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For the Comfort Lake Forest Lake Watershed District

Forest Lake Diagnostic Study and Implementation Plan Update

June 2018

Cover Image

Forest Lake

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Forest Lake (82015900) is located in the Comfort Lake-Forest Lake Watershed District (CLFLWD) and adjacent to the City of Forest Lake in northern Washington County. It has a surface area of 2,220 acres and is the largest lake in the CLFLWD and the largest lake wholly in Washington County. This lake is an important recreational and ecological resource with three public access sites, good water quality, and a healthy fish and aquatic plant community. The watershed of Forest Lake is 8,160 acres and dominated by open water lake surfaces, medium-density residential, wetlands, and forested land cover. The more developed area of the City of Forest Lake is situated along the west and southern shores of Forest Lake, and discharges storm water to Forest Lake through numerous storm water outfalls dispersed around the lake perimeter.

The summer season average water quality of Forest Lake currently meets state eutrophication standards and is not listed on the draft 2014 303(d) list of impaired waters. However, a major concern of the CLFLWD, the Forest Lake Lake Association, and lake residents is that the water quality of Forest Lake is near the thresholds and often exceeds water quality standards at certain times of the year. As a result, Forest Lake was given a water quality rating of C in the CLFLWD 2012-2021 Watershed Management Plan.

As part of this study, continuous flow and water quality grab samples were collected at twelve locations in 2016 to quantify the existing phosphorus loads to Forest Lake. These monitoring data were used as inputs into a BATHTUB lake water quality response model and calibrated to the 2012-2016 growing season average total phosphorus concentration in Forest Lake. This model was used to identify the total phosphorus load reductions needed to achieve a long-term five-year average summer phosphorus concentration at or below 30 ppb as identified in the CLFLWD 2012-2021 Watershed Management Plan.

Total phosphorus reductions needed for all 3 basins of Forest Lake is 923 lb/yr to achieve a long-term five-year average summer phosphorus concentration at or below 30 ppb. For the West Basin, a phosphorus reduction of 149 lb/yr is needed, split between the Hayward Avenue and Direct Drainage areas. For the Middle Basin, a phosphorous reduction of 599 lb/yr is needed, with most coming from the Shields Lake drainage area and the rest from the Hayward Avenue, Castlewood, and Direct Drainage Areas. For the East Basin, a phosphorus reduction of 175 lb/yr is needed, with most coming from the Judicial Ditch 6 drainage area, and the rest from the 3rd Lake Pond drainage area.

Key implementation activities identified needed to achieve the phosphorus reduction goals include:

- Treatment wetland in the 3rd Lake Pond drainage area (completed)
- A stormwater harvest and irrigation reuse system and in-lake alum treatment in the Shields Lake drainage area (in progress)
- Project feasibility and assessment studies in the JD-6, Hayward Avenue, and Castlewood drainage areas to identify potential projects (in progress)
- Street sweeping, dead-end street iron-enhanced sand filters, residential rain gardens, and shoreline restorations in the Direct Drainage area (City of Forest Lake is purchasing a regenerative air vacuum sweeper to implement an Enhanced street sweeping program)
- Potential future alum treatment in one of the basins of Forest Lake (if needed)

1. WORK PLAN & APPLICABLE REPORT SECTIONS

The focus of this Diagnostic Study and Implementation Plan is on protection efforts to maintain or improve the water quality of Forest Lake by reducing phosphorus loads to the lake, especially from storm water. The two main objectives of this project were to 1) compile and make minor updates to a large body of diagnostic work that already exists for Forest Lake, and 2) develop a comprehensive, site-specific implementation plan for Forest Lake. Implementation activities have been identified in the Forest Lake watershed as part of several independent studies. However, there exists a need to compile these implementation activities into one plan, fill any gaps in implementation activity identification, and develop a concise implementation schedule that targets projects with high phosphorus reduction cost-benefit and/or projects that can be implemented on a multi-subwatershed scale.

Objective & Task	Report Section
Objective 1. Develop a work plan	
Developed a comprehensive work plan, including milestone schedule and budget.	0
Objective 2. Collect field data	
Task A: Outfall/ tributary monitoring	
Compile list of known stormwater outfall locations based on City of Forest Lake data and input from the Forest Lake Association.	Appendix A.1
Conduct a field survey of major tributaries and stormwater outfalls to determine suitability of the channels for flow gauging and monitoring.	Appendix A.1
Flow will be monitored in 2016 (and 2017 if 2016 is a very dry year) via installation of a staff gauge and/or level logger to monitor water elevations and the development of a stage-discharge relationship (rating curve) at each site. It is estimated that up to 18 flow and water quality (total phosphorus, ortho-phosphorus and total iron) grab samples will be collected and evaluated at up to 12 sites during the spring snowmelt period and following summer rainfall events (dependent on flow conditions).	Appendix A.2
A quality assurance project plan (QAPP) will be developed before monitoring begins that presents policies, organization, objectives, and specific QA and quality control (QC) activities that when carried out will achieve the data quality needed.	On file at MPCA
Calculate outfall and tributary phosphorus loads to Forest Lake using the continuous flow record and water quality grab samples collected in 2016 (or 2017) and update watershed load and distribution of the 2007 Forest Lake diagnostic study.	0
Task B: Sediment release rate analysis	
Collect sediment samples at the deepest point in each of the three basins of Forest Lake and analyze for total phosphorus and iron-bound phosphorus.	2.2
Calculate the potential anoxic internal phosphorus load for each basin using Nurnberg regressions.	2.2
Task C: Modeling	
Re-calibrate the existing in-lake water quality model for Forest Lake with 2016 watershed and internal phosphorus loads.	2.5

Objective & Task	Report Section
Modify phosphorus load reductions needed to achieve the in-lake phosphorus concentration goal of 30 ppb, if needed.	2.5
Objective 3: Involve Stakeholders	
Task A: Solicit stakeholder feedback	
Identify stakeholder groups and gather contact information.	1.1
Gather feedback and input from stakeholders on the draft diagnostic report and proposed implementation plan development strategy.	1.1
Gather feedback and input from stakeholders on the preliminary cost-benefit ranking of identified implementation projects from the comprehensive implementation plan.	1.1
Task B: Ongoing stakeholder communication	
Ongoing communication with the City of Forest Lake regarding stormwater outfall locations and conditions, existing BMP phosphorus reduction benefits, and BMP opportunities within the municipal boundary.	1.1
Ongoing communication with the Forest Lake Association regarding stormwater outfall locations and conditions, BMP opportunities, and available BMP implementation funding.	1.1
Objective 4: Update Diagnostic Report	
Task A: Compile past reports	
Compile reports, data and analyses from past diagnostic studies for Forest Lake.	2.1
Task B: Write updated report:	
Update the compiled 2007 and other previous diagnostic reports with data collected in 2016.	0
Submit draft report to MPCA, CLFLWD, and stakeholders for review. Revise diagnostic report based on MPCA, CLFLWD, and stakeholder comments.	1.1
Objective 5: Develop implementation Plan	
Task A: Identify and rank BMPs:	
Compile implementation project information, costs, and phosphorus reduction benefits from past implementation plans for the Forest Lake watershed.	3.7
Identify priority management areas based on 2015 tributary load monitoring results, SWMM modeled subwatershed loads, and stakeholder input.	3
Identify new BMP implementation opportunities in priority management areas.	3
Develop a standardized BMP cost-benefit ranking system for potential phosphorus reduction implementation projects in the Forest Lake watershed.	3.8
Revise the BMP cost-benefit ranking system based on CLFLWD, and stakeholder comments.	3.8
Task B: Write implementation plan:	
Write an implementation plan report and submit draft report to MPCA, CLFLWD, and stakeholders for review.	3
Revise the implementation plan report based on MPCA, CLFLWD, and stakeholder comments.	1.1

1.1. Stakeholder Engagement

At the start of the project, we identified stakeholder groups to gather feedback and input on the draft diagnostic report and proposed implementation plan development strategy. Important stakeholder groups and their representatives are summarized in Table 1-1. Several meetings were held with the stakeholders, including several project update presentations to the Comfort Lake Forest Lake Watershed District Board, listed in Table 1-2.

Table 1-1. Forest Lake Diagnostic Stakeholders

Stakeholder Group	Individuals	Project Role
City of Forest Lake	Ryan Goodman, Tim Olson	Technical Advisory Committee
Forest Lake Lake Association	Doug Joens, Stev Stegner, Jerry Grundtner	Technical Advisory Committee
Comfort Lake Forest Lake Watershed District	Steve Schmaltz, Board Member Mike Kinney, District Administrator	Technical Advisory Committee
	Jackie Anderson, Board Member Jon Spence, Board Member Wayne Moe, Board Member Jackie Macnamara, Board Member	CLFLWD Board Member
CLFLWD Citizens Advisory Committee	Curt Sparks, Mark Peterson	Technical Advisory Committee
Washington Conservation District	Tara Kline, Bryan Pynn	Technical Advisory Committee

Table 1-2. Forest Lake Diagnostic Stakeholder Meetings

Date	Meeting Type and Location	Topic
October 12, 2015	TAC Meeting Watershed District Office, Forest Lake	Project goals and schedule Existing studies Outfall and tributary monitoring locations
January 28, 2016	CLFLWD Board Meeting City Hall, Forest Lake	Outfall and tributary monitoring locations
June 16, 2016		Preliminary 2016 monitoring loads
December 15, 2016		Final 2016 monitoring loads
April 26, 2017	TAC Meeting Watershed District Office, Forest Lake	2016 monitoring and updated modeling results Updated subwatershed load reduction goals Updated implementation plan priorities
October 26, 2017	CLFLWD Board Meeting/ TAC Meeting City Hall, Forest Lake	Draft diagnostic report and implementation plan

2. DIAGNOSTIC REPORT

2.1. Existing Studies

Forest Lake has been studied for decades due to its high recreational importance. Previous studies and important findings are summarized below:

MPCA Division of Water Quality (1969)

- Outlet structure constructed in Nov. 1953
- Pond at south end of SW FL44 served as a fish rearing pond for Northern Pike, operated by DNR
- Potassium endothall used in 1970 to control curlyleaf pondweed, another permit issued for 1971
- Wastewater from the Village of Forest Lake has discharged toward Rice Creek watershed since 1920
- Township of Forest Lake constructed a sewage collection and treatment system (ponds) to serve 243 homes on north side of Lakes 2 and 3 in NW part of FL44. Plant was to be abandoned after interceptor pipe to Metro WWTP was to be constructed in 1972.

Wenck Associates, Inc. (1987) Lake Diagnostic Feasibility Study for the Forest Lake Watershed Management Organization

- Recommended BMPs to prevent increased loading due to development, farm conservation plans, and golf course fertilization management plans (see Section 3.7 of this report)
- Recommended wetland treatment system on south side of Highway 97, near Iverson Avenue, via installation of a low weir to impound water in an adjacent wetland

Bruce Wilson (1990) Lake Water Quality Summary of Shields Lake, Bone Lake, Halfbreed Lake, and Forest Lake

- A reasonable phosphorus goal for Forest Lake during dry to median rainfall years is likely in the 35-45 ug/L range considering its morphometry and watershed land use.
- Based on 20 stream samples collected from Forest Lake Tributaries by the FLWMO in 1988, the average phosphorus concentration was 0.237 mg P/l. The runoff from the Forest Lake Watershed has greater phosphorus concentrations than typical “nonmetro” ecoregion lakes (0.158 mg P/l). MINLEAP predicted average phosphorus = 27 ug/l, observed phosphorus = 32-43 ug/l.
- Minimize impacts of increased urbanization using techniques such as sedimentation ponds, maintenance of wetlands, construction site BMPs, fertilizer management programs, and use of wetland treatment areas.

Orbita et al. (1990) Stable Isotopic Investigations as a Lake Management Tool in the Forest Lake Watershed of Minnesota

- Completed in 1990 by Scott Alexander, Calvin Alexander, and Doreen Orbita from the Geology Department at the U of M – Twin Cities, and Curt Sparks from HDR Engineering.

- A single measurement of a suite of cations, anions, and stable isotopes from wells surrounding Forest Lake and from the surface of Forest Lake, Keewahtin (Sylvan) Lake, and Clear Lakes was collected between 1989-1990 to identify areas of groundwater discharge into Forest Lake and recharge from the lake.
- Major conclusions from this report include:
  - Groundwater near Keewahtin (Sylvan) Lake flows southwest to northeast.
  - The ponds along TH 97 fed by Keewahtin (Sylvan) Lake provide significant seepage to Forest Lake. These ponds are acting as the discharge from Keewahtin (Sylvan) Lake and help prevent significant fluctuation in this otherwise landlocked lake.
  - Interaction between lake and groundwater in Forest Lake is minor

CLFLWD (2005) Hydraulic Capacity and Model Calibration Report

- This study identified 100-year floodplain and flood bounce through hydrology and hydraulics modeling and calibration.
- Redirection of approximately 400 acres to the FL44 wetland from the Little Comfort Lake Subwatershed was identified as a potential project.
- The FL63 wetland that serves as an outlet to Shields Lake was identified as a potential location for water quality management.

