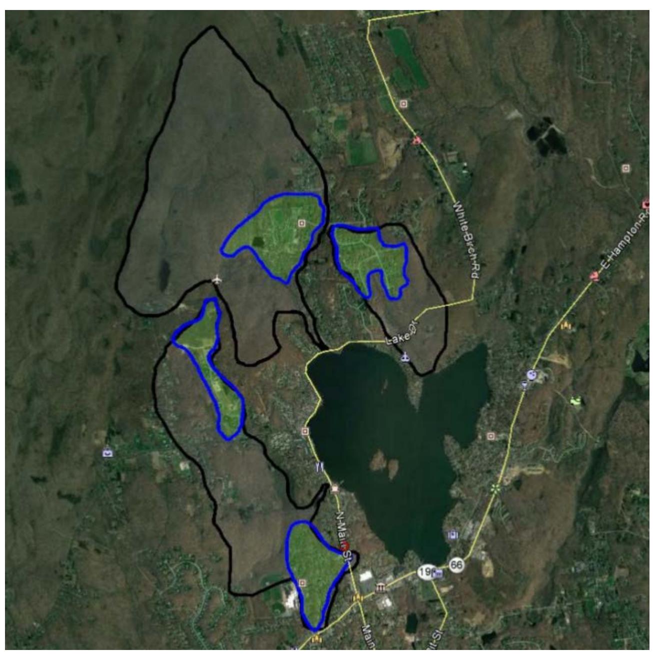
Tier 2 – Moderate Priority Zones, & Tier 3 Low Priority Zones

The area of the drainage basin not Tier 1 is shown in **Map 4**. The reaming area is divided into Tier 2 Moderate Priority zones (green) and Tier 3 low priority zones (white). Tier 2 areas are where locat development is causing Storm-water to be discharged into Hale, Christopher and Fawn Brooks upstream of the Lake. These areas need management but the effects of nutrient and sediment loads are not as significant as runoff from Tier 1 systems. Remaining lands, in white, are undeveloped forest that requires preservation, protection to maintain high water quality of existing stream water.

Map 3 – Lake Pocotopaug watershed showing Tier 1 areas, >50% impervious land use



Map 4 – Lake Pocotopaug watershed showing Tier 2 (green) and Tier 3 (White) areas



Tier 1 Management Zones

The 25 management zones in Tier 1 are listed in **Table 9**, beginning at the dam and moving clockwise around the Lake. **Table 9** gives size, fraction of impervious surface and average concentration of phosphorus and nitrogen collected between 2014 and 2016. **Table 10** gives the road system, estimated water volume generated by a 1 inch rain event and the estimated loading of phosphorus and nitrogen based for each 1 inch rain event. Between 30-40 rain events annually of 1" or more suggest total P load of between 168-224 kg P/year, about 50% higher than AECOM estimate of 131 kg P/L, but within the range of other phosphorus loading model estimates.

Table 9 – Nutrient loading estimates by sub-basin

Management Area – Identifying road Listed counter clockwise beginning at the dam	Approximate total acres*	Percent total shed area	Approx. acres of impervious*	Percent impervious surface **Bold >50**	TP average concentration ppb 2014-2016	TN average concentration ppb 2014-2016
1- Wells Ave	7.8	1.3	3.71	48	97	602
2- Shoreline	25.6	4.2	8.0	31	No data	
3- West Drive	20.0	3.2	12.4	**62**	57	570
4- Sears Park	4.9	0.8	2.73	**56**	No data	
5- Lake Blvd	7.1	1.2	5.4	**76**	94	469
6- Barbara Drive	11.9	1.9	8.5	**71**	162	796
7- Ellis Road	16.4	2.7	12.8	**78**	75	764
8 – Clark Hill Road	22.5	3.7	16.1	**72**	113	240
9 – Mountainview Drive	21.6	3.5	12.0	**55**	No data	
10 – West Street	14.4	2.3	12.0	**83**	109	341
11 – Ola Brook	10.1	1.6	0.5	5	37	260
12 – Ola Avenue	20.7	3.4	8.0	39	102	
13 – Lakewood	10.1	1.6	7.6	**75**	1,295	2,240
14 – Mott Hill Road	27.2	4.4	10.9	40	124	643
15 – Candlewood	45.6	7.4	12.2	27	73	853
16 – Pocotopaug	31.8	5.2	21.1	**66**	No data	
17 – Spellman Point	21.3	3.5	20.5	**96**	No data	
18 – North Shore	19.3	3.1	13.8	**72**	No data	
19 – Mohican	36.6	5.9	33.0	**90**	116	1,295
20 – Clearwater	50.5	8.2	42.7	**85**	28	323
21 – Meeks Point Road	64.9	10.5	56.0	**86**		
22 – O'Neil's Brook	46.2	7.5	28.3	**61**	69	571
23 – Bay Point Road	19.6	3.2	15.1	**77**	No data	
24 – Days Brook	44.6	7.2	17.5	39	64	511
25 – West Point Road	25.4	2.4	21.3	**84**	62	485
Total Acres =	**615.7**					

* Rough estimates for concept planning

Table 10 – Management zone road system, water volume, and nutrient loading during 1 inch rain event

Management Zone –	Linear feet of road	WQV = 1" rain (ft^3)	g P/in of rain	g N/in of rain
1– Wells Ave =	1,000	26,389	72	450
2– Shoreline =	1,000	72,391	?	?
3– West Drive =including North Main Street, Bellwood Court, short section of Christopher Road	3,300	76,811	124	1240
4– Sears Park, =including large gravel drive and parking lot, overland flow to rain garden, Beach and boat ramp	588	17,858	?	?
5 Lake Blvd., =including Woodland Street, Bellevue Street	1,705	30,515	81	405
6– Barbara Drive, =including Myrtle, Ellis, Bauer, and Bobby's Roads	2,760	49,201	226	1109
7– Ellis Road, =Including Edgemere 1 & 2 Condominiums	2,600	71,557	152	1548
8 – Clark Hill Road, =including lowest section of Sunset Lane and Highland Terrace	2,563	93,763	300	637
9 – Mountainview Drive. =including Hilltop Road	2,909	78,016	?	?
10 – West Street	1,359	65,183	201	629
11 – Ola Brook	0	19,981	21	147
12 – Ola Avenue =including Lake Drive, Ola Ave, West Ln	1,950	63,945	185	0
13 – Lakewood =includes Boulder Road	2,080	43,079	?	2732
14 – Mott Hill Road =Includes Hale Road	2,780	84,913	298	1546
15 – Candlewood =includes Raymond Road	2,430	122,987	254	2971
16 – Pocotopaug Drive =includes Auburn Knoll	2,770	126,285	?	?
17 – Spellman Point =	2,710	105,463	258	2046
18 – North Shore	1,270	80,428	?	?
19 – Mohican =includes Lake Drive, section of East High Street (Rte66), and Mohican, Seminole, Mohawk, Navajo, Minnetonka, Sequonia, Wangonk, and Namonee Trails.	6,842	174,044	572	6382
20 – Clearwater C1 South Section = Laurel, and Brook Trails, Park, Byron, Poe, Scott, Browning South Wangonk Cherokee, Mountain, and Pine Roads, East High Street	8,600	231,893	184	2121
21 – Meeks Point Road =includes Hawthorne, Wordsworth, Whittier, Emerson, Lowell, Barrie Tennyson, Ole, Marlborough, Bryant, Stevenson, and Chaucher Roads, Mark Twain Drive, and Meeks Point Road. Also includes sections of Laurel Ridge Condos on east side of Rte. 66.	5,740	300,138	?	?
22 – O'Neil's Brook =Includes Lake Vista Condominiums, Paul and Sandy's Too, Rte. 66, impervious land on east side of Rte. 66	4,430	175,924	344	2844
23 – Bay Point Road =Shoreline	1,380	84,880	?	?
24 – Days Brook =includes section or Rte. 66 and developed lands east of the road	1,351	137,775	250	1994
25 – West Point Road =includes Rte. 66, Lakeview West Point Road, CVS building and parking lot, part of the cemetery.	3,634	68,389	120	939
Totals =	66,751	2,401,809	5,605	44,487

Table 11 –Tier 1 management zone implementation measures required

Management Zone –	Fix necessary	Cost Estimate
1– Wells Ave =	=Bio-retention swale, or other filter along Wells Ave. to infiltrate runoff prior to Lake	$10,000-15,000
2– Shoreline =	=Inspect shoreline for evidence of runoff. Practice best management of shoreline	Self
3– West Drive =including North Main Street, Bellwood Court, short section of Christopher Road	=Outfall of culvert now under Lake Road Bridge. Investigate headwater infiltration via bio-swale and rain gardens	$10,000-15,000
4– Sears Park, =including large gravel drive and parking lot, overland flow to rain garden, Beach and boat ramp	=Improve existing rain garden with installation of a sediment fore-bay to trap sediment and prevent fine particles from inhibiting water infiltration =Potentially convert rain garden to constructed wetland with greater plant coverage =open cell pavers with pea gravel to avoid sediment runoff from open dirt parking lot – various products, varied durability reflected in total project cost =Install a vegetated strip with good infiltration downhill of compacted field (from heavy day camp use)	$5,000-10,000 $180,000-250,000 $500-1,000
5 Lake Blvd., =including Woodland Street, Bellevue Street Angelico's and Parking Lot	=Erosion control needed, direct roof runoff into ground – rain barrels. direct driveway runoff away from road =Bio-retention swale along back-side of parking lot with Lake Blvd	$10,000-15,000
6– Barbara Drive, =including Myrtle, Ellis, Bauer, and Bobby's Roads	=Infiltrate, detain, Storm-water via. bio-retention swale, or other filter on Barbara Drive, connect with Bobby's Road runoff. =Direct roof runoff into ground, direct driveway runoff away from road	$10,000-15,000
7– Ellis Road, =Including Edgemere 1 & 2 Condominiums	=Direct roof drains into ground =Collect parking-lot runoff in series of small rain gardens =Create parking lot runoff catchment bio-swale at Edgemere 2 grassy front-lawn by Lake Drive	$500 $2,000-12,000 $20,000-$25,000
8 – Clark Hill Road, =including lowest section of Sunset Lane and Highland Terrace	=Infiltrate storm-water via. bio-retention swale, or other filter down Clark Hill Road to Lake Drive =Inspect conveyance at Sunrise Lane =Inspect and improve containment of large exposed sediment piles on private property. =Dredge /clear outlet culvert at Lake	$400-6,000 $400-1,000
9 – Mountainview Drive. =including Hilltop Road	=Infiltrate/detain Storm-water via bio-retention swale or other filter along Mountainview Drive =Maintain and replace old catch basins and minimize road runoff	$4,000-8,000

10 – West Street	=Infiltrate/detain Storm-water as vegetated swale along West Street. =Direct roof runoff into the ground, direct driveway runoff away from roads	$10,000-15,000
11 – Ola Brook	=Include in EHHS monitoring, preserve integrity	$10,000-15,000
12 – Ola Avenue =including Lake Drive, Ola Ave, West Ln	=Infiltrate/detain storm-water as vegetated swale along Ola Ave =Direct roof runoff into the ground Inspect catch/basin system at Lake Drive for improvements	$10,000-15,000
13 – Lakewood =includes Boulder Road	=Infiltrate/detain storm-water as vegetated swale along Lakewood =Direct roof runoff into the ground direct driveway runoff away from road	$10,000-15,000
14 – Mott Hill Road =Includes Hale Road	=Infiltrate/detain storm-water as vegetated swale, and install series of rain gardens along Mott Hill Road. =Direct roof runoff into the ground, direct driveway runoff away from road	$10,000-15,000
15 – Candlewood =includes Raymond Road	=Infiltrate/detain Storm-water as vegetated swale, =series of rain gardens along Candlewood and Raymond Roads. =Direct roof runoff into the ground, direct driveway runoff away from road.	$10,000-15,000
16 – Pocotopaug Drive =includes Auburn Knoll	=Infiltrate/detain Storm-water as vegetated swale, series of rain gardens along Pocotopaug Drive. =Direct roof runoff into the ground, direct driveway runoff away from road	$10,000-15,000
17 – Spellman Point =	=Correct shoreline integrity, =manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces r	Self
18 – North Shore	=Shoreline integrity and best management practices along bank =Manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces	Self
19 – Mohican =includes Lake Drive, section of East High Street (Rte66), and Mohican, Seminole, Mohawk, Navajo, Minnetonka, Sequonia, Wangonk, and Namonee Trails Coco Daycare.	=Convert asphalt swale to vegetated swale and install new pipe from new leaching catch basin =LID swale to catch road runoff and increase infiltration =Minimize runoff and erosion at private boat ramp / beach area – LID open cell permeable pavers, determine source (could be seasonal only) =Install catch-basin filter inserts =Stabilize hillside of parking lot, clean catch basin (full of debris) and determine if it is connected to storm-water culvert system=	$8,000-$12,000 $1,000-$2,000 $10,000-15,000 $1,000 $1,000-5,000
20 – Clearwater C1 South Section = Laurel, and Brook Trails, Park, Byron, Poe, Scott, Browning, South Wangonk, Cherokee, Mountain,	=Shoreline integrity and best management practices along bank =Manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces	$8,600

and Pine Roads, East High Street	=Investigate replacing catch-basins and filtering inserts	
21 – Meeks Point Road =includes Hawthorne, Wordsworth, Whittier, Emerson, Lowell, Barrie, Tennyson, Ole, Marlborough, Bryant, Stevenson, and Chaucher Roads, Mark Twain Drive, and Meeks Point Road. Also includes sections of Laurel Ridge Condos on east side of Route 66.	=Shoreline integrity and best management practices along bank =Manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces =Investigate replacing catch-basins and filtering inserts	$8,600
22 – O'Neil's Brook =Includes Lake Vista Condominiums and Paul and Sandy's Too and Rte66	=Lake Vista Storm-water design improvements, unclog drains, convert to constructed wetland and maintain with annual harvest biomass =De-channelize wetland flow for O'Neil's Brook on both sides of Old Marlborough Rd. =Improve storm-water/irrigation pond at Paul and Sandy's Too, install floating wetlands	$75,000-130,000 $6,000-12,000 $4,000-30,000
23 – Bay Point Road =Shoreline	=Shoreline integrity and best management practices along bank =Manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces =Investigate replacing catch-basins and filtering inserts	$8,600
24 – Days Brook =includes section or Rte. 66 and developed lands east of the road	=Open sediment with no silt fences, protect storm drainage system and encourage LID. Planning and Zoning official needs to inspect frequently, taking regulatory action if necessary =Minimize erosion as stream passes through private property on Old Marlborough Road – LID and vegetated buffer necessary =Inspect and ensure proper capacity of onsite sewage treatment system	Self
25 – West Point Road =includes Route 66, Lakeview West Point Road, CVS building and parking lot, part of the cemetery.	=CVS Review storm-water LID designs, make improvements for better infiltration =More woody plantings needed =Switch to infiltrating catch basins =Establish vegetation on open sediment along road banks =Infiltrate runoff from West Point Road, direct roof runoff into ground, direct driveway runoff away from road	$20,000

Zones are ranked by estimated phosphorus runoff in Figure 12. Nitrogen loading from each zone is also shown but not ranked. Phosphorus ranking show that Meeks and Mohican have very high loading estimates while all other zones show at least half the loading and very little difference from one another, gradually decreasing in load rate until Ola Brook at near zero. Although the chart shows ranking by phosphorus loading, the implementation feasibility, and cost/benefit effectiveness are often more important and should be considered first in prioritizing an action plan.

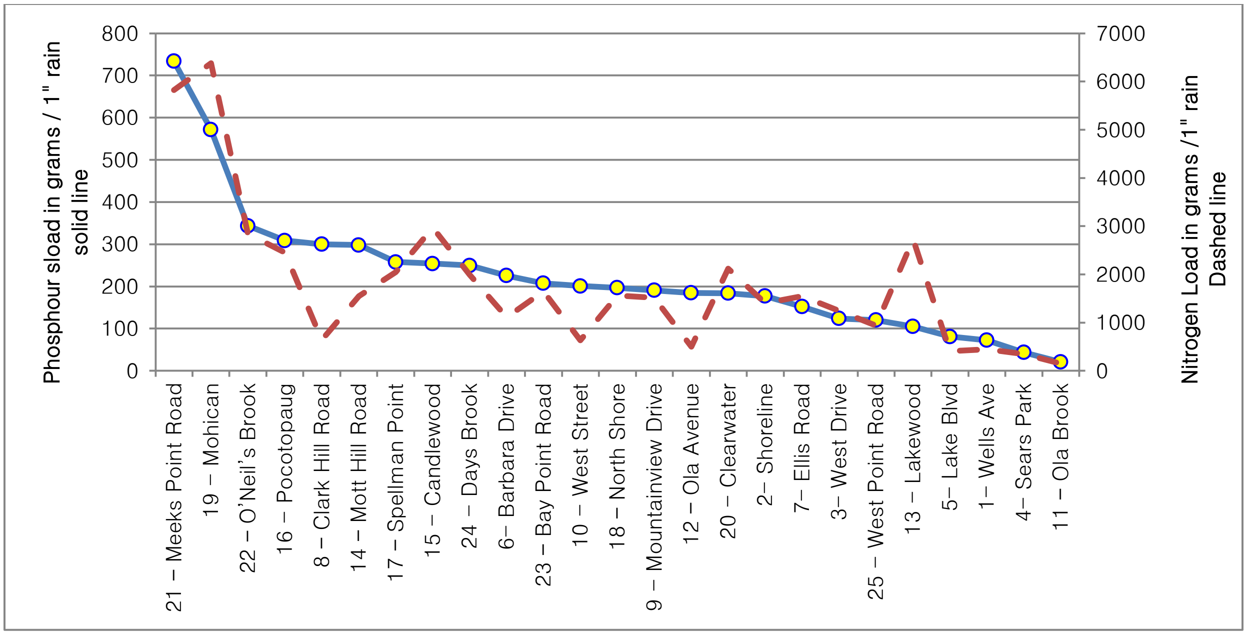


Figure 12 – Sub-basins ranked by phosphorus export per 1 inch rain event

One possible way of ranking is by expected remediation effort. Storm water generated increases with impervious surface and length of road surface. As the volume of storm water flow increases the available space required to capture for infiltration water from when fixing one set of complementary draining roads at a time To estimating containment The systems are ranked by linear feet of road surface (**Figure 13**) together with estimated phosphorus loading--blue squares with white crosses.

Figure 13 – Sub-basins ranked by phosphorus export and length of road surface

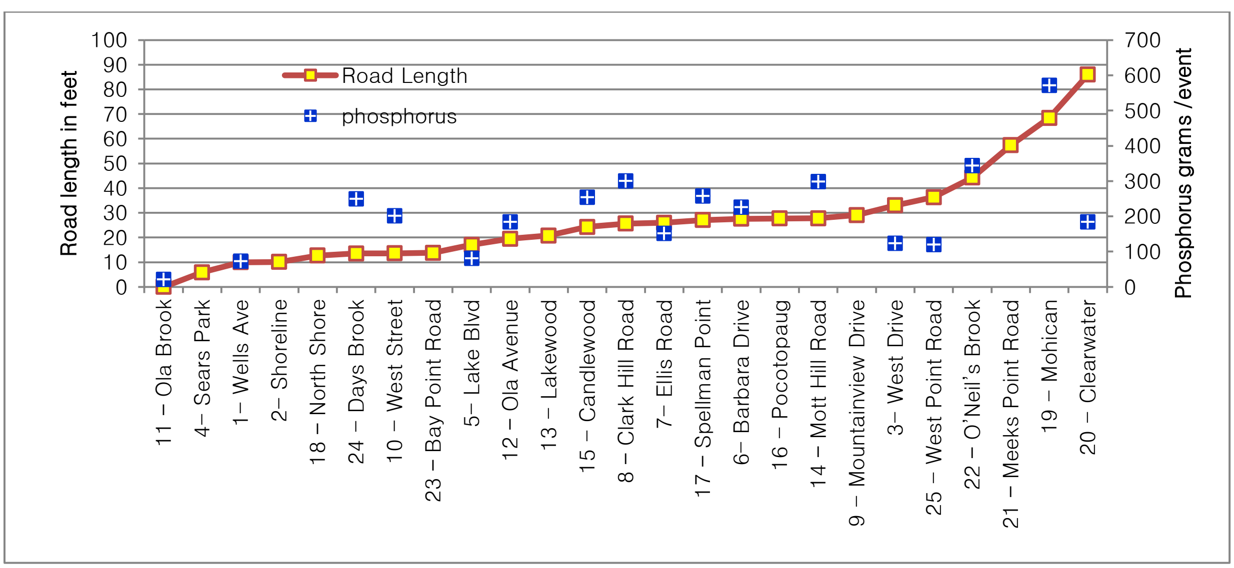


Table 12 –Tier 1 First level priority management zones

Priority	Management Zone –	Predicted Fix(es) Necessary	Cost Estimate
1	8– Clark Hill Road, =including lowest section of Sunset Lane and Highland Terrace	=Infiltrate storm-water via. bio-retention swale, or other filter down Clark Hill Road to Lake Drive =Inspect conveyance at Sunrise Lane =Inspect and improve containment of large exposed sediment piles on private property. =Dredge /clear outlet culvert at Lake.	$26,000
2	10– West Street	=Infiltrate/detain storm-water as vegetated swale along West Street. =Direct roof runoff into the ground, direct driveway runoff away from roads.	$15,000
3	15– Candlewood =includes Raymond Road	=Infiltrate/detain storm-water as vegetated swale, =series of rain gardens along Candlewood and Raymond Roads. =Direct roof runoff into the ground, direct driveway runoff away from road.	$25,000
4	14– Mott Hill Road =Includes Hale Road	=Infiltrate/detain storm-water as vegetated swale, and install series of rain gardens along Mott Hill Road. =Direct roof runoff into the ground, direct driveway runoff away from road	$30,000
5	6– Barbara Drive, =including Myrtle, Ellis, Bauer, and Bobby's Roads	=Infiltrate, detain, storm-water via. bio-retention swale, or other filter on Barbara Drive, connect with Bobby's Road runoff. =Direct roof runoff into ground, direct driveway runoff away from road	$25,000
7	5– Lake Blvd., =including Woodland Street, Bellevue Street Angelico's and Parking Lot	=Erosion control needed, direct roof runoff into ground – rain barrels. direct driveway runoff away from road =Bio-retention swale along back-side of parking lot with Lake Blvd	$ 25,000
8	7– Ellis Road, =Including Edgemere 1 & 2 Condominiums	=Direct roof drains into ground =Collect parking-lot runoff in series of small rain gardens =Create parking lot runoff catchment bio-swale at Edgemere 2 grassy front-lawn by Lake Drive	$ 37,500
10	13 – Lakewood =includes Boulder Road	=Infiltrate/detain storm-water as vegetated swale along Lakewood =Direct roof runoff into the ground direct driveway runoff away from road	$ 25,000
9	3– West Drive =including North Main Street, Bellwood Court, short section of Christopher Road	=Outfall of culvert now under Lake Road Bridge. Investigate headwater infiltration via bio-swale and rain gardens	$ 36,000
6	12– Ola Avenue =including Lake Drive, Ola Ave, West Ln	=Infiltrate/detain storm-water as vegetated swale along Ola Ave =Direct roof runoff into the ground Inspect catch/basin system at Lake Drive for improvements	$ 45,000
11	25 – West Point Road =includes Route 66, Lakeview West Point Road, CVS building and parking lot, part of the cemetery.	=CVS Review storm-water LID designs, make improvements for better infiltration =More woody plantings needed =Switch to infiltrating catch basins =Establish vegetation on open sediment along road banks =Infiltrate runoff from West Point Road, direct roof runoff into	$ 20,000