Wenck Associates, Inc. (2007) Watershed and Lake Water Quality Modeling Investigation for the Development of a Watershed Capital Improvement Plan

- Built the CLFLWD Watershed Loading and Lake Response Model, based on CLFLWD XP-SWMM H/H model flow estimates, unit area loads for non-point sources, shoreline septic loads, livestock loads, atmospheric loads, internal sediment loads, and the Canfield-Bachmann 1981 natural lakes phosphorus sedimentation model.
- Summarized water quality.
- Identified opportunities for improvement.
- Identified projects that impact water quality and prioritized in terms of results and cost effectiveness (see Section 3.7 of this report).
- Includes Keewahtin (Sylvan), Shields, and Forest (West, Middle, and East) Lakes.

2.2. Lake Characteristics

Physical Characteristics

Forest Lake is a deep lake with a maximum depth of 37 feet and a total surface area of 2,220 acres. Forest Lake is the largest lake in the CLFLWD and the largest lake wholly in Washington County (Table 2-1). Due to its shape, Forest Lake can be identified as having three basins: West (Lake 1), Middle (Lake 2), and East (Lake 3). Forest Lake has three public access sites and high recreational use. Forest Lake accepts stormwater discharge through a large number of stormsewer outfalls along the lake perimeter. Aquatic invasive species currently present in Forest Lake include: curlyleaf pondweed, Eurasian watermilfoil, flowering rush, and zebra mussels.

Table 2-1. Forest Lake physical characteristics by basin

Basin	Surface area (ac)	Mean depth (ft)	Volume (ac-ft)	Maximum depth (ft)
East	779	12.6	9,779	35
Middle	367	11.1	4,089	37
West	1,074	9.9	10,590	22
TOTAL	**2,220**	**11.0**	**24,458**	**37**

Fish Community

The 2007 CLFLWD Water Quality Investigation found:

- Forest Lake has the healthiest fish community of all lakes in the District. Top predator and panfish groups are well represented.
- Rough fish abundance in Forest Lake has been low in DNR surveys.

The most recent DNR fish survey was conducted on July 9, 2013 and found the following fishery status:

- Forest Lake is a popular Walleye and Muskellunge fishery for east Metro area anglers and is managed for:
  - Walleye stocked at 2.0 pounds of fingerlings per littoral acre (3,062 pounds) in odd numbered years.
  - Muskellunge stocked biennially in fall at a rate up to 1.5 fingerlings per littoral acre (2,296 fish).
  - A targeted survey in 2015 and 2016 found that Forest Lake contains an adult Muskellunge population of 179 individuals
- Fish species sampled in Forest Lake include: black crappie, bluegill, golden shiner, hybrid sunfish, largemouth bass, muskellunge, northern pike, pumpkinseed, rock bass, walleye, yellow bullhead, and yellow perch.
- No common carp were found during the survey

Upstream Shields Lake has a history of carp and winterkills. The 1982 DNR Fisheries Standard Survey noted that substantial numbers of young of the year carp were found. The 1985 DNR Fisheries Standard Survey noted Shields Lake probably sustains spawning runs of carp from Forest Lake, adult carp were observed but not captured, and the fish population is typical of frequent winterkills although none have been verified. In 1994, the lake was partially drawn down and treated with rotenone to kill all fish, followed by an alum treatment of unknown dose. The 1995 DNR Fisheries Standard Survey .Carp have been historically observed in Shields Lake. A winter aeration system has been in place since 1995. An electric fish barrier was installed at the outlet of Shields Lake in 19XX..

Aquatic Vegetation

The most recent point-intercept aquatic plant survey in Forest Lake was completed on July 11-12, 2013 by Steve McComas, Blue Water Science. Native plants grow out to a water depth of about 12 feet and cover approximately 1,173 acres (Figure 2-1). Forest Lake has a good diversity of aquatic plants, with 17 submerged species (includes curlyleaf pondweed) and two water lily species. The dominant plant in the survey was chara followed by coontail.

Forest Lake is delineated and treated annually for curlyleaf pondweed, Eurasian watermilfoil and flowering rush. Eurasian watermilfoil was first found in Forest Lake in 2015, therefore not identified in the 2013 point-intercept survey.

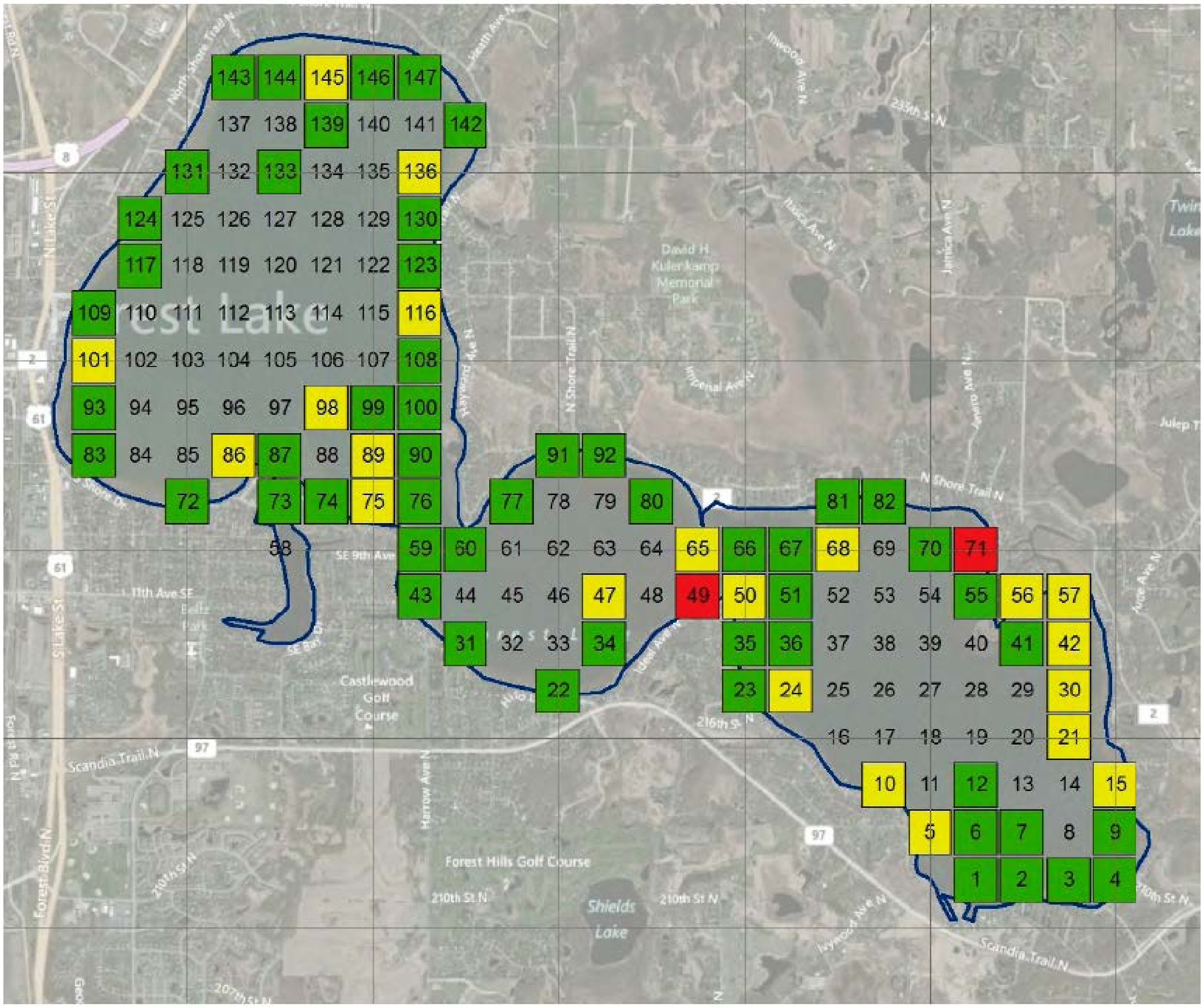


Figure 2-1. Native aquatic plant coverage of Forest Lake on July 11-12, 2013 (Figure S-1, Blue Water Science). Key: Green shading = light growth, yellow shading = moderate growth, and red shading = heavy growth.

Lake Sediment

Internal loading in lakes refers to the phosphorus load that originates in the bottom sediments or macrophytes and is released back into the water column. Internal loading can occur via:

1. Chemical release from the sediments: Caused by anoxic (lack of oxygen) conditions in the overlying waters or high pH (greater than 9). If a lake's hypolimnion (bottom area) remains anoxic for a portion of the growing season, the phosphorus released due to anoxia will be mixed throughout the water column when the lake loses its stratification at the time of fall mixing.
2. Physical disturbance of the sediments: Caused by bottom-feeding fish behaviors (such as carp and bullhead), motorized boat activity, and wind-driven mixing. This is more common in shallow areas of lakes.

Internal loading due to the anoxic release from the sediments of each basin was estimated based on the expected release rate of phosphorus from the lakebed sediment, the lake anoxic factor, and the lake area. Lake sediment samples were collected and tested for concentration of total phosphorus (TP) and bicarbonate dithionite extractable phosphorus (BD-P), which analyzes iron-bound phosphorus. Phosphorus release rates were calculated using statistical regression equations, developed using measured release rates and sediment P concentrations from a large set of North American lakes (Nürnberg 1988; Nürnberg 1996). Internal loading due to physical disturbance is difficult to reliably estimate and was therefore not included in the lake phosphorus analyses.

Lake sediment samples were collected from the top 10 cm of sediment at the deepest point in each basin of Forest Lake on October 15, 2015, and analyzed for total phosphorus, iron-adsorbed phosphorus, and percent organic matter. The average estimated total sediment phoshporus release rate estimated using the Nurnberg equations is summarized in Table 2-2. These estimates were used to determine acceptable calibration ranges for the BATHTUB model (see Section 2.5).

Table 2-2. Internal phosphorus load assumptions and summary

	Sediment P Concentration (mg/kg dry)		Organic Matter	Anoxic Factor	Estimated Total Sediment P Release Rate NA Lakes Dataset (mg/m^2-anoxic day)			Average Estimated Total Sediment P Release Rate NA Lakes Dataset
Basin	**Iron P (BD-P)**	**Total P (TP)**	**%**	**(days)**	**BD-P**	**TP**	**Average**	**(mg/m^2-calendar day)**
Forest East	402	3,900	10%	42	4.94	10.52	7.73	0.89
Forest Middle	1,024	1,900	10%	45	13.47	2.98	8.23	1.01
Forest West	716	1,300	9%	44	9.24	0.72	4.98	0.60

2.3. Water Quality

In-lake water quality has been monitored in Forest Lake since 1987. The CLFLWD annually summarizes in-lake water quality in the CLFLWD Water Monitoring report, available on the CLFLWD website. Growing season averages are illustrated by basin in Figure 2-2 (in-lake phosphorus), Figure 2-3 (chlorophyll-a), and Figure 2-4 (Secchi depth). Summer averages are shown in relation to the State standard for non-shallow lakes in the North Central Hardwood Forest Ecoregion, and the long-term (2040) District goals from the 2012-2021 CLFLWD Watershed Management Plan. The District goals for in-lake phosphorus concentration and Secchi depth for Forest Lake are listed in Table 2-3 and Table 2-4 below.

Figure 2-2 through Figure 2-4 depict the summer average water quality from 1993 through 2016. Each black circle represents the growing season (June – September) average total phosphorus concentration in the surface water of each basin. The solid red line denotes the state North Central Hardwood Forests lake water quality standard. Black circles above the red line exceed the state standard. The dashed red line denotes the District's long-term goal for Forest Lake based on a 5-year summer average. The solid blue line denotes the most recent 5-year average of the annual growing season average total phosphorus concentrations. When the blue line is above the dashed red line, the lake has not met the District goal.

The progress of Forest Lake, and upstream Keewahtin (Sylvan) and Shields Lakes, towards achieving their respective District 2020, 2030, and 2040 goals are shown for in-lake phosphorus in Table 2-3, and for Secchi depth in Table 2-4. The lakes are listed in order of increasing in-lake phosphorus concentration, and therefore, in order of achieving their respective District goals, from closest to furthest.

Trends in lake water quality data are summarized for each lake as part of the annual CLFLWD Water Monitoring Report prepared by the Washington Conservation District. Lake water quality trends for Forest Lake, and upstream Keewahtin (Sylvan) and Shields Lakes, are shown in Table 2-5 below, reproduced from Table 18 of the 2016 CLFLWD Water Monitoring Report. Keewahtin (Sylvan) Lake has improving (decreasing) phosphorus concentration, and improving (increasing) Secchi depth. Forest (Middle Basin) and Shields Lake have declining (increasing) phosphorus concentrations, and Forest (West Basin) and Shields Lakes have declining (decreasing) Secchi depth. Forest (East Basin) has no trend in (unchanging) water quality.

In general, water quality is better in the East and Middle basins compared to the West basin. The East and Middle basins have deeper average water depths than the West basin (Table 2-1), with shallower lakes typically having poorer water quality than deeper lakes.

Growing Season Average Total Phosphorus

Note that each black circle represents the growing season (June – September) average concentration. The solid red line denotes the state water quality standard. Black circles above the red line exceed the state standard. The dashed red line denotes the District's long-term 5-year average goal for Forest Lake. The solid blue line denotes the most recent 5-year average of the annual growing season average. When the blue line is above the dashed red line, the lake has not met the District goal.

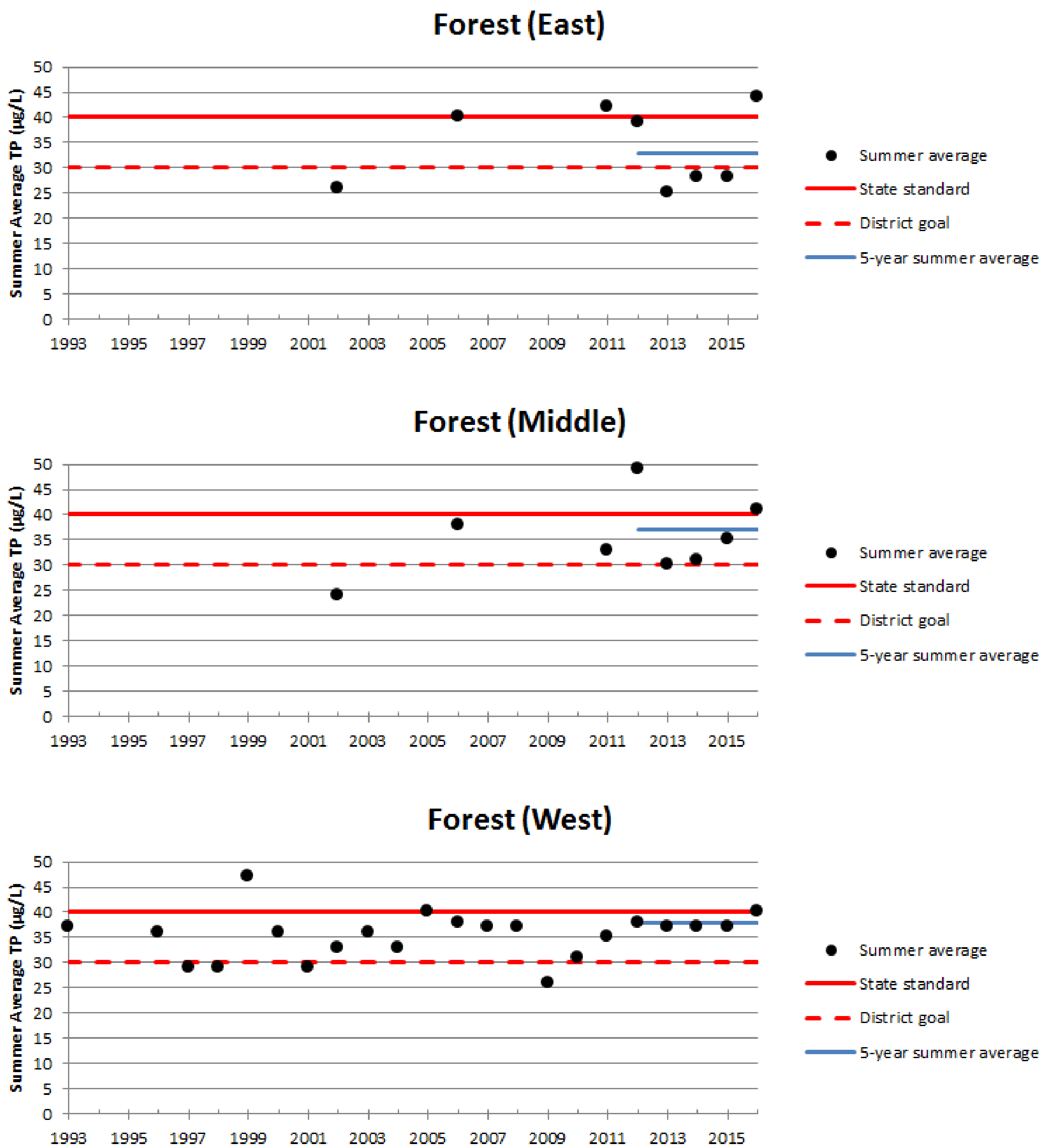


Figure 2-2. 1993-2016 annual growing season average in-lake phosphorus concentration by basin: Top graph - Forest (East), Middle graph - Forest (Middle), and Bottom graph – Forest (West)

Growing Season Average Chlorophyll-a (Algae)

Note that each black circle represents the growing season (June – September) average concentration. The solid red line denotes the state water quality standard. Black circles above the red line exceed the state standard. The dashed red line denotes the District's long-term 5-year average goal for Forest Lake. The solid blue line denotes the most recent 5-year average of the annual growing season average. When the blue line is above the dashed red line, the lake has not met the District goal.

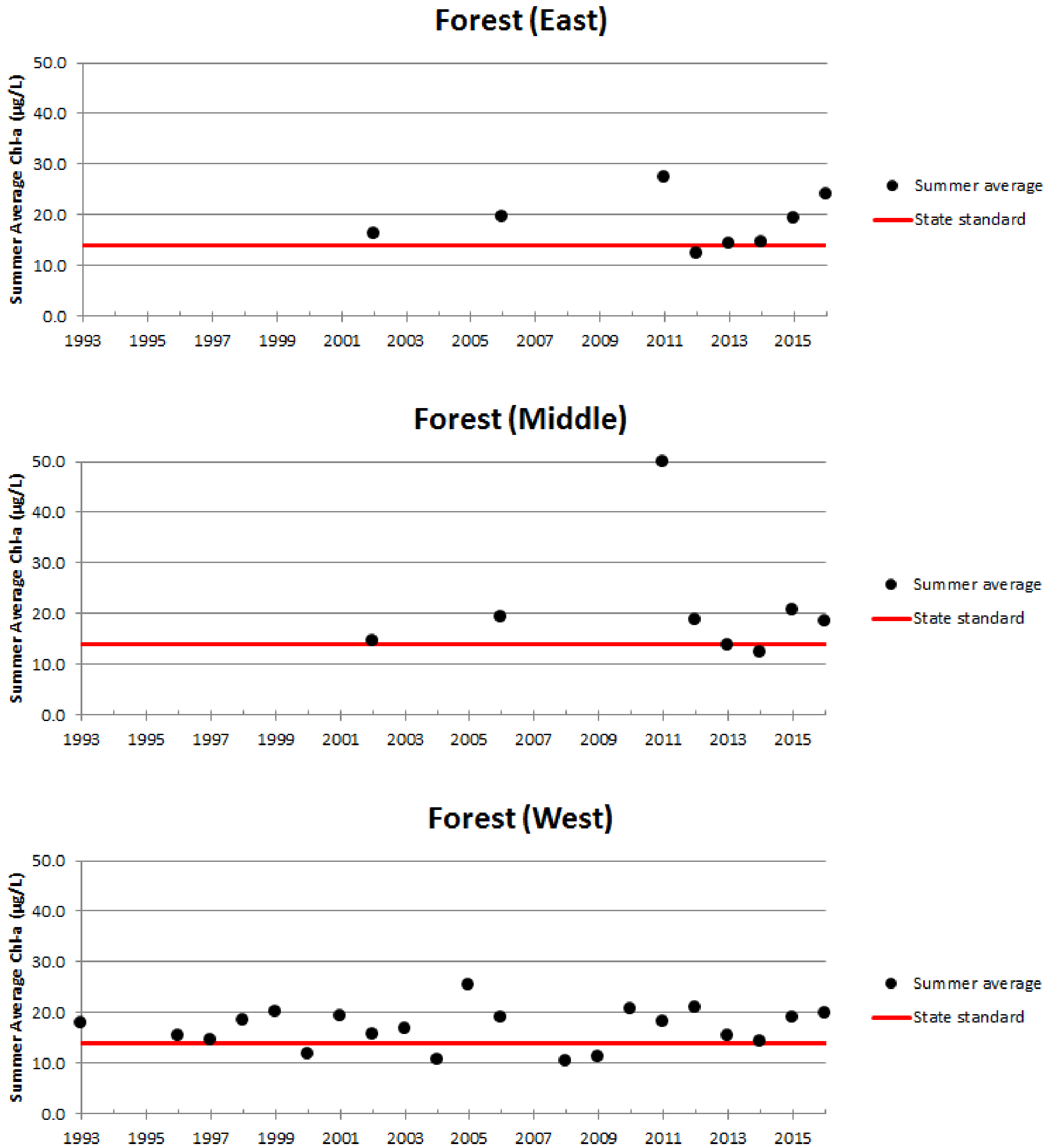
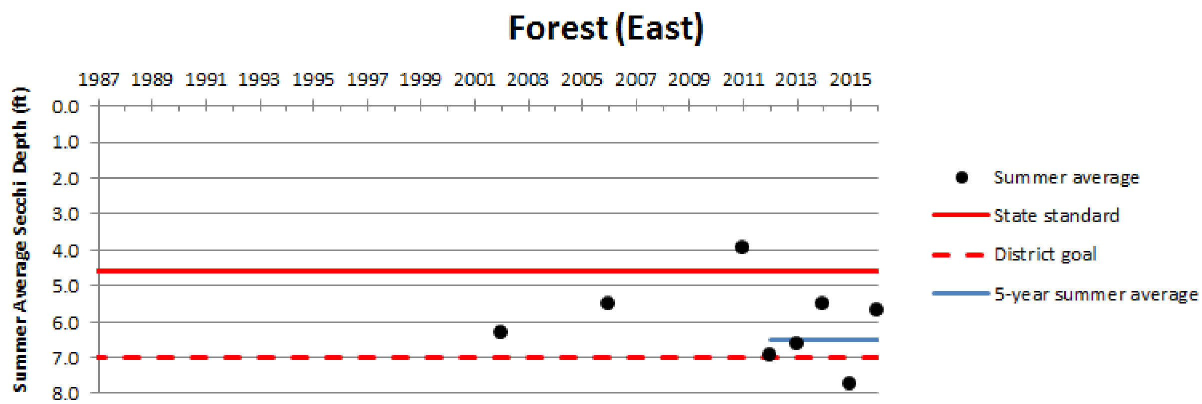
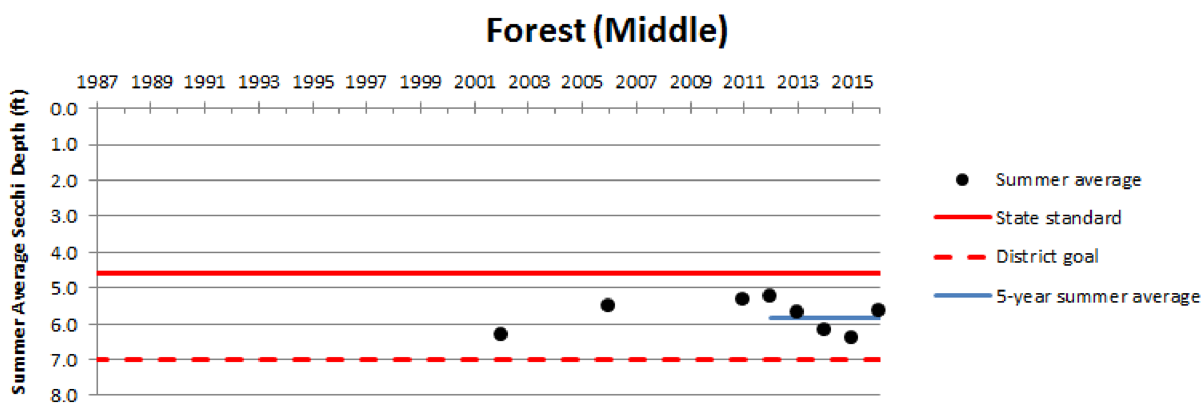


Figure 2-3. 1993-2016 annual growing season average chlorophyll-a concentration by basin: Top graph - Forest (East), Middle graph - Forest (Middle), and Bottom graph – Forest (West)

Growing Season Average Secchi Depth (Water Clarity)

Note that each black circle represents the growing season (June – September) average depth. The solid red line denotes the state water quality standard. Black circles above the red line exceed the state standard. The dashed red line denotes the District's long-term 5-year average goal for Forest Lake. The solid blue line denotes the most recent 5-year average of the annual growing season average. When the blue line is above the dashed red line, the lake has not met the District goal.