		ground, direct driveway runoff away from road	
12	1– Wells Ave =	=Bio-retention swale, or other filter along Wells Ave. to infiltrate runoff prior to Lake	$ 12,000
13	16 – Pocotopaug Drive =includes Auburn Knoll	=Infiltrate/detain storm-water as vegetated swale, series of rain gardens along Pocotopaug Drive. =Direct roof runoff into the ground, direct driveway runoff away from road	$ 30,000
14	9 – Mountainview Drive. =including Hilltop Road	=Infiltrate/detain storm-water via bio-retention swale or other filter along Mountainview Drive =Maintain and replace old catch basins and minimize road runoff	$ 22,000
15	11 – Ola Brook	=Include in EHHS monitoring, preserve integrity	Self
Total First level priority = $373,500			
Complex management systems with no available space, require further investigation			
D1	19 – Mohican =includes Lake Drive, section of East High Street (Rte66), and Mohican, Seminole, Mohawk, Navajo, Minnetonka, Sequonia, Wangonk, and Namonee Trails Coco Daycare.	=Convert asphalt swale to vegetated swale and install new pipe from new leaching catch basin =LID swale to catch road runoff and increase infiltration =Minimize runoff and erosion at private boat ramp / beach area – LID open cell permeable pavers, determine source (could be seasonal only) =Install catch-basin filter inserts =Stabilize hillside of parking lot, clean catch basin (full of debris) and determine if it is connected to storm-water culvert system=	$ 48,000
D2	20 – Clearwater C1 South Section = Laurel, and Brook Trails, Park, Byron, Poe, Scott, Browning, South Wangonk, Cherokee, Mountain, and Pine Roads, East High Street	=Further investigate conveyance to the lake =Shoreline integrity and best management practices along bank =Manage for no surface runoff from yard areas, roof tops, driveways, and road surfaces. =Investigate replacing catch-basins and filtering inserts	$ 8,600
D3	21 – Meeks Point Road =includes Hawthorne, Wordsworth, Whittier, Emerson, Lowell, Barrie, Tennyson, Ole, Marlborough, Bryant, Stevenson, and Chaucher Roads, Mark Twain Drive, and Meeks Point Road. Also includes sections of Laurel Ridge Condos on east side of Route 66.	=Further investigate conveyance to the lake =Shoreline integrity and best management practices along bank =Manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces =Investigate replacing catch-basins and filtering inserts	$ 8,600
D4	22 – O'Neil's Brook =Includes Lake Vista Condominiums and Paul and Sandy's Too and Rte66	=Lake Vista Storm-water design improvements, unclog drains, convert to constructed wetland and maintain with annual harvest biomass =De-channelize wetland flow for O'Neil's Brook on both sides of Old Marlborough Rd. =Improve storm-water/irrigation pond at Paul and Sandy's Too, install floating wetlands	$145,000
D5	24 – Days Brook =includes section or Rte. 66 and	=Protection of open sediments, protect storm drainage system and encourage LID.	$ 20.000

	developed lands east of the road	=Minimize erosion as stream passes through private property on Old Marlborough Road with LID and vegetated buffer	
D6	4- Sears Park, =including large gravel drive and parking lot, overland flow to rain garden, Beach and boat ramp	=Improve existing rain garden with installation of a sediment fore-bay to trap sediment and prevent fine particles from inhibiting water infiltration =Potentially convert rain garden to constructed wetland with greater plant coverage =open cell pavers with pea gravel to avoid sediment runoff from open dirt parking lot – various products, varied durability reflected in total project cost =Install a vegetated strip with good infiltration downhill of compacted field (from heavy day camp use)	$ 250,000
Total Complex management systems = $460,220			
Shoreline management systems entirely of private property			
S1	2- Shoreline =	=Inspect shoreline for evidence of runoff. Practice best management of shoreline	Self
S2	17 – Spellman Point =	=Correct shoreline integrity, =manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces	Self
S3	18 – North Shore	=Shoreline integrity and best management practices along bank =Manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces	Self
S4	23 – Bay Point Road =Shoreline	=Shoreline integrity and best management practices along bank =Manage for no surface runoff from yard areas, roof tops. Driveways. and road surfaces =Investigate replacing catch-basins and filtering inserts	Self

Tier 2 and Tier 3 Required Management Measures

The 4 management zones in Tier 2 are listed in **Table 12** and the Tier 3 management zones in **Table 13.** **Table 12** lists; size, fraction of impervious surface and receiving brook were runoff is directed. and average concentration of phosphorus and nitrogen collected between 2014 and 2016.

Table 13 –Tier 2 Management zones

Tier 2 Management Area –Identifying road and ➔ receiving brook. Listed counter clockwise beginning at the dam	Approximate total acres	Percent total shed area	Approx. acres of impervious*	Percent impervious surface **Bold >50**	TP average concentration ppb 2014-2016	TN average concentration ppb 2014-2016
26- North Maple Street ➔ Christopher Brook	74		32.5	44		
27- Old Clark Hill Road ➔ Christopher Brook	65		18	27		

28- Campground → Hales Brook	102		45	42		
29- Seven Hills → Fawn Brook	70		29.6	42		

Table 14 –Tier 3 Management zones

Tier 3 Management Area –Identifying road Listed counter clockwise beginning at the dam	Approximate total acres	Percent total shed area	Approx. acres of impervious Not including above	Percent impervious surface **Bold >50**	TP average concentration ppb 2014-2016	TN average concentration ppb 2014-2016
30- Christopher Brook	751		38	5.0	17	478
31- Hales Brook	394		18	4.6	12	185
32- Fawn Brook	74		5	6.8	45	602

Table 15 –Tier 2 management zones implementation measures required

Priority	Identifying road	Predicted Fix(es) Necessary	Cost Estimate
1	27- Old Clark Hill Road	=Improve failing level-spreader and increased retention capacity to prevent overflow to Christopher Brook =Review design plans and improve 5 areas: dig forebays and improve outflow/nutrient retention of wetlands =Inspect ongoing construction and cite violations as necessary =Stop fertilization of lawns in neighborhood	$30,000
2	29- Seven Hills	=Limit fertilization of lawns on private property in the watershed, particularly in Seven Hills development =Annual maintenance of drains Improve existing Storm-water catchment areas: re-grade/level, make it not a flow-through systems for small storms =High and shallow marsh in the wetland system to reduce nutrient loading from 7Hills and upstream private property, potentially maintain/export nutrients by seasonal vegetation cuttings	$25.000
3	26- North Maple Street =Fairlawn Ave, Hills Ave., Beech Crest Drive, Maplewood Drive, Section of East Hampton High School	=Active monitoring of new construction, minimize erosion and protect catch basins from sedimentation using well maintained silt covers =Maintain minimal/appropriate fertilization of athletic fields near Christopher Brook =Direct outfall of culverts into bio=retention	Self
4	28- Nelson's Family	Ensure no contamination of Hales Brook, critical for	Self

	Campground	overall WQ of the Lake – work with private property owners for LID	

Table 16 –Tier 3 management zones storm-water implementation measures required

Tier 3 Management Area –Identifying road Listed counter clockwise beginning at the dam	Predicted Fix(es) Necessary	Cost Estimate
30- Christopher Brook	Town of East Hampton should buy and prevent building on as much land in this sub-basin as possible.	
31- Hales Brook	Town of East Hampton should buy and prevent building on as much land in this sub-basin as possible.	
32- Fawn Brook	Town of East Hampton should buy and prevent building on as much land in this sub-basin as possible.	

Table 17 – Tier-1 priority list of Management Zone fixes

Priority	Management Zone Name
1	Clark Hill Road
2	West Street
3	Candlewood
4	Mott Hill Road
5	Barbara Drive
6	Lake Blvd
7	Ellis Road
8	Lakewood
9	West Drive
10	Ola Avenue
11	West Point Road
12	Wells Ave
13	Pocotopaug Drive
14	Mountainview Drive
15	Ola Brook
Complex systems	
D1	Mohican
D2	Clearwater
D3	Meeks Point Road
D4	O'Neil's Brook
D5	Days Brook
D6	Sears Park
Private Shorelines	
S1	Shoreline
S2	Spellman Point
S3	North Shore
S4	Bay Point Road

Best Management Practices & Low Impact Development Management Measures

The following section discusses alternatives in Storm-water Filtering Systems. Existing conditions controls based on the scientific literature. Wherever possible, storm-water management should focus on increased infiltration and natural filtering; however, nutrient filtration systems are more appropriate where onsite infiltration is not feasible[3].

Types

Dry Detention Area

Dry detention basins are designed to store and infiltrate storm-water runoff in a level, vegetated depression. Nutrient reduction is variable but TP reductions are near 16-29%. Dry detention reduces TN by about 10-26% and TSS at 66-80%. The variation in nutrient decrease can be attributed to differing soil characteristics and is also dependent on the design of the dry detention system. Improper grading will prevent even dispersal of rainwater and reduce pollutant reduction. If water is allow to pool for long periods of time, phosphorus may be released from the sediments as biologically available ortho-phosphorus. To restate, proper design and construction are critical and pollution control can be further increased by manipulating underlying fill.

Wet Detention Ponds

Wet storm-water detention ponds, such as the ponds at Paul & Sandy's and Lake Vista, are designed to let particles settle out, thereby reducing TSS up to 94%. However, if the pond is not designed and sized correctly it will merely act as a flow through system with no containment. Improperly designed wet detention ponds may also have the inflow and outflow too close together, negating any particulate-holding ability. On average, TN concentration reductions for these types of ponds are around 9-32%. Wet detention ponds are not designed to retain phosphorus; TP reductions in the scientific literature are recorded around 5% while there is research to suggest that ortho-P concentrations in effluent may increase to 266% greater than influent concentrations.

In the case of very large water volumes from impervious surface runoff, wet detention ponds may be necessary, but these systems should be combined with additional phosphorus reducing mechanisms to limit nutrient pollution to the Lake.

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[3]: Jiang et al. 2015, Piza et al. 2011, Yang et al. 2014, Barret et al. 2004, U.S. EPA 2000, Young et al. 1996,

Constructed Wetlands

Constructed wetlands are similar to wet detention ponds in that they are consistently flooded, yet these marsh areas are designed to be shallow and well-vegetated. Storm-water nutrients in constructed wetland systems are partially used by plants. More robust wetland plants, such as cattails, uptake and store nutrients before they reach the Lake. Constructed wetlands create wildlife habitat and are aesthetically pleasing, but they also require periodic inspection to ensure proper pollutant filtering. Ongoing research suggests that initial TP reduction of constructed wetlands can be as high as 60%, but as nutrients saturate the system over 10-20 years, retention capacity declines (Micsh et al. 2000). Like all forms of storm-water treatment, an understanding of the underlying sediment is critical to initial design, maintenance, and lasting efficiency.

Bio-retention

The primary goal of a bi-retention system is to infiltrate storm-water onsite in a shallow depression. With proper design and construction rain gardens are excellent at reducing the overall water volume entering a lake system as road runoff or through underground culverts. Depending upon the design, rain gardens are also capable of reducing sediments and nutrients.

Porous Pavement

Porous pavement systems are designed to infiltrate storm-water and reduce overland runoff during heavy rain. Typical sidewalks, parking lots, and roadways are built using impervious materials that do not allow rainwater to penetrate into the underlying soils. Porous pavement, made of either cement or asphalt, is constructed with tiny holes that allow water to filter through and infiltrate onsite, rather than being directed into storm drains. Flow reduction studies determined that permeable interlocking concrete and porous pavement with an underlying gravel sub-base reduce overland runoff by 33-38%. However, permeability relies on the void spaces in the pavement material and can be easily clogged if not maintained. Porous pavement should not be sanded during winter months and biennial vacuuming may be necessary.

Vegetated Swale

A dry vegetated swale is a depression in the land that captures storm-water runoff from impervious surfaces, such as roadways and sidewalks. Vegetated swales are designed in completely infiltrate the runoff and should not be a zone of standing water. Infiltrate capacity may be enhanced by manipulating the underlying sediments, but dry swales need to be engineered and constructed based on the estimated water load that they would be expected to handle. Recent studies have suggested that Total Phosphorus and Nitrogen reductions are near 30% for well-designed swales, but that a poorly designed system that creates standing water may actually increase dissolved P significantly.

Rainwater Harvest Systems (rain barrels)

Based on a recent EPA literature review of 23 cities over varying climatic regions, onsite rainwater storage from roof gutter systems reduce long term storm-water runoff volumes from residential areas by about 20%. This percentage, however, is heavily dependent on local impervious surface cover and population density. In the case of Lake Pocotopaug, the high density residential areas in the direct watersheds A, B, & C would greatly benefit from onsite rainwater harvest barrels. Rain barrels capture roof runoff during storm events and temporarily store the water for household use, e.g. watering gardens and onsite infiltration.

Floating Treatment Systems

Like traditional constructed wetlands, floating wetlands act by storing nutrients via vegetative uptake, but instead in a hydroponics treatment system. Existing wet storm-water retention ponds can be retrofitted with floating wetland systems for increased nutrient uptake. Published research suggests that floating wetlands can reduce TP outflow by approximately 27% (Borne 2014). Further studies indicate that some integrated floating wetland systems with biofilm carriers increase periphyton growth and TP uptake to over 80% (Zhang et al. 2015). This type of technology is relatively new, but experimental sites in Christopher Brook Pond or Paul & Sandy's Too retention pond may reduce the high inlet concentrations to Lake Pocotopaug. Floating treatment systems, however, require more frequent maintenance than other types of storm-water controls.