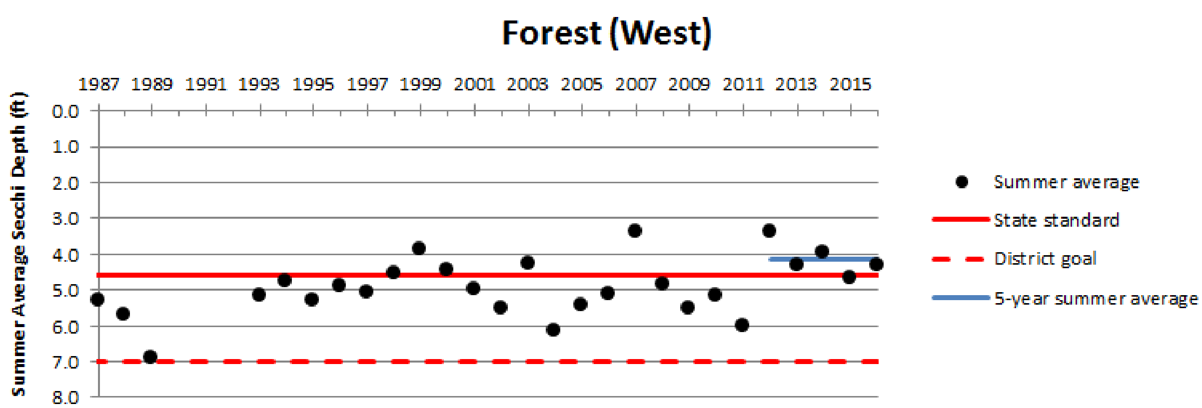


Figure 2-4. 1987-2016 annual growing season average Secchi depth by basin: Top graph - Forest (East), Middle graph - Forest (Middle), and Bottom graph – Forest (West)

Table 2-3. Progress towards District In-Lake Phosphorus Concentration goals

Lakes (in order of increasing TP)	In-Lake Phosphorus Concentration (µg/L)						
	10-Year Average		5-Year Average				
	2007-2016	Years of Data	Existing (2011-2016)	Years of Data	District Goal		
					2020	2030	2040
Keewahtin (Sylvan)	**16**	10	**16**	5	**20 ✓**	**20 ✓**	**20 ✓**
Forest	**35**	10	**36**	5	**37 ✓**	**37 ✓**	**30**
Forest East	**34**	6	**33**	5	**37 ✓**	**37 ✓**	**30**
Forest Middle	**37**	6	**37**	5	**37 ✓**	**37 ✓**	**30**
Forest West	**36**	10	**38**	5	**37**	**37**	**30**
Shields	**234**	6	**240**	5	**100**	**60**	**60**

✓ = meets District Goal; ## = does not meet District Goal

Table 2-4. Progress towards District Lake Secchi Depth Goals

Lakes (in order of increasing TP)	Secchi Depth (ft)						
	10-Year Average		5-Year Average				
	2007-2016	Years of Data	Existing (2011-2016)	Years of Data	District Goal		
					2020	2030	2040
Keewahtin (Sylvan)	**15.1**	10	**14.9**	5	**10 ✓**	**10 ✓**	**10 ✓**
Forest	**5.2**	10	**5.5**	5	**5 ✓**	**5 ✓**	**7**
Forest East	**6.1**	6	**6.5**	5	**5 ✓**	**5 ✓**	**7**
Forest Middle	**5.8**	6	**5.8**	5	**5 ✓**	**5 ✓**	**7**
Forest West	**4.6**	10	**4.1**	5	**5**	**5**	**7**
Shields	**3.4**	6	**3.3**	5	**4.26**	**4.26**	**4.26**

✓ = meets District Goal; ## = does not meet District Goal

Table 2-5. Lake Water Quality Trends (Table 18 from the 2016 CLFLWD Water Monitoring Report by WCD)

Lake	Acres	Secchi Disk Trend	Total Phosphorus Trend
Forest (West)	1,086	**Declining**	No Trend
Forest (Middle)	364	No Trend	**Declining**
Forest (East)	790	No Trend	No Trend
Shields	30	**Declining**	**Declining**
Keewahtin (Sylvan)	75	**Improving**	**Improving**

2.4. Watershed Phosphorus Loads

Monitoring Approach

One of the objectives of this diagnostic study was to spatially refine the watershed load estimates to Forest Lake through tributary monitoring. Continuous flow and water quality grab samples were collected at twelve locations in 2016 to quantify the phosphorus loads to Forest Lake. Continuous flow data was collected using a level logger, and instantaneous flow measurements were collected using a Marsh McBirney flow meter. A rating curve was developed for these sites using instantaneous flow measurements collected during water quality grab sampling events.

An ISCO sampler was installed at one outfall along the south shore of the West Basin to collect representative storm water quality from highly urbanized sites with flashy hydrology. At all other sites, water quality grab samples were collected into bottles following rainfall events. The water quality samples were analyzed for total phosphorus (TP), ortho-phosphorus (OP), and total suspended solids (TSS). Flow and water quality data were used as inputs to the FLUX32 model to estimate the total load discharged over the monitoring period.

Twelve tributaries and the Forest Lake outlet were monitored for continuous flow gauging and water quality grab sampling during the 2016 monitoring season (Figure 2-5). These 12 tributaries captured 65% of the total watershed area to Forest Lake (Table 2-6). An additional 7 tributaries were not suitable for continuous flow gauging, but were monitored for water quality grab samples (Table 2-7), and 5 subwatersheds were not monitored due to lack of an overland tributary (DD-W, DD-M, DD-E, R9, and R12). Unmonitored subwatershed flow and load estimates were based on the areal runoff depths and TP yields from nearby or similar subwatersheds, as indicated by the far right column of Table 2-7, multiplied by the area of the unmonitored subwatershed.

Results

The total phosphorus subwatershed yields were mapped to identify high phosphorus loading areas (Figure 2-6). In general, the watersheds to the West and Middle Basins, and the JD6 subwatershed, had the highest phosphorus yields. The East Basin watershed had much lower phosphorus yields due to less development, greater infiltration, and subsurface groundwater flow.

Watershed loads to Forest Lake have been estimated as part of several efforts over the last 30 years. First, tributary and outfall monitoring of flow and phosphorus concentration was conducted as part of the 1987 diagnostic study. Next, watershed loads were estimated based on land use export coefficients as part of the 2007 CIP model, and a PC-SWMM model as part of the District's H&H model. Most recently, watershed loads were estimated for the direct drainage area by the Washington Conservation District using WinSLAMM.

The phosphorus yields (lb TP per acre per year) based on the 2016 monitoring were compared with the 2007 SWMM (Figure 2-7) and 2014-2015 WinSLAMM (Figure 2-8) phosphorus yield estimates. Compared to the 2016 monitoring data, the SWMM and WinSLAMM models tended to overpredict phosphorus yields from the Cranberry and Keewahtin (Sylvan) Lake subwatersheds,, which are depressional with subsurface groundwater flow, and underpredict phosphorus yields from the direct drainage area, with mostly overland flow.

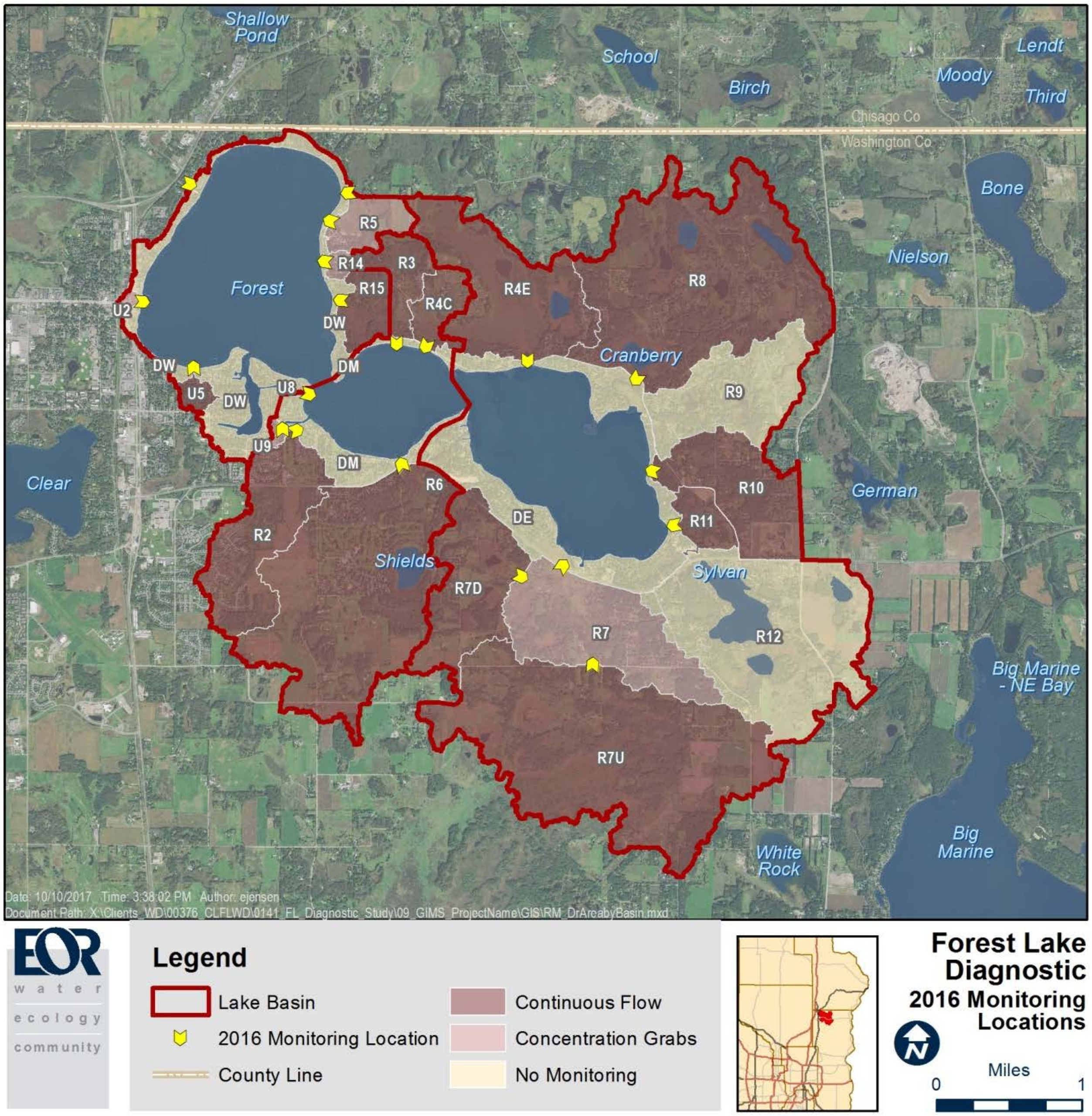


Figure 2-5. 2016 Forest Lake drainage areas by basin and monitoring type.

Monitoring location site names are based on the 1987 Diagnostic study nomenclature (Figure 3-15 in Appendix A). U = urban, R = rural.

Table 2-6. 2016 monitored subwatershed flow and load estimates (based on 2016 monitoring data)

Subwatershed	Basin	Drainage Area (ac)	Annual Flow (ac-ft/yr)	FWMC TP (ppb)	Annual TP Load (lb/yr)
U5	West	31.0	32.0	233	18.2
R2	Middle	401.4	265.2	283	127.6
R6	Middle	1,038.6	955.2	264	686.6
R7d	East	377.1	183.7	171	85.5
R7u	East	1,329.3	929.4	201	507.4
R11	East	87.0	55.0	143	21.2
R10	East	340.9	62.3	188	31.8
R8	East	1,108.5	292.2	80	62.9
R4E	East	513.5	312.0	88	74.2
R4C	Middle	103.0	9.7	239	6.2
R3	Middle	127.1	56.8	397	60.8
R15	West	103.9	44.9	335	40.6
SUBTOTAL (% total)		**5,561.3 65%**	**3,198.5 69%**		**1,723.0 69%**

Table 2-7. Unmonitored subwatershed flow and load estimates (based on 2016 monitoring data)

Subwatershed	Basin	Drainage Area (ac)	Annual Flow (ac-ft/yr)	FWMC TP (ppb)	Annual TP Load (lb/yr)	Based on Monitored Subwatersheds:
R4W	West	129.0	56.7	363	56.0	R3 & R5S
U9	Middle	12.8	8.5	177	4.1	Castle East
R14	West	20.1	8.8	363	8.7	R3 & R5S
R7	East	484.8	287.6	189	147.5	R7d & R7u
U2	West	8.8	9.1	209	5.2	U5
U8	West	1.6	1.7	209	0.9	U5
R5	West	109.3	48.1	363	47.5	R3 & R5S
DD-W	West	357.3	368.9	209	209.3	U5
DD-M	Middle	158.6	104.8	177	50.4	Castle East
DD-E	East	453.2	286.5	142	110.6	R11
R9	East	366.8	67.0	188	34.2	R10
R12	East	886.9	162.1	188	82.7	R10
SUBTOTAL (% total)		**2,989.2 35%**	**1,409.7 31%**		**757.1 31%**	