Implementation Milestones (elements F & G)

Action Plan for Watershed Improvement

The following outline action plan is designed to forecast needs and actions ahead of time based on what we know now. As the process of managing the lake and watershed moves forward all aspects of the plan will shift as new information is gathered. The essential prerequisite of the plan is that it is revisited regularly to incorporate new water quality and planning information.

List of Measurable Milestones

- Updating Town of East Hampton websites with educational material
- PWD documentation of catch basin maintenance and construction
- Updates to watershed photo-documentation: LID projects on public and private property (provided homeowner approval)
    - Serve as examples at public educational sessions
- Monthly Town watershed planning meetings, involve lake consultant and LID engineer
- Completion of grant applications for plan implementation
- Completion of materials for lake and watershed educational programs for incoming Commissioners and Councilmen
- High School environmental club continued participation
- Record curation of beach postings due to harmful cyanobacteria blooms
- Updates to Town IW regulations
- Town conservation budgeting approval rates may indicate growing public participation
- Increasing lakeside property values with water quality improvements
- Tracking progress of LID/BMPs in the watershed will be facilitated by the working excel document (**Appendix 3**) and
- corresponding photo-documentation of existing conditions (**Appendix 4**)

Town Office

1. Continue to hold monthly Lake planning meetings at town hall open to all lake planning personnel.
    a. Include Chatham Area Health Department re: summer cyanobacteria season.
    b. Include CT DEEP re: regulations update and funding grant sources
2. Establish monitoring program to measure the effectiveness of implementation (Element I).
3. Establish monitoring program to track change in water quality during the 2017 season (Element H).
4. Conduct field review of Tier-1 management systems with town staff and consulting engineering firms

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5. Differentiate Tier-1 measures into projects for Town staff and larger projects to be bid to contractors.
6. For Town staff projects, develop program to measure the effectiveness of remediation measures and regular maintenance practices.
7. Begin preparation of design plans and other pre-bid specifications for each system on 1st level priorities list.
8. Discus need for a Town Watershed/Environmental Planner position.
9. Apply for 319 and STEAP Grant funding for first set of Tier-1 projects.
10. Organize ongoing educational sessions for Town commissioners.
11. Investigate development of Town revolving fund for lakeside homeowner LID.
12. Town and Middlesex Land Trust cooperate to purchase land and acquire easements for LID
13. Hold end of year planning meeting set goals for next year.

Town Field

14. Enforce IW regulations and inspect current construction within the watershed, enlist CT DEEP for wetlands/construction enforcement if necessary.
15. Work with Town LID engineer to move forward with Christopher Brook road reconstruction project, involve lake consultant and ensure responsible construction and minimal erosion.
16. Determine wastewater treatment methods and capacity for the three lake islands – ensure proper disposal and minimize lake nutrient loading from onsite treatment systems.
17. Require soil testing and minimal fertilizer use on high school athletic fields, ensure runoff from high school construction is not impairing the bordering wetlands that lead to Christopher Brook.
18. Address and schedule maintenance of existing catch basins as identified in excel document, ensure ongoing record keeping.
19. Develop contacts and working relationship with local business owners, inspect private properties mentioned as nonpoint pollution sources and build partnerships to implement BMPs and LID in future.

Lake

20. Continue lake water quality sampling (as per element I below) to maintain ongoing dataset, gather more information on lake level and outlet flow durations,
21. Collect water depth measurements and construct a new bathymetry map.
22. Survey aquatic plant distribution with special attention on benthic cyanobacteria mats.
23. Monitor cyanobacteria cell numbers in open water off of beach.

Public Education / Information

24. Incorporate 501(3)c Friends of Lake Pocotopaug (FOLP) into action plan to garner public support, create communication list to reach homeowners and beach associations.
25. List educational materials from this watershed plan on Town Lake Conservation Commission and FOLP websites.
26. Hold informational open Town meeting for educating residents – floating workshop.

27. Engage Park and Recreation Department day camp at Sear's Park – lakeside science educational activities.
28. Partner with local high school and plan to budget Town funds to invest in "floating island technology" for nutrient uptake experimental sites: Christopher Brook pond, Hales Brook outlet pool, Paul & Sandy's detention basin.

Technical, Financial, and Authoritative Assistance Needs (element D)

The successful execution and completion of the projects outlined in this report and the improvement of the water quality of Lake Pocotopaug will rely on assistance from several groups and experts. An initial exploration of different Technical, specific data or design type information, Authoritative/Institutional, expertise and construction conducted by the Town, and Financial, costs of the fixes, is included here:

Technical Assistance Needs include:

- CT River Coastal Conservation District,
  - Collaboration on habitat restoration, lake and stream bank vegetation, landscaping plant selection,
  - Assistance with public education and private property projects.
  - Open space planning and management.
- CT DEEP
  - Oversight on water quality standards at Lake Pocotopaug and progress of de-listing Lake Pocotopaug from the 303(d) list.
  - Assistance with funding strategies.
- University of Connecticut
  - Latest research into new LID and best management strategies.
  - Updated removal efficiency values for management measures.
  - Assistance with LID design strategies
- US EPA and USACE
  - Guidance with cyanobacteria blooms, permits for wetland and stream channel projects.
- Specialists in:
  - Low Impact Engineer and Soil Scientist for design and implementation of management measures/

    - Limnology and Lake Manager for collecting compiling data on the watershed to gauge improvement and to monitor the lake to track water quality standards.

- Chatham District Health Department
    - Guidance with cyanobacteria bloom conditions and beach postings.

Town of East Hampton Institutional Needs

- Public Works Department
    - Using design plans and materials, can probably implement a majority of the low cost hard surface fixes on public property.
    - Accomplish proscribed maintenance programs.
    - Assist with implementation of private property fixes.
- Park and Recreation Department
    - Using design plans and material, can probably implement low cost soft surface fixes.
        - Possible partner with CT River and Coastal Conservation District.
    - Provide assistance to private property fixes.
    - Help with education of environmental understanding and good stewardship practices
- Planning and Zoning / Inland Wetlands
    - Review new development applications for continuity with LID management measures being implanted throughout the watershed.
    - Regular inspections of sites of active development.
    - Routine inspections to determine proper functioning of management measures.
- High School Educators
    - Environment Club monitoring of aquatic insect populations and brook water quality important aspect of Monitoring Effectiveness of Implementation (element I).
    - Expand programs and curriculum to include lake and watershed examination and monitoring.
    - Assist with public education programs

Criteria to determine load reduction and change in water quality (element H)

Determining Degree of Load Reduction

Overall infiltration of what is now storm water throughout the near shore drainage basin of the lake is expected to reduce phosphorus nutrient loading. In addition, LID is expected to reduce sediment loading (TSS) to the Lake by 30-60% causing further reductions in nutrient loading. More specific nutrient pollution reduction capabilities are outlined in section Management Zones Element C.

1. All inlets to the lake will be monitored for water flows and total phosphorus and total nitrogen monthly.
2. At least three storm-water collections per year for nutrient concentrations at inlets where improvements have occurred that show values below the mean for that sub-basin.
    a. Maximum values should not exceed prior maximum values.
    b. Values should show long-term decline to more background conditions.
3. Sub-basins where no improvements have taken place should show consistency with prior averages and ranges.
4. Measure nutrient retention and cycling within existing wetlands and at constructed LID sites, focus on vegetative storage and possible increased uptake rates at experimental locations by manipulating sediment storage capacities.
5. Update nutrient loading models to reflect BMP/LID and land use changes and zooplankton sampling, toxin analysis and beach sampling, phycocyanin and chlorophyll pigment fluorometry.
6. Storm-water with be collected from fifteen known sites where Storm-water enters the lake will be visited during 3 storm events. All inlets samples will be analyzed for total phosphorus, total nitrogen, total suspended solids, and water flow.

Indicators to Measure Change in Water Quality

- Water clarity

Lake Pocotopaug water clarity will be measured at the two established stations monthly in March, April, October and November and twice monthly May through September.

- Show Lake water clarity is increasing. Measure water clarity at least monthly and track attainment of these goals:

Summer Secchi Disk =	>1.5 meters
Maximum annual Secchi disk depth =	>2.5 meters

- Cyanobacteria population numbers
  - Lake Pocotopaug cyanobacteria numbers will be estimated monthly in March, April, October and November and twice monthly May through September.
  - Show cyanobacteria population numbers are declining.
    - Summer and fall cyanobacteria numbers below 50,000 cells/mL.
    - Spring and fall diatom numbers declining below X cells/mL

- Dissolved oxygen content
  - Lake Pocotopaug dissolved oxygen content will be measured from top to bottom of the water column at each of the two established lake stations. Profiles will be measured monthly in March, April, October and November and twice monthly May through September. Dissolved oxygen content in the lake should be improving.
    - Anoxic boundary should remain below 4 meters during summer.
    - Long term goal of anoxic water only below 5 meters depth.

- Nitrogen and phosphorus concentrations
  - Lake Pocotopaug total phosphorus, nitrate-Nitrogen, ammonia-nitrogen and total-nitrogen will be measured at top middle and bottom depths of the water column at each of the two established lake stations. Profiles will be measured monthly in March, April, October and November and twice monthly May through September.
    - Nitrogen and phosphorus concentrations in Markham and Oakwood deep water basins show declining values with TP less than 20 μg/L and TN less than 400 μg/L and values on-average lower than the long-term average.

Monitoring effectiveness of implementation (element I)

Excel Spreadsheet

The Town of East Hampton has had several watershed studies over the past 21 years that each effectively identified various pollution sources in the Lake Pocotopaug watershed. However, a list of locations in need of watershed improvements are only valuable if they are used appropriately and can be easily interpreted and adapted. The ability to track construction and improvements over time is exceedingly important to measuring progress.

This report includes an organized, user-friendly excel document that lists every catch basin in the watershed by WPT# (**Appendix 3**). The excel file lists the inflows and outflow connections for every catch basin where connections were visible (questionable connections are indicated) and describes the condition of the site. There are supplemental maps and a GPS file that are intended for continued use by the Public Works Department and the Watershed Planner. As LID and BMP are implemented, this file will serve as a way to update storm-water maintenance information.

Additionally, the excel document highlights the catch basins that receive greater amounts of road runoff, indicating that they are in need of more frequent cleaning. This file can be added to in order to track the catch basin cleaning schedule over the years.

General Recommendations

- Appoint an individual responsible for overseeing progress and Town interdepartmental communication for watershed planning
- Create lake science and watershed management educational program for incoming Town commissioners and councilmen
- Organize water quality info sessions and ongoing community educational events in conjunction with local nonprofits and lake associations – focus on LID
- Establish a lake LID buffer zone of 150ft (in accordance with IWA buffer zone definition) around the perimeter of the lake – limit activities and building within buffer zone, all IW applications should be reviewed by Town lake consultant
- Enforce watershed lawn fertilizer limitations, bolster with educational outreach
- Establish good Town communication with private property owners in the watershed – acquire necessary easements for LID and storm-water management

- ➢ Encourage an active network of Town residents and participation in financial planning for watershed improvement
- ➢ Allocate Town funds in budget to Public Works Department for LID construction on Town property and future easements – provide PWD access to GPS for high level record keeping of all major and minor construction within watershed with appropriate locations, dates, costs, and names of outside contractors (include private property fixes identified in this plan). Information shall not be lost if there is a change in Town personnel.
- ➢ Incentivize LID on private property through Town funding assistance – potential revolving LID grant program
- ➢ Work with local high school and environmental club to incorporate their rapid bio-assessment data into watershed improvement efforts and monitoring
- ➢ Utilize high school student/college research programs to study effectiveness of vegetated floating islands for nutrient removal in Hales Brook outlet pond, Christopher Brook Pond, and other locations.
- ➢ Determine potential outside funding sources and apply for grant programs
- ➢ Establish conservation areas for forested property in Hales Brook watershed
- ➢ Involve the Middlesex Land Trust in enhancing natural wetlands to improve nutrient retention in watershed K
- ➢ Continue active watershed water quality monitoring and in-lake sampling for long term adaptive lake management

Organizational Changes

The Town of East Hampton needs to appoint a Town employee as an interdepartmental planning agent whose responsibility is implementing, inspecting, and maintaining the watershed fixes of this plan on public property. This individual will also be in charge of communication with private property owners to encourage BMPs and LID as specified in this document.