Table 2-8. 2016 subwatershed flow and TP load estimates by basin

Subwatershed	Drainage Area		Annual Flow		Annual TP Load	
	(ac)	% total	(ac-ft/yr)	% total	(lb/yr)	% total
WEST BASIN						
DD-W	357.3	4.2%	368.9	8.0%	209.3	8.4%
R4W	129.0	1.5%	56.7	1.2%	56.0	2.3%
R5	109.3	1.3%	48.1	1.0%	47.5	1.9%
R15	103.9	1.2%	44.9	1.0%	40.6	1.6%
U5	31.0	0.4%	32.0	0.7%	18.2	0.7%
R14	20.1	0.2%	8.8	0.2%	8.7	0.4%
U2	8.8	0.1%	9.1	0.2%	5.2	0.2%
U8	1.6	0.02%	1.7	0.04%	0.9	0.04%
TOTAL	**761.0**	**8.9%**	**570.3**	**12.4%**	**386.4**	**15.6%**
MIDDLE BASIN						
R6	1,038.6	12.1%	955.2	20.7%	686.6	27.7%
R2	401.4	4.7%	265.2	5.8%	127.6	5.1%
R3	127.1	1.5%	56.8	1.2%	60.8	2.5%
DD-M	158.6	1.9%	104.8	2.3%	50.4	2.0%
R4C	103.0	1.2%	9.7	0.2%	6.2	0.3%
U9	12.8	0.1%	8.5	0.2%	4.1	0.2%
TOTAL	**1,841.5**	**21.5%**	**1,400.2**	**30.4%**	**935.7**	**37.7%**
EAST BASIN						
R7u	1,329.3	15.5%	929.4	20.2%	507.4	20.5%
R7	484.8	5.7%	287.6	6.2%	147.5	5.9%
DD-E	453.2	5.3%	286.5	6.2%	110.6	4.5%
R7d	377.1	4.4%	183.7	4.0%	85.5	3.4%
R12	886.9	10.4%	162.1	3.5%	82.7	3.3%
R4E	513.5	6.0%	312.0	6.8%	74.2	3.0%
R8	1,108.5	13.0%	292.2	6.3%	62.9	2.5%
R9	366.8	4.3%	67.0	1.5%	34.2	1.4%
R10	340.9	4.0%	62.3	1.4%	31.8	1.3%
R11	87.0	1.0%	55.0	1.2%	21.2	0.9%
TOTAL	**5,948.0**	**69.6%**	**2,637.7**	**57.2%**	**1,158.0**	**46.7%**
WHOLE LAKE	**8,550.5**		**4,608.1**		**2,480.1**	

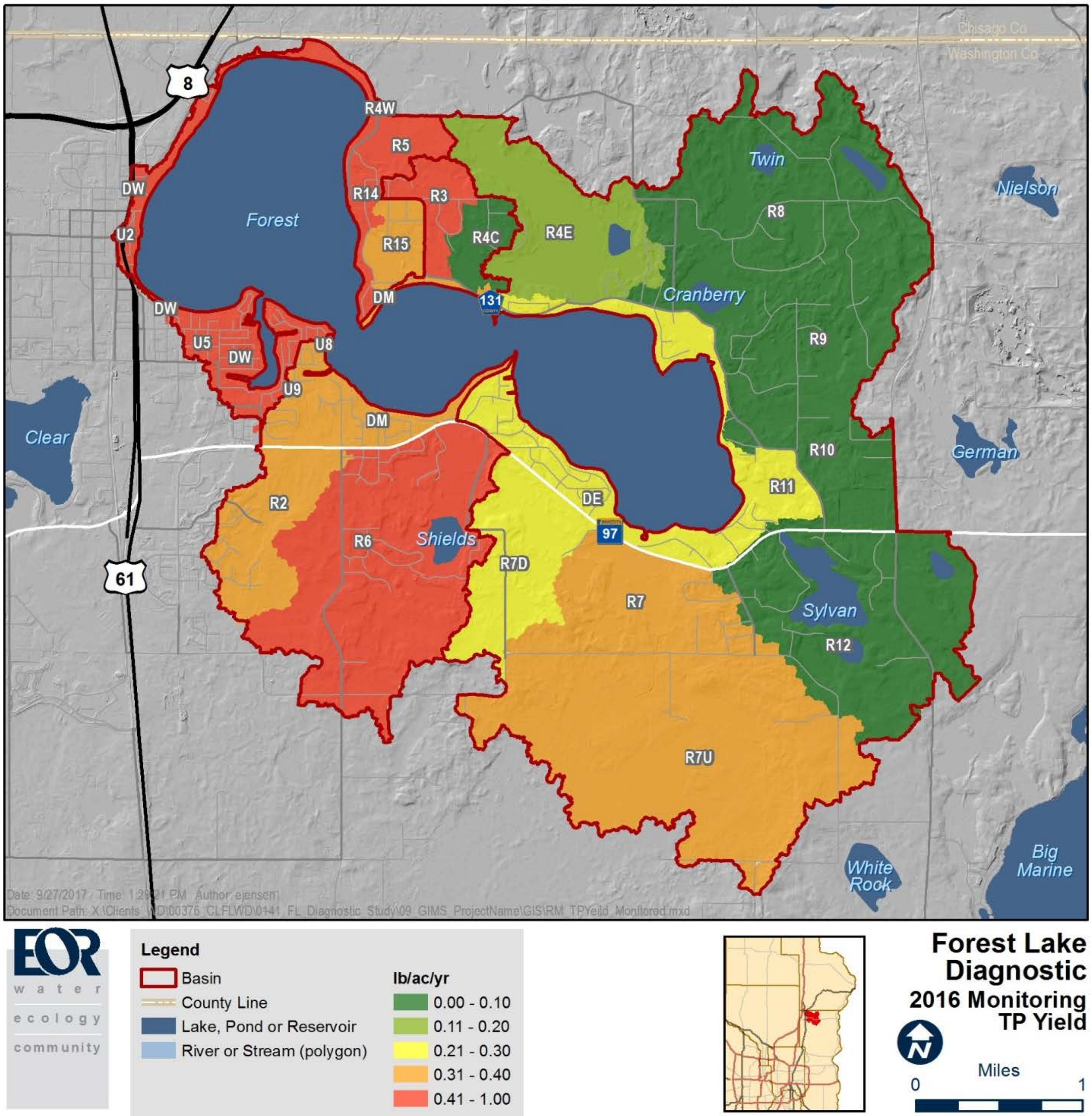


Figure 2-6. 2016 Monitoring TP Yields by Subwatershed

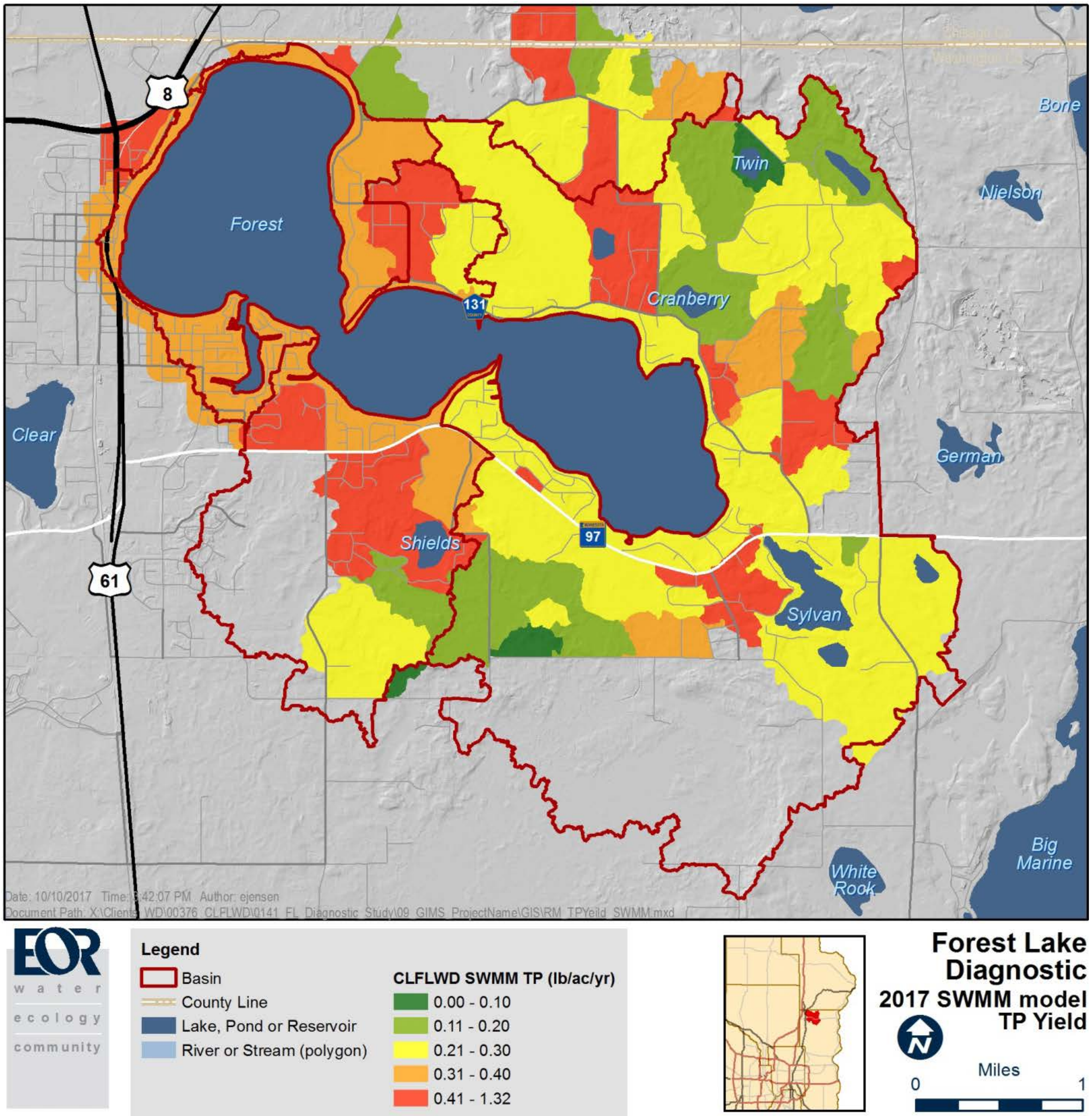


Figure 2-7. 2007 CLFLWD SWMM TP Yields by Subwatershed

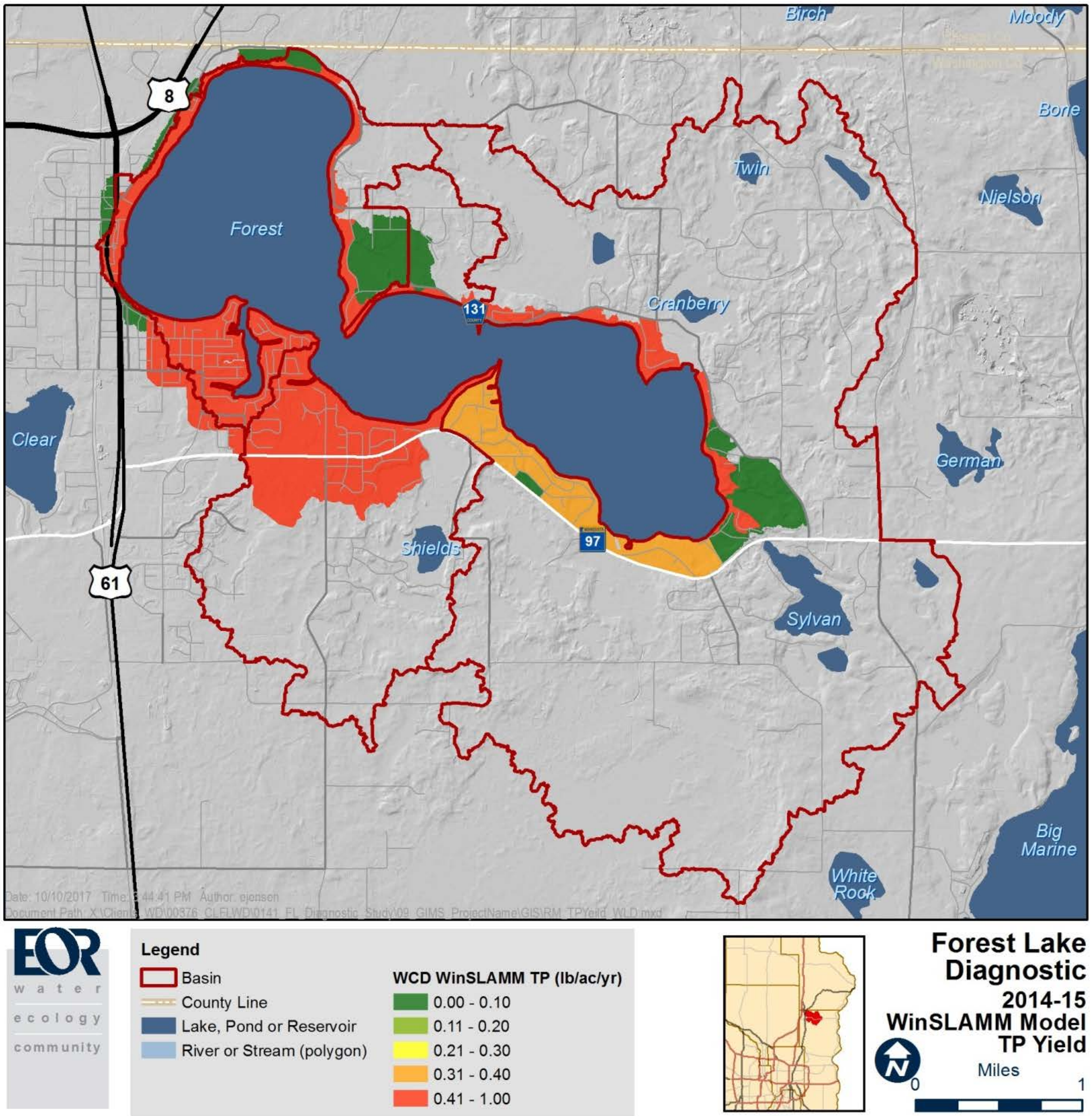


Figure 2-8. 2014-2015 Washington Conservation District WinSLAMM TP Yields by Subwatershed

2.5. Phosphorus Load Reduction Goals

The modeling software BATHTUB (Version 6.1) was selected to link phosphorus loads with in-lake water quality. A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). It has been used successfully in many lake studies in Minnesota and throughout the United States. BATHTUB is a steady-state annual or seasonal model that predicts a lake's summer (June through September) mean surface water quality. BATHTUB's time-scales are appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health. The heart of BATHTUB is a mass-balance phosphorus model that accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and groundwater; and outputs through the lake outlet, water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

In typical applications of BATHTUB, lake and reservoir systems are represented by a set of segments and tributaries. Segments are the basins (lakes, reservoirs, etc.) or portions of basins for which water quality parameters are being estimated, and tributaries are the defined inputs of flow and pollutant loading to a particular segment. For this study, each lake basin was represented as a separate segment, and each phosphorus source was represented as individual tributaries to each basin (i.e., the segment). BATHTUB allows a choice among several different phosphorus sedimentation models. The Canfield-Bachmann phosphorus sedimentation model (Canfield and Bachmann 1981) best represents the lake water quality response of Minnesota lakes and is commonly used for lake water quality and TMDL studies.