Specific Duties of Town Watershed Planning Appointee

- Communication with the Town PZ/IW, Lake & Conservation commissions, PWD, Lake consultant, Town Manager, and Town Council
- GIS experience and GPS mapping abilities for tracking progress in watershed – update the catch basins excel document as necessary
- Work with the Town's hired LID engineer and lake consultant
- Oversee all construction sites to ensure BMP and limit exposed sediment
- Communicate with lake homeowner and beach associations
- Communicate with apartment and condominium managers
- Communicate and educate the Friends of Lake Pocotopaug nonprofit and the Middlesex Land Trust

- Work with private property owners and be in charge of a Town revolving LID fund/ matching grant program
- Communicate with State Department of Transportation (DOT) for Route 66 maintenance and storm-water culvert design improvements
- Make improvements to Town Inland Wetland regulations to limit development in watershed and lakeside activities
- Engage Local Health Department and State Representatives to discuss future lake protection legislation on a state level
- Assist Town in applying for grant funding for LID in the watershed

Public Information and Education (element E)

Information and Education

A cohesive effort is critical in order to move forward with implementing the pollution fixes specified in this Nine Elements Watershed Plan. Watershed improvement hinges on public environmental education and involvement. The Town of East Hampton owns approximately five acres of the entire 2,315-acre Lake Pocotopaug watershed. Without a community effort and ongoing educational activities to encourage responsible land-use practices, there will be no improvements in the water quality of the Lake. This dilemma is the essence of nonpoint source pollution and it can only be solved with considerable effort towards public participation. The Town must work with all stakeholders to incentivize LID in the watershed, while maintaining close connections to community leaders. In the case of private property, motivation and guidance for BMPs is essential.

High School Student Activities

Current curriculum at East Hampton High School includes water quality sampling and testing at 13 different inlet stations around the lake. Students test the water at these stations for pH, Conductivity, Water temperature, Dissolved oxygen, Total Dissolved Solids and Turbidity. Rapid bioassessment of aquatic insects has been done at one location once seasonally since 2006 representing 10 years of indicator organisms tracking. The Rapid bioassessment involves counting 14 different stream animals including insects and fish larvae. There is interest in high school students building and maintaining floating wetlands.

Educating within Town Government

The Town must require all P&Z, IWW, and the Conservation Lake Commissioners to attend a LID and nonpoint source pollution educational session. The session can be offered by a qualified contract organization, or it can be offered through the Town if a capable person is hired as watershed planner. The educational sessions can also be open to and modified for homeowner association members and business owners within the Lake Pocotopaug watershed.

The Park and Recreation Department may utilize future funds to incorporate watershed educational activities into their summer day camp and community events. Educational signage should be erected at LID sites on public property.

Educational handouts developed for Lake Pocotopaug and designed for public education are included in Appendix _. There is also a list of web-links to various storm-water management and LID publications that are freely available as online educational documents.

Educational Flyer:

WHAT CAN YOU DO TO HELP CLEAN UP LAKE POCOTOPAUG?

What you do in your own back yard can impact the entire watershed, including the health of Lake Pocotopaug.

If your home has a roof, a lawn, or a driveway, chances are your property creates stormwater runoff. Property owners can play a role in improving water quality by soaking up stormwater runoff to prevent it from reaching nearby lakes, streams, and other waters.

Some easy, important steps you can take:

- **Soak up rain at its source.** Rain that falls on your roof, driveway, and other hard surfaces flows into storm drains and then into Lake Pocotopaug, picking up contaminants along the way. If rain soaks directly into the ground, the soil absorbs the contaminants, keeping them out of the lake

  Ways to reduce runoff:

  - Reduce impermeable surfaces.
  - Rainwater is a resource: Cut down on your water use by capturing and using rainwater in the garden by redirecting your gutter downspouts into rain barrels
  - Install a rain garden and plant bare areas in your yard with natural vegetation.
- **Create a buffer garden of natural vegetation along the lakeshore.** Buffer gardens slow the flow of water from your lawn into the lake and will absorb nutrients and fertilizers before they can enter the lake.
- **If you must fertilize, do so very sparingly** Fertilizer makes your lawn green, and it makes the lake green! Use low phosphate, slow release nitrogen fertilizer on vegetated areas only.
- **Maintain a natural lake shoreline.** Clearing trees, erecting walls, and dumping sand can disturb the ecosystem and negatively affect lake health.
- **Never dump anything into storm drains.** Storm drains flow directly into Lake Pocotopaug.

Appendix 1

Limnology and Water Quality

Lake Pocoptapaug has a surface area of approximately 501 acres with a watershed area of 2,315 acres[4] (**Table 18**). The watershed to lake size ratio is small (4.6:1), why is there relatively low water recharge due to limited amount of water flowing to the lake. Flushing rate established by prior studies is about 1.0 per year. Much, 61% of the Lake Pocotopaug watershed is forested, but a large portion 25% of the drainage surrounding the lake is high density residential or commercial usage. Building within the watershed has been tremendous since the 1980s and there are multiple developments that have been constructed post 2006.

Table 18 – Basic statistics of Lake Pocotopaug

Surface Area	501	Acres
Total Volume	6,064	Ac-ft.
Maximum Depth	38.0	Feet
Mean Depth	12.1	Feet
Watershed	2,315	Acres

The bathymetric data available was published in the *CT Fisheries Guide to Lakes and Pond* (1959) and passed on to (*Frink and Norvell 1984*), is likely originally surveyed in the early 1930s. The contour lines were georeferenced in a GIS program and assigned an appropriate coordinated system (**Map 5**). Acreages of each depth were then used to create a table of surface area and volume for each layer of water, information necessary to update nutrient mass balance estimates for the lake (**Table 19 & 20**). The surface area and water volume is shown in **Figure 14**.

[4] Estimates on the size of the watershed and lake surface area vary

Map 5 – Bathymetric map of Lake Pocotopaug

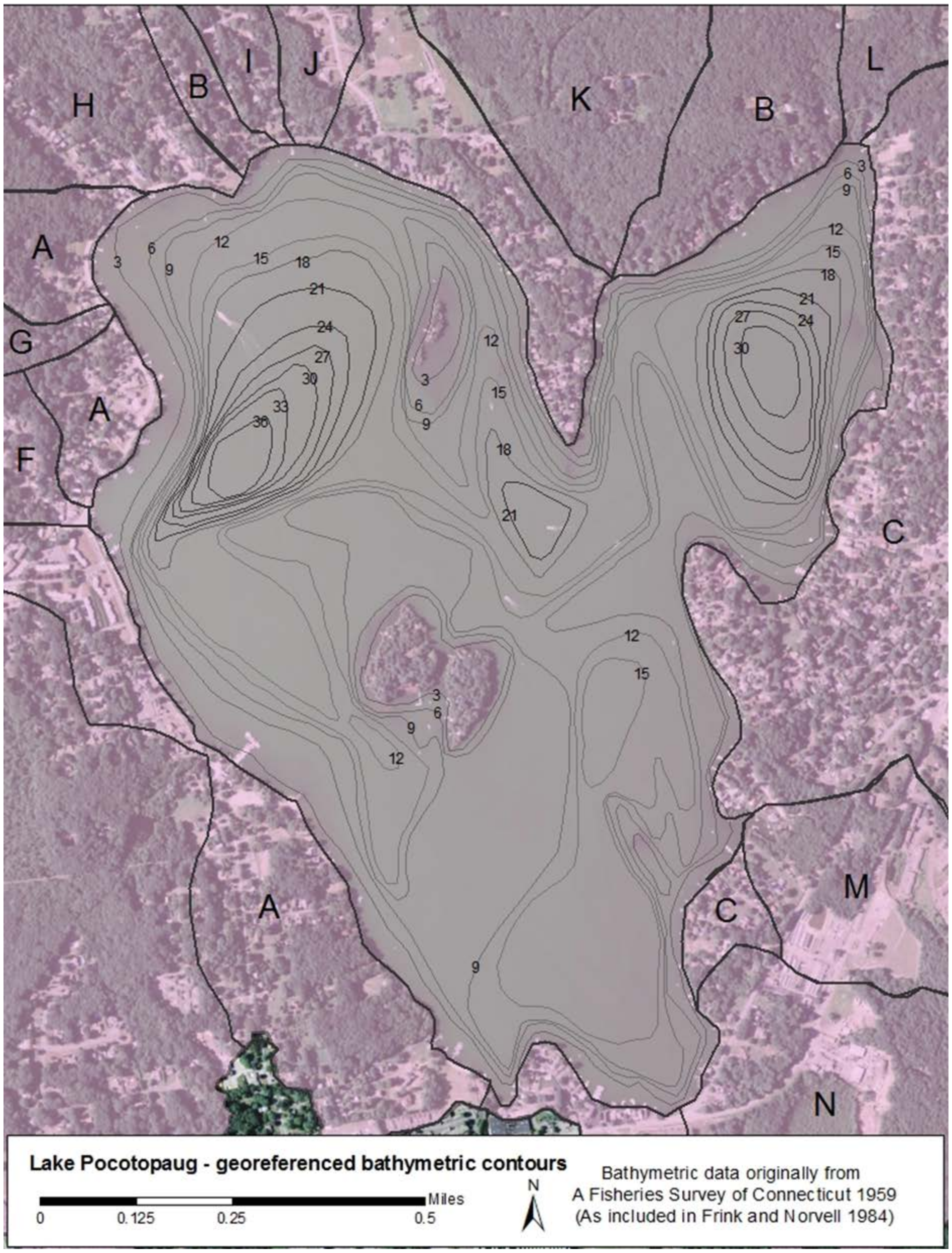


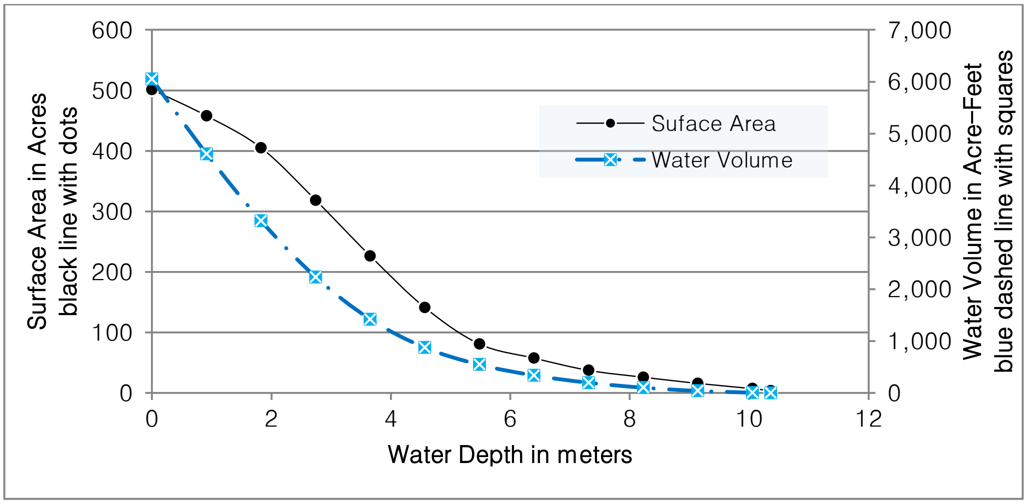
Table 19 – Surface area by depth of Lake Pocotopaug basin

DEPTH	SURFACE AREA			
	Cumulative From Bottom		Of Each Stratum	
(feet)	(acres)	(percent)	(acres)	(percent)
0	501	100	43	8.7
3	458	91	53	10.6
6	405	81	87	17.3
9	318	64	92	18.4
12	226	45	85	17.0
15	141	28	60	12.0
18	81	16	23	4.6
21	58	12	20	4.0
24	37	8	11	2.3
27	26	5	10	2.0
30	16	3	9	1.7
33	7	2	4	0.7
36	4	0.7	4	0.7
	TOTAL =		501	ACRES

Table 20 – Water volume by depth of Lake Pocotopaug basin

DEPTH	VOLUME			
	Cumulative From Bottom		Of Each Stratum	
(feet)	(acre- feet)	(percent)	(acre- feet)	(percent)
0	6,064	100.0	1,438	23.7
3	4,626	76.3	1,293	21.3
6	3,333	55.0	1,082	17.8
9	2,250	37.1	813	13.4
12	1,437	23.7	546	9.0
15	892	14.7	329	5.4
18	563	9.3	207	3.4
21	356	5.9	141	2.3
24	215	3.5	95	1.6
27	120	2.0	62	1.0
30	58	0.9	34	0.6
33	24	0.4	16	0.3
36	7	0.1	7	0.1
	TOTAL =		6,064	AC-FT