The input required to run the BATHTUB model includes lake geometry (Table 2-1), climate data (Table 2-10), and water quality and flow data for phosphorus sources to the lake (Table 2-12 through Table 2-14). Climate and groundwater data were based on the 2007 CLFLWD Capital Improvement Plan Lake Response Model (http://www.clflwd.org/documents/CLFLWDWQStudy-CIPPlan_Wenck_2007.pdf). Existing watershed phosphorus loads were based on the 2016 monitoring data.

Some amount of internal loading is implicit in the BATHTUB lake water quality model; therefore, internal loading rates added to the BATHTUB model during calibration represents the excess sediment release rate beyond the average background release rate, accounted for by the model development lake dataset. The implicit amount of internal loading in BATHTUB is typically smaller than the calibrated BATHTUB rates for shallow lakes because the BATHTUB model development lake dataset is less representative of this lake type, and therefore accounts for less implicit internal loading in shallow lakes. Shallow lake sediments can easily be disturbed by wind-driven mixing of the water column or physical disturbance from boats and carp.

The Forest Lake BATHTUB model was calibrated to the 2012-2016 growing season average total phosphorus concentration (Table 2-9). When the predicted in-lake total phosphorus concentration is lower than the average observed (monitored) concentration, an explicit additional load is added to calibrate the model. When the predicted in-lake total phosphorus concentration is higher than the observed (monitored) concentration, the TP sedimentation rate (or treatment capacity of the lake) is increased.

The East and Middle basins were overpredicted for in-lake phosphorus concentrations and therefore the phosphorus sedimentation factor (the amount of phosphorus from the watershed that settles to the lake bottom without flowing downstream) was increased (Table 2-9). The West basin was underpredicted for in-lake phosphorus concentration and therefore an additional load, likely internal, was added to the West Basin.

To determine the phosphorus load reduction goals for Forest Lake, all FWMC TP greater than 150 ppb were reduced to 150 ppb in BATHTUB (see Table 2-12 through Table 2-14). With all tributaries achieving a phosphorus concentration goal of less than 150 ppb, all 3 basins would be very close to the long-term District goal of 30 ppb without any further reductions from internal loading.

Table 2-9. Basin calibration and observed, predicted, and goal scenario in-lake TP concentrations

Basin	Calibration	Observed In-lake TP (ppb)	Predicted In-lake TP (ppb)	Goal Scenario In-lake TP (ppb)	In-lake TP % Reduction to Meet Goal
East (3rd)	Increase P sedimentation by 1.55x	32.4	32.4	27.6	15%
Middle (2nd)	Increase P sedimentation by 1.4x	35.6	35.7	29.2	18%
West (1st)	0.262 mg/m2-day excess internal load	36.8	36.8	31.0	16%
Area Weighted Average		**35.1**	**35.0**	**29.5**	**16%**

Table 2-10. BATHTUB climate inputs (from the 2007 CLFLWD CIP Lake Response Model)

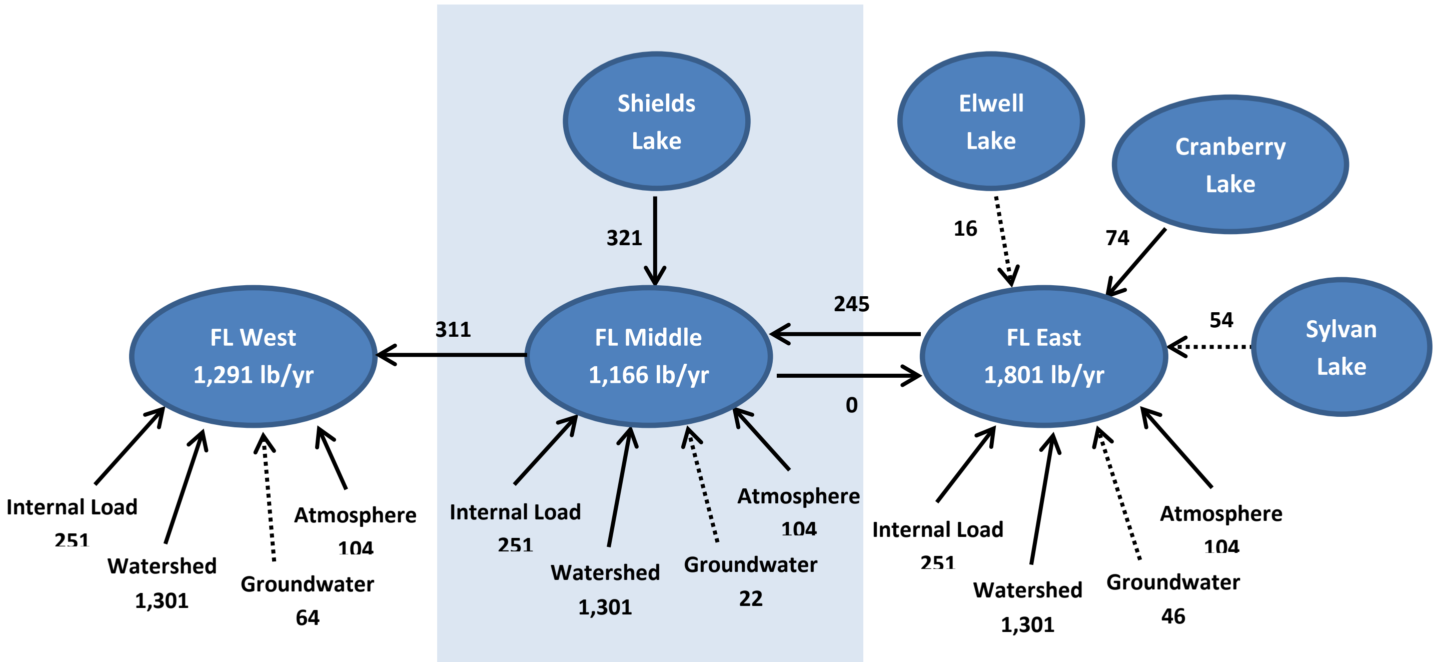
Parameter	Value
Precipitation	25.84 in/yr
Evaporation	28.65 in/yr
Atmospheric Deposition	0.12 kg/ha/yr

Table 2-11. 2016 Updated Existing Phosphorus Loads by Lake Basin

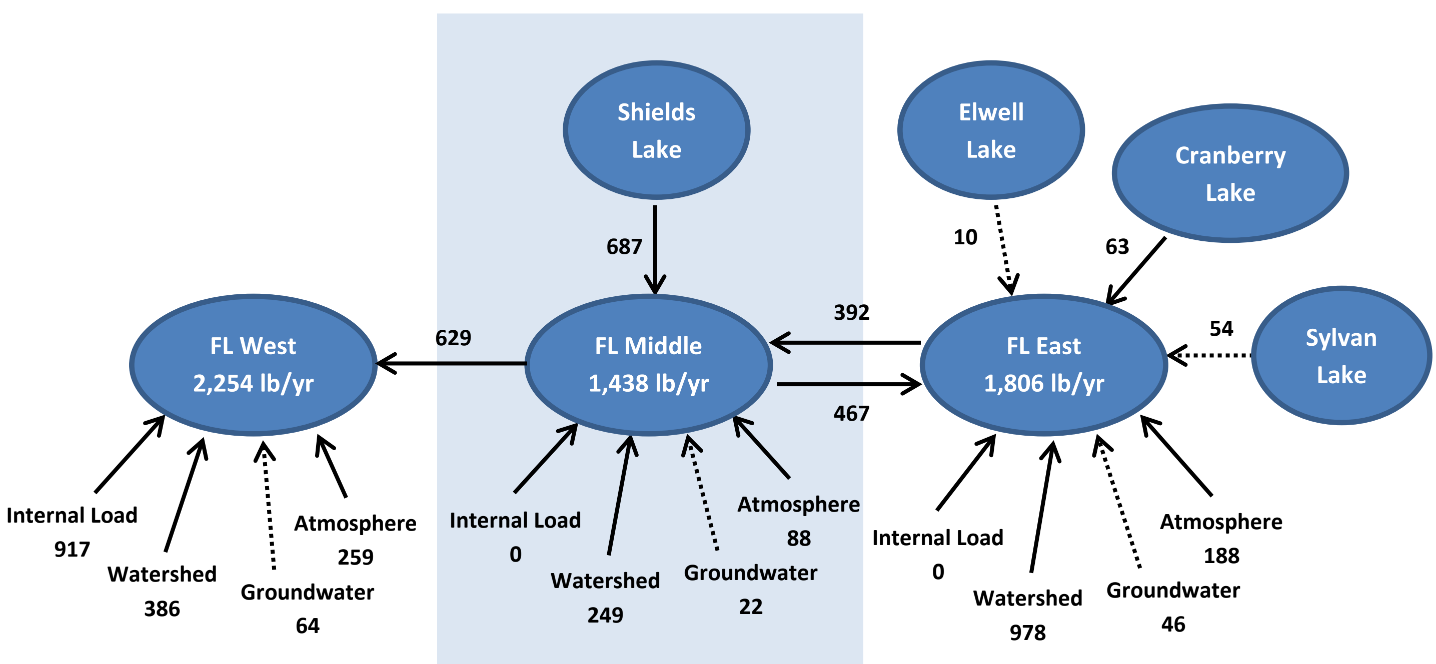
Phosphorus Source	Forest Lake East		Forest Lake Middle		Forest Lake West	
	lb/yr	% total	lb/yr	% total	lb/yr	% total
Atmospheric Deposition	188	*10%*	88	*6%*	259	*11%*
Watershed Runoff	978	*54%*	249	*17%*	386	*17%*
Excess Internal Load	0	*0%*	0	*0%*	917	*41%*
Groundwater	46	*3%*	22	*2%*	64	*3%*
Upstream Lakes	127	*7%*	687	*48%*		
Net Diffusive/Advective Inflow**	467	*26%*	392	*27%*	629	*28%*
Total	**1,806**		**1,438**		**2,505**	

* This represents the net flow of phosphorus between the Forest Lake Basins. That is to say the exchange of water between basins.