Figure 14 – Surface area and water volume at depth in Lake Pocotopaug basin



Water Quality Monitoring Results

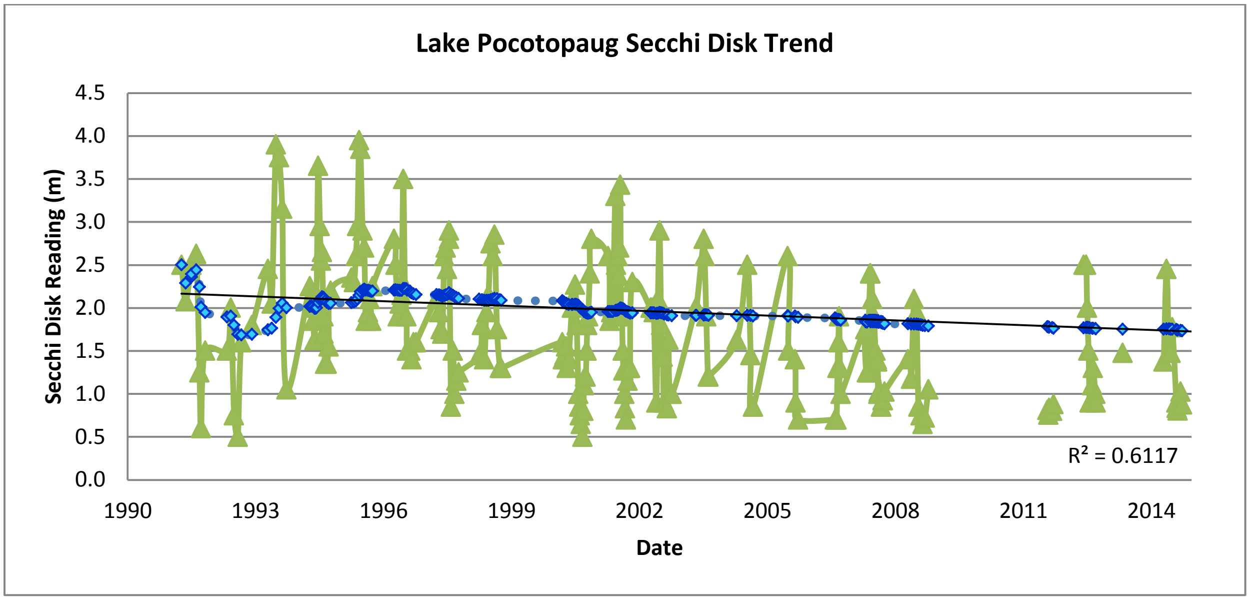
Water quality data were acquired from the aforementioned lake study reports and updated with recent 2014-2016 sampling results. The following section is an overview of historical water quality at Lake Pocotopaug.

Water Clarity as Secchi Disk Transparency

Secchi disk transparency estimates light penetration, with declining Secchi disk depth caused by increased water cloudiness. The increase in turbid water caused by increasing phytoplankton numbers or (and) fine suspended sediments in the water column. If the decline of Secchi disk is caused by phytoplankton (algae) then typically phosphorus is considered the limiting nutrient loading. However, phosphorus may not be limiting phytoplankton and siltation may be an important cause of poor clarity at some times of the year. Long term Secchi disk transparency for Lake Pocototaug is shown in **Figure 15**. The chart shows a green line as measured Secchi depth and the long term running average in blue. The chart shows a generally declining trend in water clarity with a period of good clarity between 1993 and 1996 and poorer clarities after 2002:

1. Maximum seasonal clarity has declined from 3.9m in 1993 to 2.4m in 2015
2. Minimum seasonal clarity has consistently been between 2.0 and 0.5 meters.
3. Minimum seasonal clarity of less than 1.0m has become regular occurrence each year.
4. Mean clarity has shown long term decrease from 2.2m in 1990 to 1.75m in 2015.
5. Clarity rapidly declines each season from maximum to minimum clarity.
6.

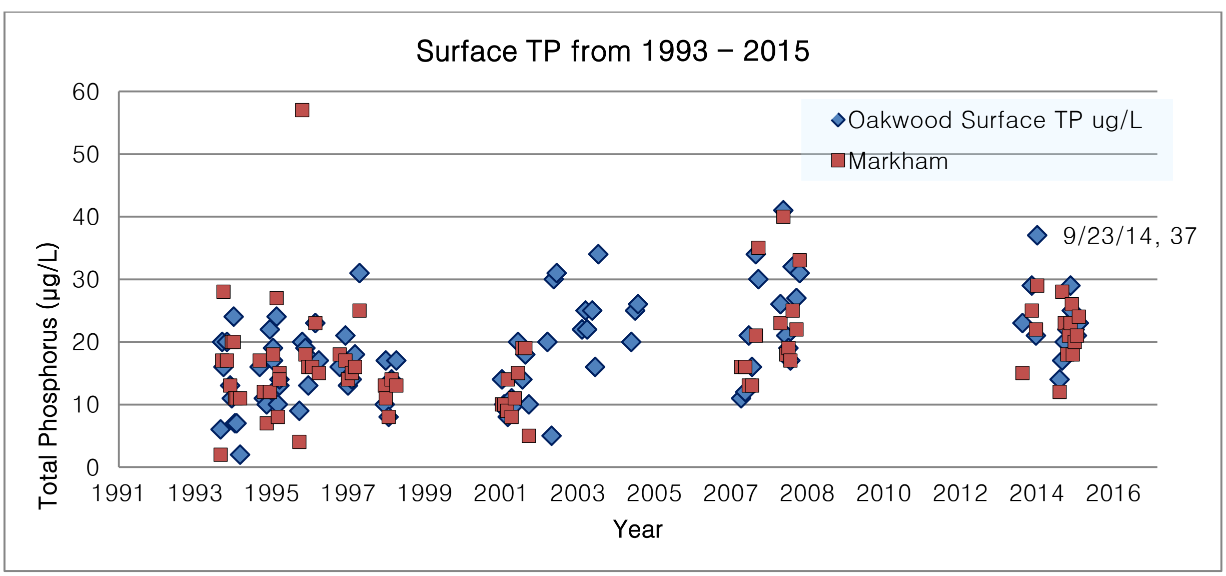
Figure 15 – Long-term Secchi disk trend in Lake Pocotopaug 1991-2015



Surface Total Phosphorus (TP)

TP has been measured at two locations: Oakwood Bay >30ft on west side and Markham Bay >30ft on east side (see **Map 5**). Early data, 1993-1997 showed surface total phosphorus to be mostly between 10-20μg/L with a few values each season that reached 30μg/L. Monitoring conducted since 2007 has detected no results less than 10μg/L with instead most results now 20-30μg/L with some values reaching 40μg/L have been noted (**Figure 16**).

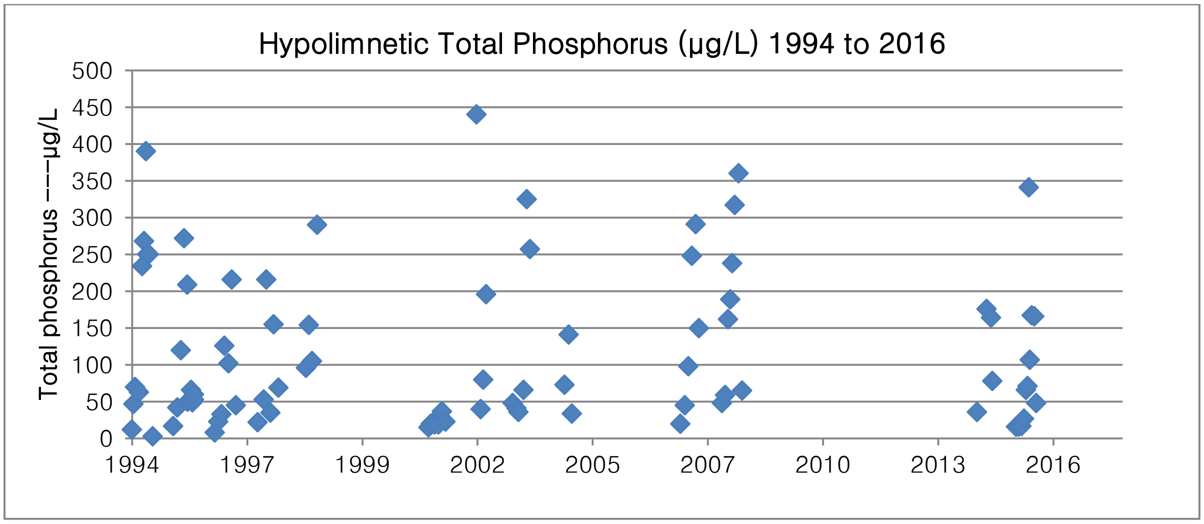
Figure 16 – Lake Pocotopaug total phosphorus trend 1994-2015



Bottom Total Phosphorus (TP)

Bottom total phosphorus results (**Figure 17**) ranged from near zero to 450µg/L. Data from 2001 shows lowest seasonal bottom phosphorus of <50µg/L seemingly out of place against all other years that show bottom phosphorus exceeding 100µg/L. Recent data 2014-2015 show comparable results with maximum phosphorus between 174 and 341µg/L.

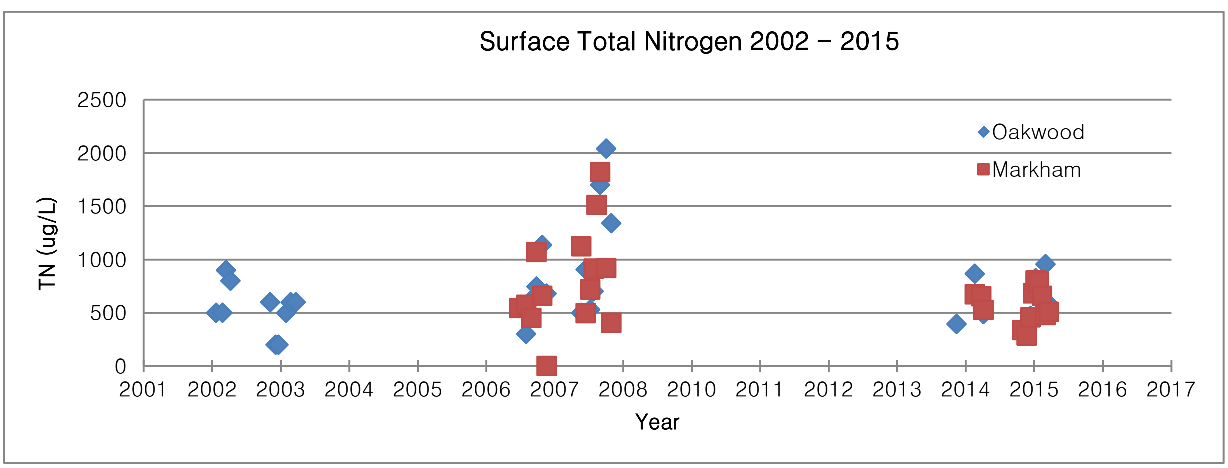
Figure 17 – Lake Pocotopaug bottom water total phosphorus 1994-2015



Surface Total Nitrogen (TN)

There are large gaps in nitrogen data because it was historically measured less frequently than phosphorus. Though phosphorus is the commonly accepted nutrient that limits productivity in freshwaters, Lake Pocotopaug has very high TN concentrations in surface waters (**Figure 18**).

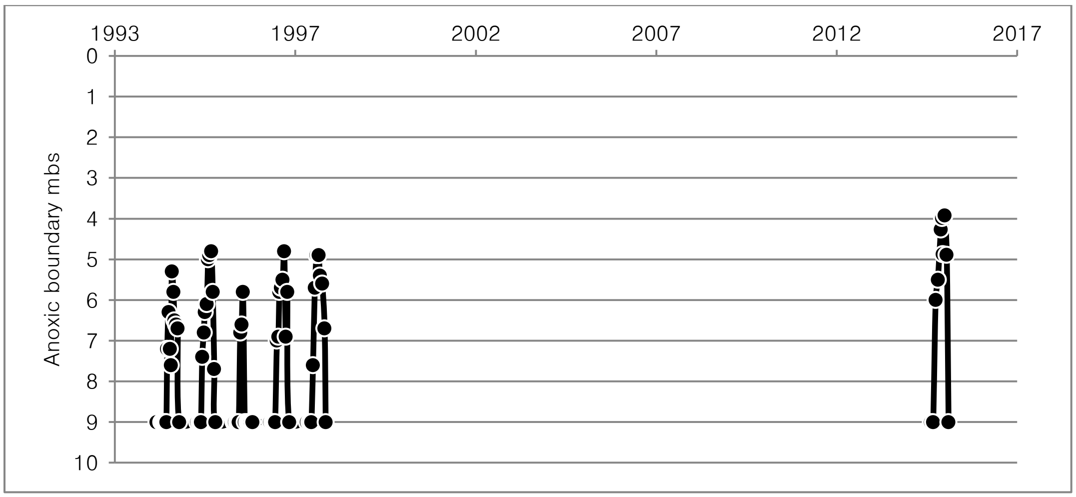
Figure 18 – Long-term trend in Total Nitrogen in Lake Pocotopaug 2002 -2015



Dissolved Oxygen

Dissolved oxygen profiles representing seasonal dynamics of Lake Pocotopaug were measured through the 1990's but sporadically between 1998 and when NEAR started monitoring again in 2014. Accumulation of organic matter, mostly as dead algae cells, at the bottom of lakes leads to dissolved oxygen depletion. Once all dissolved oxygen has been consumed by bacteria the water is labeled anoxic. Data in **Figure 19** suggests that volume of anoxic water in Lake Pocotopaug during summer months has increased over time. Prior data shows that anoxic water rarely reached to 5 meters below the surface while in 2015 anoxic water was found above 4 meters[5].

Figure 19 – Long-term trend in anoxic boundary Lake Pocotopaug



Phytoplankton

Plankton has been measured infrequently in the historical literature reviewed during this study. Only a few of the many years that either watershed of in-lake monitoring was conducted included seasonal algae collections. Frequent cyanobacteria collections made during 2015 (**Table 21** and **Figure 20**) show that water clarity decreased rapidly when cyanobacteria numbers increased from <2000 to 50,000 cells/mL. Cell numbers higher than 50,000cells/mL did not lead to further decreases in clarity (**Figure 20**). Instead, water clarity remained constant over a wide range of cell numbers (50,000 cells/mL–300,000cells/mL).

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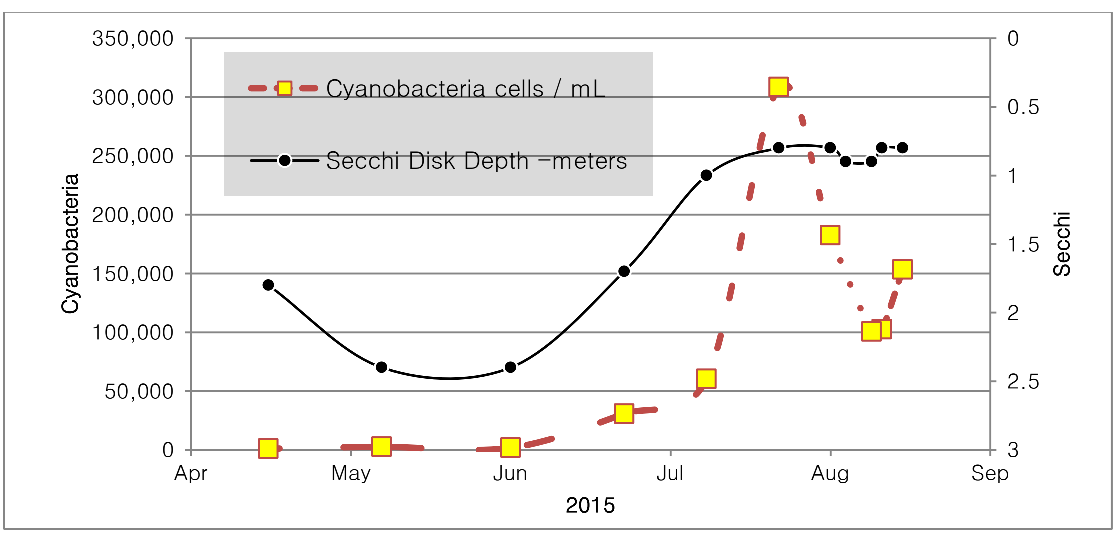
[5] The anoxic boundary is measured down from the surface to the first occurrence of dissolved oxygen of 1 mg/L. Below this depth all water is devoid of dissolved oxygen.

Table 21 – Phytoplankton and water clarity in Lake Pocotopaug during 2015

Date	Secchi Depth Meters	Feet	Cyanobacteria cells/mL	Taxa
8/17/2015	0.8	2.6	153,469	Chrysosoporum
8/13/2015	0.8	2.6	102,446	Chrysosoporum
8/11/2015	0.9	2.9	100,612	Chrysosoporum
8/6/2015	0.9	2.9		Chrysosoporum
8/3/2015	0.8	2.6	182,480	Chrysosoporum
				(name change)
7/24/2015	0.8	2.6	308,603	Aphanizomenon
7/10/2015	1.0	3.3	60,408	Aphanizomenon
6/24/2015	1.7	5.6	30,671	Aphanizomenon
6/2/2015	2.4	7.5	1,700	Anabaena
5/8/2015	2.4	7.5	2,500	Anabaena
4/16/2015	1.8	5.9	918	Anabaena

Figure 20 – Trend in cyanobacteria cell numbers during 2015



Aquatic macrophytes

NEAR conducted an aquatic plant survey of Lake Pocotopaug on September 21, 2015, the first since CT Agricultural Experiment Station surveyed aquatic plants in 2006[6]. During our survey we found only 7 species of aquatic plants sparsely scattered around the lake with most found at less than 10% occurrence **Table 22**. Instead much of the littoral zone was covered in a thick benthic mat of cyanobacteria (bottom dwelling blue-green algae), identified as species of *Oscillatoria* and *Lygnbya* (**Map 6**). These findings are consistent with CAES who only found two species of aquatic plants at only 4 of over 250 search points surrounding the shoreline of the lake. No aquatic non-native invasive species were found in that survey.

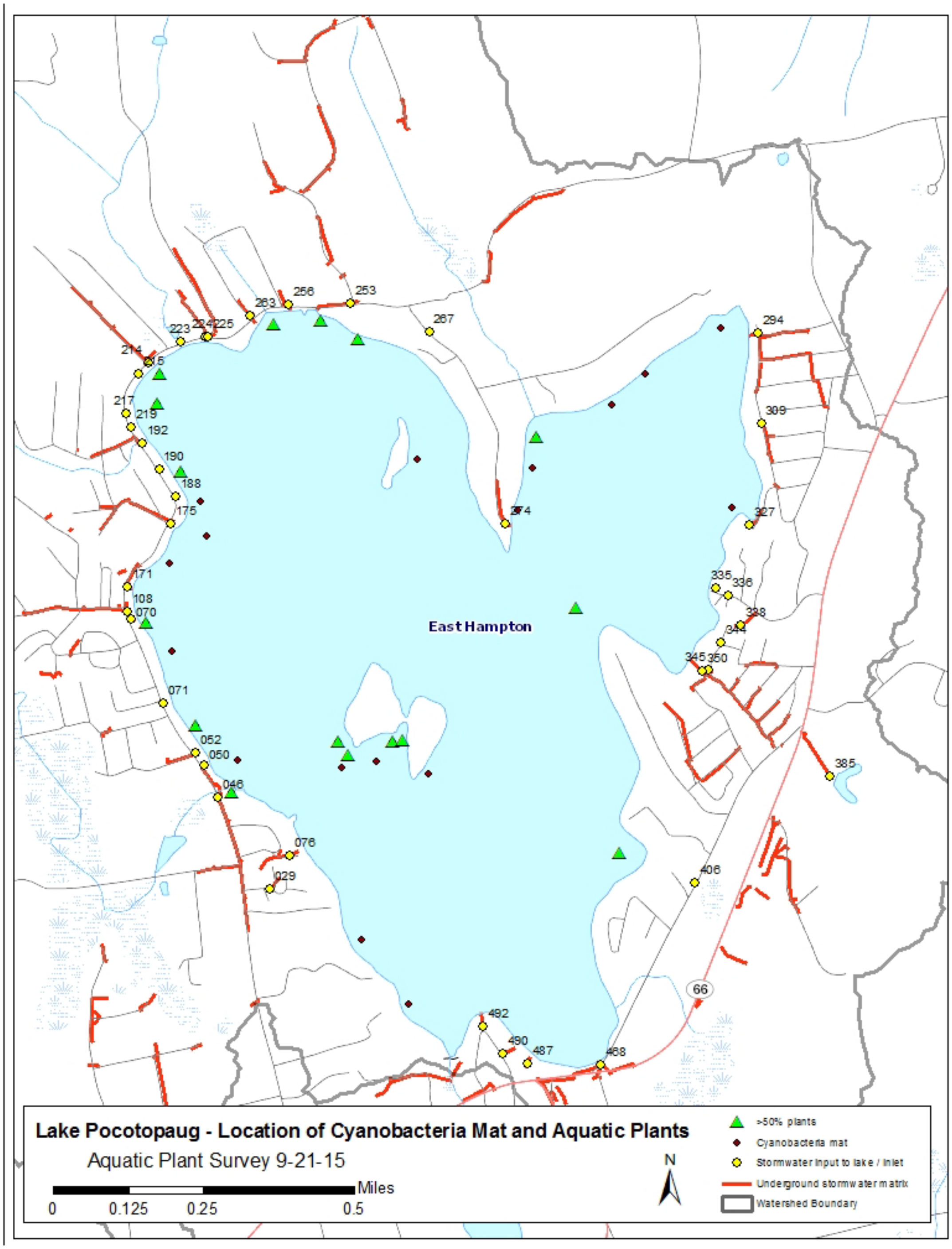
Percent occurrence is a value representing the number of waypoints where a species was documented divided by the total number of waypoints. Average percent cover represents the mean density of each species in areas where it was located. The percent cover of the littoral zone takes into account the average density and frequency of occurrence to calculate an approximate coverage of the entire survey area. Based on the depths at which plants and cyanobacteria mats were located, the littoral zone extends to roughly 7.5 ft. The littoral region where plants are capable of growing was then calculated as 72% of the lake's surface area. However, much of this surface area consists of barren rocky sediments, and 41% is dominated by cyanobacteria mat instead of rooted aquatic plants.

Table 22 – Aquatic plants found in Lake Pocotopaug on September 21, 2015

Species # Key	Name	% Occurrence	AVG% Cover	% Cover Littoral Zone
1	Benthic cyano mat	30	39	41
2	Najas flexilis	5	8	1
3	Vallisneria americana	12	37	17
4	Potamogeton bicupulatus	8	31	9
5	Nitella	8	6	2
6	Elodea nuttallii	9	14	4
7	Potamogeton berchtoldii	3	25	3
8	Potamogeton epihydrus	1	5	0.2

[6] http://www.ct.gov/caes/lib/caes/invasive_aquatic_plant_program/pdfmaps/pocotopaug_lake.pdf

Map 6 – Locations of aquatic plants (triangles) and benthic cyanobacteria mats (dots) on September 21, 2015



Appendix 2

Document Summary

There is an extensive list of monitoring reports and in-lake management publications for Lake Pocotopaug. Those reviewed in detail during this study are given in **Table 23**. Initial work was done by E. Deevey in the 1930's, and CAES in 1974. Since the early 1990's lake and watershed monitoring has been done by multiple citizen organizations, as well as consulting scientists and engineers. Predictive phosphorus and nitrogen load modeling started in 1995 and culminated in the Lake Loading Response Model in 2009. Generally most years between 1991 and 2007 have some information from either the lake or the watershed but not all testing was done consistently during each of those years leaving some holes in long-term trend analysis. All sampling stopped at the end of 2007 with no data collected[7] until monitoring resumed in 2014.

Table 23 – List of reports reviewed in this study

	Author	Date
A	Frink and Norvell	1984
B	Fugro-McClelland	1993
C	Ad Hoc Lake Advisory Committee	1995
D	Lake Advisory Committee (Phosphorus Modeling and Mitigation)	1995
E	WMC Consulting Engineers	1995
F	ENSR (Analysis of first Alum treatment performed by Aquatic Control Technologies in 2000)	2001
G	Aquatic Control Technologies (Post-Alum treatment)	2001
H	ENSR (Lake and Watershed Restoration Evaluation)	2002
I	ENSR (Investigation of Nutrient Flux and Sediment Oxygen Demand of Shallow Sediments)	2002
J	ENSR (In-Lake Water Sampling and Algal Assay Results)	2003
K	ENSR (2003 In-Lake Water Sampling Results)	2004
L	AECOM (Lake Loading Response Model in TMDL Development for Lake Pocotopaug)	2009

[7] Secchi disk data was collected continuously during that period

A. *Frink and Norvell (1984)*

Monitoring conducted on 4 dates, 2 in 1973-1974 & 2 in 1979-1980. Lake classified as mesotrophic with an average Secchi disk transparency of 3.6 meters (11.8 feet).

B. *Fugro-McClelland (1993)*

Monitoring period was 1987 to 1992. Rainfall erosion event in 1987 following large land clearing on Baker Hill for development caused highly turbid water to flow into Lake Pocotopaug. The Lake Area Task Force was formed. Continued pollution from this development was documented through 1989. The first recorded severe algal bloom (cyanobacteria) occurred in September 1990. CT DEP and CT Department of Health Services (CT DHS) became involved. A volunteer Lake Study Group began a more in-depth monitoring program.

C. *Ad Hoc Lake Advisory Committee (1995)*

The Town Council of East Hampton formed the Lake Advisory Committee (LAC) to organize information and provide recommendations for a lake and watershed management plan. The LAC report encouraged a permanent monitoring program and LAC. The report also suggested hiring a town planer and securing a continuous funding supply for lake improvement projects. The LAC recommended ongoing education to Inland Wetlands and Planning and Zoning commissioners and stressed the importance of a cooperative plan for managing lake water level via a privately owned dam.

D. *LAC Phosphorus Modeling and Mitigation Plan Report (1995)*

First attempt to model TP loading to the Lake from sources other than internal loading were made in this report. Estimates for atmospheric loading (207 kg/yr) and wildlife (20 kg/yr) are extremely high. NEAR investigation of references used for LAC 1995 report showed estimates used for model construction were likely drawn from case studies that were unaligned with the conditions of Lake Pocotopaug.

E. *WMC Consulting Engineers (1995)*

Storm-water Renovation and Management Plan reviewed the Town of East Hampton Planning & Zoning and Inland Wetlands & Watercourses regulations and suggested the following:

- Required referral to the Wetlands Commission for any proposed activity in the watershed.
- P&Z regulation to include a requirement for approved designs of LID for building in the watershed, including a maximum impervious area requirement and frequent inspections to ensure compliance.
- IWW regulations should have a buffer zone requirement that limits certain land use and activities in the watershed, needs strict enforcement.

- Utilize an erosion and sedimentation control checklist for any development in watershed

The WMC report also provides a detailed list of storm-water detention hydraulic inadequacies and suggests specific fixes to catch basins, driveways, parking lots, roof drains, and channel stabilization. Total estimated costs were $3,122,000.

F. *ENSR International: Analysis of first Alum treatment performed by Aquatic Control Technologies in 2000 (2001)*

Frugro McClelland (1993) was the first to suggest that internally generated phosphorus contributes significant phosphorus load to Lake Pocotopaug annually. Aluminum sulfate (Alum) was proposed option for reducing internal loading. Following this suggestion, and lake nutrient data provided by Volunteer Lake Study Group data collection through 1998, the Town contracted with Aquatic Control Technologies (ACT) to plan an Alum treatment for the summer of 2000. The original plan was to treat all areas greater than 15-feet deep. However, despite the use of a sodium aluminate buffer and a relatively stable pH, an unexpected fish kill occurred after treating only 22 of the proposed 177 acres at a dosage of 40 g/m^2 **[IN REVIEW]**. The remaining areas were untreated in 2000. Treatment maps demonstrate that the 22 acres treated were, on average, only 16-feet deep and not located in either of the deep holes where the internal loading had been documented as occurring. Thus, the 2000 Alum treatment may have occurred in areas not likely to release phosphorus during the summer (Lake data shown later indicates that the ALUM failed to inactivate phosphorus loading in the deeper anoxic waters (ENSR 2002).

G. *Aquatic Control Technologies Post-Alum treatment report (2001)*

In 2001, a second Alum treatment plan was proposed. In a combined effort, ENSR and ACT took appropriate planning measures to calculate a treatment dosage between 42-48 g/m^2 of aluminum sulfate to bottom waters in a modified treatment area of 140 acres. The Alum:Aluminate (buffer) **[IN REVIEW]** ratio was reduced to half that used in the 2000 treatment resulting in stable pH and alkalinity, and no fish toxicity. The ACT report makes mention of improving Secchi disk transparency on the days of treatment (spread out per CT DEEP permit requirements from May 22nd – June 8th) from 5.5 feet to 10.5 feet, but it seems there is little data available. ENSR collected water quality samples prior to the treatment on 5/17/01 and following the treatment on 6/13/01 (Table 24).

The pre and post-Alum treatment water quality data showed that the treatment did not have a lasting effect on Secchi disk transparency, nor phytoplankton and chlorophyll concentrations. Note that by 8/23/01 water transparency declined to 3.5 feet and phytoplankton biomass rose to 15,912 µg/L, despite any reduction in bottom water Total Phosphorus (TP) – likely resulting from the Alum treatment and sediment inactivation.

Table 24 – Water quality data from May and June 2001 before and after Alum Treatment

Date	Sample Location	TP (ug/L)	Turbidity (NTU)	Secchi (ft)	Chlorophyll (ug/L)*	Phytoplankton (ug/L)*
5/17/01	LP-1 Surface	10	1.9	6.0	3.29	3,876
5/17/01	LP-1 Bottom	21	3.4	~	~	~
5/17/01	LP-2 Surface	10	1.9	6.0	2.55	3,312
5/17/01	LP-2 Bottom	20	2.2	~	~	~
6/13/01	LP-1 Surface	9	1.7	8.5	1.5	4,449
6/13/01	LP-1 Middle	14	1.7	~	~	~
6/13/01	LP-1 Bottom	19	2.0	~	~	~
6/13/01	LP-2 Surface	9	1.7	7.5	6.34	4,472
6/13/01	LP-2 Middle	17	2.2	~	~	~
6/13/01	LP-2 Bottom	23	3.3	~	~	~

H. *ENSR International Lake and Watershed Restoration Evaluation (2002)*

The first comprehensive lake study included extensive in-lake monthly water quality sampling, as well as phytoplankton and zooplankton population analyses. The study concluded that in-lake surface phosphorus is relatively low given the observed algal blooms and poor water clarity. ENSR suggested that watershed phosphorus loading should be reduced by 60%. The study addressed the potential internal loading of phosphorus and notes that future Alum treatments may still be necessary. Specific reference is made to the non-algal turbidity affecting water clarity as a result of suspended sediments from poor watershed management practices. The report included with multiple descriptions of BMPs for catch basin sumps and detention and infiltration system improvements.

Concluding recommendations included stocking Walleye, a piscivorous fish species, to provide "top-down" control of phytoplankton by reducing the large population of zooplanktivorous fish. This method of trophic biomanipulation was expected to produce visible increases in zooplankton and decreases in phytoplankton over a course of 3 to 5 years.

I. *ENSR Investigation of Nutrient Flux and Sediment Oxygen Demand of Shallow Sediments (2002)*

This report specifically investigated the possibility of nutrients leaching from shallow lake sediments in the oxic zone and not previously treated with Alum. By measuring the shallow-water sediment oxygen demand (SOD) in three locations around the lake, ([In Review]. it was determined that the sandy sediments have a very low oxygen demand. Results are indicative of very low sediment bacterial decomposition and use of oxygen in shallow waters, fitting to sandy sediments with low organic material. Nutrient flux was measured using a DPA analyzer and results showed no release of phosphate nor nitrate/nitrite. One of the three sites removed ammonia from the water-column, while the other two sites did not.

J. *ENSR In-Lake Water Sampling and Algal Assay Results (2003)*

Algal and zooplankton population analysis revealed similar trends in 2002 as in 2001. Spring and fall were dominated by diatoms and chrysophyte algae, while the cyanobacteria genera Anabaena aphanizomenoides (currently taxonomically reclassified as Aphanizomenon spp.) prevailed in the summer months. Similar low zooplankton trends were observed with declines in population it late summer.

An algal assay was performed in the laboratory using water collected from the surface (epilimnion) and bottom (hypolimnion) waters of Lake Pocotopaug to determine phytoplankon response to phosphorus dilution. Results for epilimnetic waters demonstrated that severe dilutions resulted in phytoplankton die off, and moderate dilution yielded no growth. However when hypolimnetic water was used instead of epilimnion water dilution did not decrease algae growth, showing that the cyanobacteria did not actively grow in hypolimnetic water. These studies indicate that the species of cyanobacteria dominant in Lake Pocotopaug may be adapted to low phosphorus conditions such that when phosphorus is below a threshold level that algae doesn't grow, and that phosphorus may not be limiting at higher concentrations. **[IN REVIEW]**

K. *ENSR 2003 In-lake Water Sampling Results (2004)*

While the 2002 ENSR report makes reference to poor watershed practices and high turbidity in storm-water sampling, it is this 2004 report that specifically analyzed the field data collected inlets between 2001 and 2003. Samples were collected from 15 inlet sites. Only three samples were collected during a 'Dry' weather event in September 2003 because additional tributaries were not flowing. Passive storm-water samplers were used to collect first flush 'Wet' weather data, and 'Post-wet' samples were collected the morning after the rain event.

Two sites are identified as significant sediment and nutrient pollution sources: LP-10 (renamed to O'Neill's Brook in later reports) had very high nutrient concentrations and turbidity despite a small watershed area. The report suggests that the two storm-water retention basins in this sub-watershed were likely insufficient at retaining nutrients. The second pollution location was identified as the Clark Hill storm drain. In an attempt to quantify the efficiency of newly installed Stormceptor® devices, samples were taken upstream and at the downstream discharge. It appears that these BMPs reduce Total Phosphorus and turbidity, but dissolved phosphorus and nitrogen were reduced by a lesser amount. However, ENSR makes note that some reduction may be attributed to downstream dilution from road runoff and no true conclusions were made about actual removal capacities.

Overall, the AECOM 2009 report recommends more storm-water sampling and attention to watershed pollution and the unknown volume of water flowing into the Lake during baseflow and storm conditions.

Phytoplankton and zooplankton were quantified via monthly sampling. Cyanobacteria remains dominant during the summer months and zooplankton populations were still considered low. Final recommendations include treating the lake with a copper-based algaecide when cyanobacteria cells begin to dominate. It is suggested that a treatment would halt a bloom before it fully develops. A hypolimnetic copper treatment was also proposed based on a hypothesis that algal resting cells are migrating from bottom waters and transporting nutrients.

12 AECOM Lake Loading Response Model in TMDL Development for Lake Pocotopaug (2009)

LLRM is the most recent and most thorough watershed model of nutrient loading to the Lake. Using GIS land-use data acquired from UCONN and the State of Connecticut, the sub-watersheds were broken down into fourteen classifications representing varying levels of development, agricultural use, and forested or wetland cover. Water runoff coefficients and rainwater infiltration rates were utilized in predicting runoff from varying precipitation events. Nitrogen and phosphorus runoff coefficients were used to then model specific nutrient contributions for each land cover type in each sub-basin. This model was the first for Lake Pocotopaug to factor in infiltration, subterranean flow, and nutrient attenuation in the watershed to yield more accurate loading estimates. LLRM then predicts potential improvements in water quality based on watershed nutrient loading reductions from LID and BMPs. Multiple chlorophyll and water clarity models from the literature were employed.

NEAR reviewed the LLRM model and compared predictions to on-the-ground 2014-2016 sampling results and flow readings. Loading estimates from the LLRM model were supplemented by NEAR calculated loading events, and the same general sub-basins were identified as pollution sources in 2016 as in 2009. The following section identifies specific locations of nutrient pollution and makes multiple references to the AECOM LLRM model.

Appendix 3

Culvert GPS Waypoint File Separate Document

Excel worksheet of watershed existing condition and recommendations. Developed to be a working document the spreadsheet can be altered as measures are implemented as both sub-basin and total water progress can be tracked. Northeast Aquatic Research, LLC: Lake Pocotopaug Storm-water / Descriptions.

Appendix 4

Watershed Reconnaissance PowerPoint Separate Document

Appendix 4 is a PowerPoint presentation showing locations where management measures are needed. Slides show photos of pollution sources arranged by sub-basin. Assisting this slide show is the corresponding GPS file and culvert document.

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