2007 Modeled Existing Phosphorus Loads



2016 Monitored Existing Phosphorus Loads



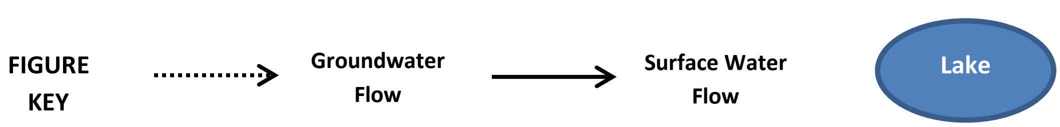


Table 2-12. Forest Lake East BATHTUB existing and goal tributary inputs

Forest Lake – East	Flow (hm3/yr)	Existing TP (ppb)	Goal TP (ppb)	TP Reduction %	TP Reduction (lb/yr)	Implementation Area
DD-E	0.3533	142.01	142.01	0%		
R8	0.3603	79.21	79.21	0%		
R4E	0.3847	87.51	87.51	0%		
R7	0.3545	188.72	150.00	21%	30	JD6 Subwatershed
R7d	0.2265	171.32	150.00	12%	11	
R7u	1.1460	200.85	150.00	25%	128	
R9 (Groundwater)	0.0826	55.90	55.90	0%		
R10	0.0768	187.63	150.00	20%	6.4	3rd Lake Pond
R11	0.0678	142.01	142.01	0%		
Keewahtin (Sylvan) (R12) Groundwater	0.8094	30.00	30.00	0%		
Regional Groundwater	0.3763	55.91	55.91	0%		

Table 2-13. Forest Lake Middle BATHTUB existing and goal tributary inputs

Forest Lake – Middle	Flow (hm3/yr)	Existing TP (ppb)	Goal TP (ppb)	TP Reduction %	TP Reduction (lb/yr)	Implementation Area
DD-M	0.1292	176.95	150.00	15%	7.7	Direct Drainage
R2	0.3270	176.95	150.00	15%	19	Castlewood
U9	0.0104	176.95	150.00	15%	0.6	
R3	0.0701	393.48	150.00	62%	38	Hayward Ave.
R4C	0.0119	236.97	150.00	37%	2.3	Hayward Ave.
R6	1.1778	264.43	60.00	77%	531	Shields Lake
Regional Groundwater	0.1775	55.90	55.9	0%		

Table 2-14. Forest Lake West BATHTUB existing and goal tributary inputs

Forest Lake – West	Flow (hm3/yr)	Existing TP (ppb)	Goal TP (ppb)	TP Reduction %	TP Reduction (lb/yr)	Implementation Area
DD-W	0.4549	208.73	150	28%	59	Direct Drainage
U2	0.0112	208.73	150	28%	1.5	
U5	0.0395	208.73	150	28%	5	
U8	0.0020	208.73	150	28%	0.3	
R14	0.0109	363.35	150	59%	5	Hayward Ave.
R4W	0.0699	363.35	150	59%	33	
R5	0.0593	363.35	150	59%	28	
R15	0.0554	332.21	150	55%	22	
Regional Groundwater	0.5190	55.91	55.91	0%		

Load Reduction Scenarios

Phosphorus reductions are needed from six implementation areas of Forest Lake to achieve the District long-term water quality of less than 30 ug/L summer average phosphorus concentration in all 3 basins, listed counterclockwise beginning from the Forest Lake Outlet:

1. Direct Drainage Area – U2, U5, U8, DD-W, DD-M, and DD-E subwatersheds
2. Castlewood – U9 and R2 subwatersheds
3. Shields Lake – R6 subwatershed
4. Judicial Ditch 6 – R7, R7u, R7d subwatersheds
5. 3rd Lake Pond – R10 subwatershed
6. Hayward Avenue – R5, R14, R15, R4C, and R4E subwatersheds

These are based on the reduction scenario shown in Table 2-12 through Table 2-14 which assumes all tributaries discharging to any of the three basins to Forest Lake achieve a flow weighted mean concentration of 150 ppb or less. A summary of the total reductions needed by Implementation Area and Basin with the predicted in-lake phosphorus concentration by Basin are summarized in Table 2-15 and Figure 2-9. Total phosphorus reductions needed for all 3 basins of Forest Lake is 923 lb/yr.

However, implementation and tributary load reductions may not be distributed evenly among the three basins due to project constraints such as site suitability, cost, and landowner willingness. One alternative load reduction scenario is that all of the excess internal load in Forest Lake is reduced (917 lb/yr) without any watershed load reductions. Under this scenario, BATHTUB predicted the East and West Basins would achieve an in-lake phosphorus concentrations of 29 ppb, and the Middle Basin an in-lake phosphorus concentration of 31 ppb. Another alternative load reduction scenario is that 33% of the total load reductions needed are achieved from watershed load reductions to the East Basin only (or 375 lb/yr through implementation in the JD-6 and 3rd Lake Pond Implementation Areas) with 50% of the excess internal load reduced (or 459 lb/yr). Under this scenario, BATHTUB predicted the Middle and West Basins would achieve in-lake phosphorus concentrations of 31 ppb and the East basin would achieve an in-lake phosphorus concentration of 28 ppb.

Table 2-15. Load reduction scenario based on all tributaries achieving 150 ppb or less

Basin	Existing In-lake Phosphorus Concentration (ppb)	Implementation Area	Annual TP Reduction Needed (lb/yr)	Predicted In-lake Phosphorus Concentration (ppb)
East (3rd Lake)	32.4	JD-6	169	27.6
		3rd Lake Pond	6.4	
		TOTAL	**175**	
Middle (2nd Lake)	35.6	Shields Lake	531	29
		Hayward Ave.	40	
		Castlewood	20	
		Direct Drainage area	7.7	
		TOTAL	**599**	
West (1st Lake)	36.8	Hayward Ave.	83	31
		Direct Drainage Area	66	
		TOTAL	**149**	
TOTAL			**923**	

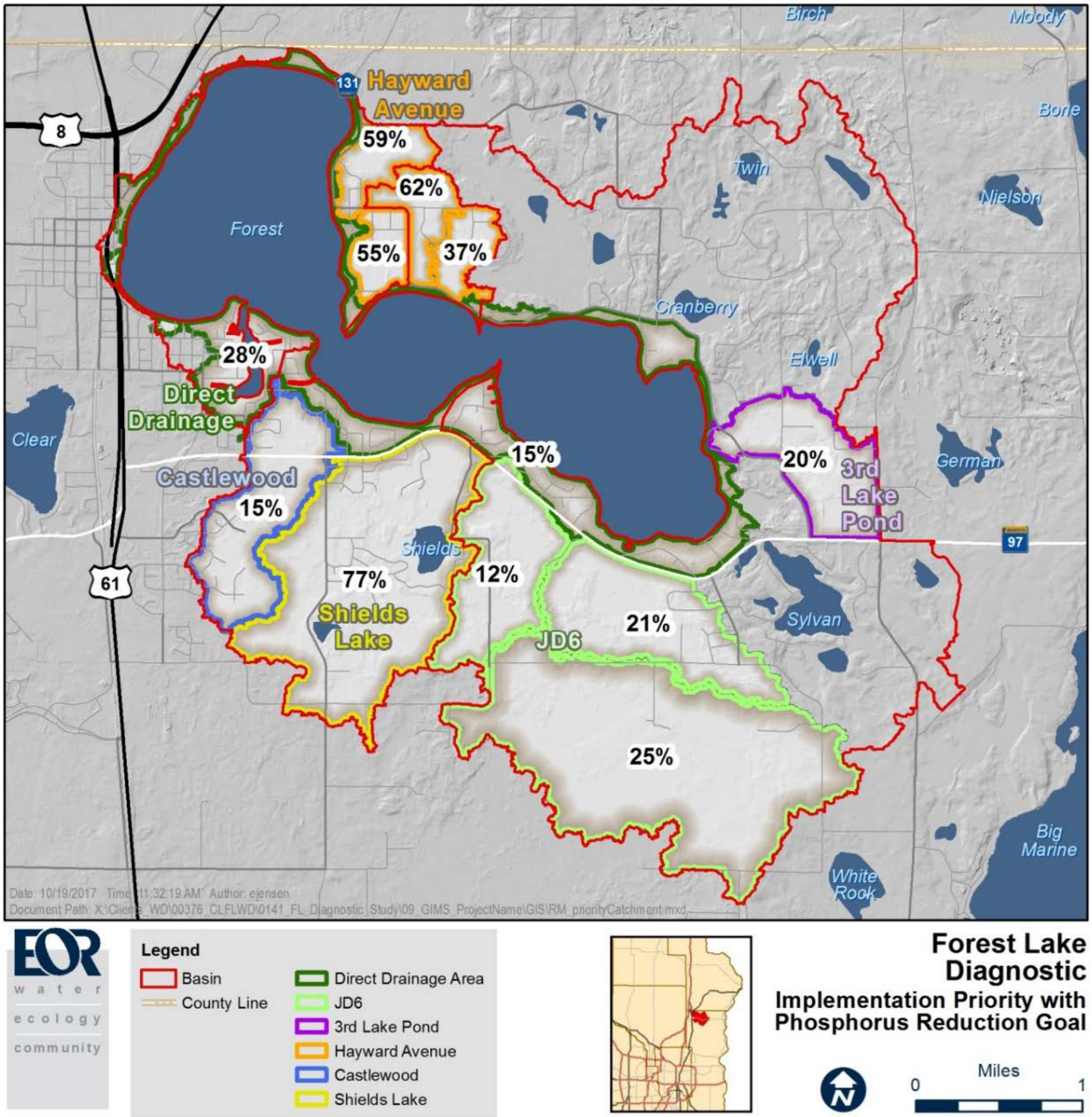


Figure 2-9. Implementation priority areas and phosphorus reduction goals

3. IMPLEMENTATION PLAN

The overall implementation strategy of the District is a five-phase adaptive management approach:

1. **Targeted Tributary Monitoring:** Targeted tributary monitoring is sequential monitoring along tributaries to target sources of high phosphorus loads on the landscape. Tributary monitoring is useful for identifying legacy phosphorus loads that may otherwise be hidden based on existing land uses and practices, and refining watershed loading estimates that were previously based on regional land use averages. The outcome of this phase is a refined understanding of the distribution of watershed phosphorus sources on the landscape.
2. **Diagnostic Modeling Report:** A diagnostic model is used to calibrate monitored watershed loads with other known phosphorus loads (such as atmospheric deposition, point sources, and internal load) and observed in-lake conditions. In addition, the model is used to determine the reductions needed from each phosphorus source to achieve District goals. The outcome of this phase is a refined estimate of the distribution of the total phosphorus load among all sources, and reductions needed.
3. **Project Feasibility & Planning:** A BMP feasibility study is completed to identify the most cost-effective practices to reduce phosphorus from the landscape and other sources. These studies typically require field reconnaissance, hydraulic and hydrologic modeling, engineering cost estimates, and coordination with landowners and stakeholders. The outcome of this phase is a cost-benefit ranking of potential projects, 30% plans for the highest ranked projects, preliminary landowner agreements, and grant writing for implementation funding.
4. **Project Design & Implementation:** Project design and implementation can begin once funding and landowner agreements have been secured, and includes 60% and final plans, permitting and coordination with regulatory agencies, project bidding, and construction oversight. The outcome of this phase is the construction or implementation of practices.
5. **Project Effectiveness Monitoring:** Following construction of phosphorus reduction practices, monitoring of influent and effluent flows and phosphorus concentrations for the project is needed to determine the effectiveness of the project. Once a significant number of practices have been implemented, the adaptive management approach restarts with targeted tributary monitoring to identify any new or remaining phosphorus hotspots and determine additional reductions needed for lake resources to meet District goals.

The following implementation plan outlines recommendations for utilizing this adaptive management plan in each of the six priority implementation areas identified in Forest Lake (Figure 2-9). A summary of the current progress and proposed timeline for these priority implementation subwatersheds is provided in Table 3-1. For each subwatershed in the following section, the report provides:

- Map of the subwatershed
- Summary of the phosphorus load reduction goals from Section 2.5
- Adaptive management approach progress and timeline details
- Implementation recommendations for achieving the phosphorus load reduction goals

Table 3-1. Adaptive Management Approach Progress and Timeline for Priority Implementation Subwatersheds

Subwatershed	Targeted Tributary Monitoring	Diagnostic Modeling Report	Project Feasibility & Planning	Project Design & Implementation	Project Effectiveness Monitoring
Direct Drainage	✓	✓	✓	2018 –	2021-2022
Castlewood	2017-2018	2018	2018-2019	2019-2020	2021-2022
Shields Lake	✓	✓	✓	2018-2019	2020
Judicial Ditch 6	2017-2018	2018	2018-2019	2019-2024	2020-2026
3rd Lake Pond	✓	✓	✓	2017-2018	2017-2018
Hayward Avenue	2018	2018	2018-2019	2019-2021	2020-2023

3.1. Direct Drainage Area

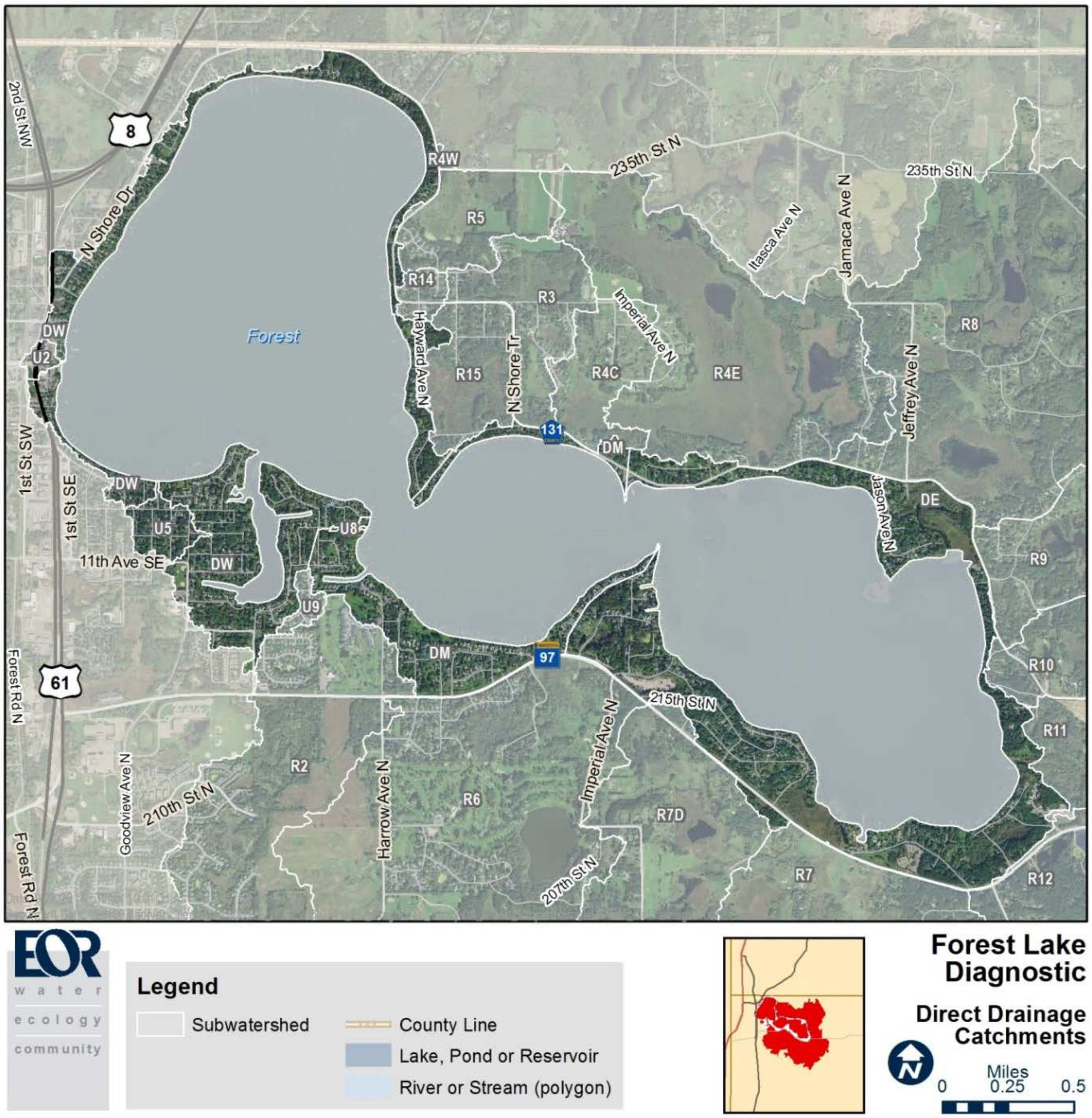


Figure 3-1. Direct Drainage Subwatershed Location

Diagnostic Summary

As a percent of the total for Forest Lake, the direct drainage area contributes:

- 12 percent of the total drainage area
- 17 percent of the total flow
- 16 percent of the total phosphorus load

The existing TP FWMCs were 142-209 ppb, with a **0-28% reduction needed** to achieve the TP FWMC goal of less than 150 ug/L.

Implementation Recommendations

Table 3-2. Direct Drainage Subwatershed Implementation Progress & Timeline

Adaptive Management Phase	Direct Drainage Area Implementation Progress	Timeline
Targeted Tributary Monitoring	2016 monitoring of U2, U5 and U8	Completed
Diagnostic Modeling Report	March 2014 Forest Lake South Stormwater Retrofit Analysis January 2016 Forest Lake North Stormwater Retrofit Analysis	Completed
Project Feasibility & Planning	March 2014 Forest Lake South Stormwater Retrofit Analysis January 2016 Forest Lake North Stormwater Retrofit Analysis October 2017 Forest Lake Enhanced Street Sweeping Plan	Completed
Project Design & Implementation	Preliminary designs and 30% plan sets were completed by S.E.H. for three selected BMPs identified in the FL-01 subwatershed from the South Stormwater Retrofit Analysis. A FY17 CWF Project & Practices grant was submitted to fund implementation of these projects, but was not awarded to the District. http://www.clflwd.org/documents/Agendaitem7a-ForestLakeSouthBMPs-SEH.pdf FY18 CWF Project & Practices grant submitted by the City of Forest Lake to purchase a regenerative air street sweeper and implement the enhanced street sweeping plan.	2018 →
Project Effectiveness Monitoring	Future activity	2021-2022

Stormwater Retrofits

Subwatershed Stormwater Retrofit Analysis is a watershed management tool to help prioritize stormwater retrofit projects by performance and cost effectiveness. A Stormwater Retrofit Analysis was completed by the Washington Conservation District for the north and south shores of Forest Lake in 2014 and 2015. WinSLAMM was used for the water quality modeling, and the entire subwatershed was investigated via field reconnaissance. Stormwater practice options were compared, for each catchment, given their specific site constraints and characteristics. A stormwater practice was selected by weighing cost, ease of installation and maintenance and ability to serve multiple functions. Concept designs were drafted for individual projects identified through the cost/benefit analysis and ranking. Links to the completed studies can be found in Table 3-1 above.

South Shore Stormwater Retrofit Analysis

The analysis concluded that a variety of proposed stormwater BMP retrofit practices were identified totaling 181 lbs of total phosphorus reduction (35% reduction from Existing Conditions). The study analyzed seven catchments (totaling 930 acres) and their existing stormwater management practices for annual pollutant loading - total phosphorus, total suspended solids and runoff volume specifically. The model estimated that the base condition loading of total phosphorus was 662 lbs per year, with existing treatment (wetlands, street sweeping, bioretention areas) reducing the total phosphorus load 23%, or a total of 509.8 lbs per year. See Table 3-3 and Figure 3-2 for a prioritized list of the proposed Best Management Practices identified from the analysis.

Identified BMPs include:

- Maintenance of, or alterations to, existing stormwater treatment practices
- Residential curb-cut raingardens
- Stormwater pond retrofits
- Stormwater wetland retrofits
- Stormwater reuse
- Iron-enhanced sand filters (IESFs)
- Bioswales and filterstrips

North Shore Stormwater Retrofit Analysis

The analysis concluded that a variety of proposed stormwater BMP retrofit practices were identified totaling 72.85 lbs of total phosphorus reduction (37% reduction from Existing Conditions). The study analyzed thirty-three catchments (totaling 637 acres) and their existing stormwater management practices for annual pollutant loading - total phosphorus, total suspended solids and runoff volume specifically. The model estimated that the base condition loading of total phosphorus was 232.5 lbs per year, with existing treatment (wetlands, street sweeping, bioretention areas) reducing the total phosphorus load 16%, or a total of 196.1 lbs per year. See Table 3-4 and Figure 3-3 for a prioritized list of the proposed Best Management Practices identified from the analysis. The single most cost-effective practice identified was to increase street sweeping of all major roads to 4x annually. [Note that street sweeping was excluded from the prioritized BMP list in Table 3-4 because a cost-benefit analysis was conducted for the entire direct drainage area to Forest Lake as part of the Forest Lake Enhanced Street Sweeping Plan (Table 3-5)].

Identified BMPs include:

- Street Sweeping (increased coverage and frequency)
- Maintenance of, or alterations to, existing stormwater treatment practices
- Residential curb-cut raingardens
- Shoreline buffers (enhanced to pond 1" of water over 50% of each buffer footprint)
- Iron-enhanced sand filters (IESFs)
- Bioswales and filterstrips

Table 3-3. South Shore Prioritized List of Retrofit projects

Project Rank	Basin	Retrofit Type	Projects Identified	TP Reduction (lb/yr)	Total Project Cost	$Cost/ lb-TP/year (10-year)
1	Middle	Stormwater Wetland Outlet Modification	1	4.1	$240	$6
2	Middle	Ditched Wetland Outlet Modification	1	5.0	$750	$15
3	Middle	Ditch Diversion with Pretreatment/ Forebay	2	6.6	$23,920	$590
4	West	6th Street Dead End – IESF, Diversion + Pretreatment	1	9.1	$56,750	$850
5	West	Residential Raingardens	15	12.6	$73,554	$852
6	Middle	217th St. North & Scandia Trl North Raingardens	2	2.9	$16,200	$903
7	West	Residential Raingardens	10	7.9	$49,036	$906
8	West	Residential Raingardens	5	3.3	$24,518	$1,084
9	West	Woodland Drive – IESF with Pretreatment	1	4.4	$37,250	$1,102
10	Middle	Heath Avenue Wetland – Restoration & Expansion	1	3	$20,000	$1,129
11	Middle	Stormwater Reuse – Golf Course Irrigation	1	19.3	$222,000	$1,306
12	Middle	Hilo Lane North Raingardens with Pretreatment	3	2.7	$25,518	$1,362
13	Middle	Lakeside Woods – WQ swale meander	1	1.2	$12,000	$1,417
14	Middle	IESF & Pretreatment/Outlet Collector	2	2.8	$41,695	$1,846
15	Middle	Hilo Lane North Raingardens with Pretreatment	5	3.1	$40,530	$1,912
16	East	Stormwater Wetland Pretreatment Basins	13	3.5	$34,500	$2,014
17	West	10th Ave SE – Depavement, split flow, raingarden	1	1.8	$31,150	$2,335
18	West	7th Street Dead End – Water Quality Swale (Bioswale) with Pretreatment	1	1.1	$18,000	$3,629
19	West	Lakeside Woods – 3 raingardens	3	1.8	$47,036	$4,002
20	West	Swale (Bioswale) with Pretreatment & stormsewer routing	1	0.7	$21,700	$5,365
21	West	5th Street Dead End – Filter Strip with Pretreatment/ Level Spreader	1	0.4	$8,650	$6,043
22	Middle	Shoreline Buffers	25	3.3	$211,000	$9,424
23	Middle	Shoreline Buffers	75	9.8	$633,000	$9,520
24	Middle	Shoreline Buffers	50	6.5	$422,000	$9,569

Project Rank	Basin	Retrofit Type	Projects Identified	TP Reduction (lb/yr)	Total Project Cost	$Cost/ lb-TP/year (10-year)
25	West	Shoreline Buffers	180	19.8	$1,516,500	$11,295
26	West	Shoreline Buffers	120	13.2	$1,011,500	$11,299
27	West	Shoreline Buffers	60	6.6	$506,500	$11,311
28	East	Shoreline Buffers	90	4.1	$380,000	$14,756
29	East	Shoreline Buffers	270	12.2	$1,140,000	$14,877
30	East	Shoreline Buffers	180	8.1	$760,000	$14,938

Table 3-4. North Shore Prioritized List of Retrofit projects

Project Rank	Basin	Retrofit Type (refer to catchment profile pages for additional detail)	Projects Identified	TP Reduction (lb/yr)	Total Project Cost	$Cost/ lb-TP/year (10-year)
18	East	BMP 15k - BioInfiltration Simple	1	0.71	$6,728	$1,399
19	West	Priority Shoreline 102,103,104,105	15	8.69	$96,850	$1,810
20	West	BMP 2b - Vegetated Swale	1	0.14	$1,620	$2,085
21	Middle	BMP 9h - BioInfiltration Simple	1	0.42	$4,567	$2,409
22	Middle	BMP 10i - BioInfiltration Mod Complex	1	0.69	$15,026	$2,451
23	East	BMP 25v - IESF Bench Retrofit	1	0.83	$18,339	$2,812
24	West	BMP 6g,7f,8e - Retention Swales and BioInfiltration Mod Complex	3	1.14	$21,022	$2,831
25	Middle	Priority Shoreline 108, 109	7	2.49	$47,479	$3,094
26	East	BMP 19n - BioInfiltration Simple	1	0.32	$5,432	$3,153
27	West	BMP 4d- BioInfiltration Simple	1	0.45	$9,049	$3,322
28	Middle	Priority Shoreline 110, 111, 112, 113	18	8.21	$167,549	$3,334
29	East	BMP 21r- BioInfiltration Simple	1	0.31	$7,026	$3,454
30	East	BMP 16m - BioInfiltration Simple	1	0.27	$5,346	$3,620

Project Rank	Basin	Retrofit Type (refer to catchment profile pages for additional detail)	Projects Identified	TP Reduction (lb/yr)	Total Project Cost	$Cost/ lb-TP/year (10-year)
31	East	Priority Shoreline 119, 120,121,122,134	22	7.03	$159,016	$3,683
32	East	BMP 20q - BioInfiltration Simple	1	0.17	$4,481	$3,739
33	East	BMP 24u - Swale Inlet and Raingarden Outfall Modification	1	0.07	$2,620	$3,743
34	West	Priority Shoreline 101	3	1.12	$29,489	$4,296
35	West	Priority Shoreline 136-140	10	2.15	$61,600	$4,655
36	West	Priority Shoreline 106	3	0.97	$27,704	$4,674
37	Middle	BMP 11j - BioInfiltration Mod Complex	1	0.66	$18,113	$4,790
38	East	Priority Shoreline 123 to 133	12	5.13	$150,705	$4,822
39	West	BMP 3c - BioInfiltration Mod Complex	1	0.36	$14,305	$4,951
41	East	Priority Shoreline 115, 116, 117	11	2.04	$70,523	$5,612
42	East	Priority Shoreline 118	3	0.80	$27,704	$5,623
43	West	BMP 1a - Parking Lot Retrofit	1	0.44	$22,506	$6,082
46	East	Priority Shoreline 114	3	0.62	$26,213	$6,884
47	Middle	Priority Shoreline 107	10	1.51	$84,206	$9,077
51	West	Priority Shoreline 135	1	0.12	$7,375	$10,064
58	West	Priority Shoreline 100 & 141	10	0.87	$61,600	$11,490
62	East	BMP 22s - Swale with Ponding	1	0.03	$3,364	$16,213

Figure 3-2. Location of South Shore Prioritized List of Retrofit projects (From page 7 of the WCD 2014 South Shore Stormwater Retrofit Assessment)

The blue circles represent the location of a potential project, and the numbers in the blue circles correspond with the Project Rank listed in Table 3-3 of this report. The green lines with white numbering (FL-XX) are the subwatersheds delineated for the WCD 2014 South Shore Stormwater Retrofit Assessment.

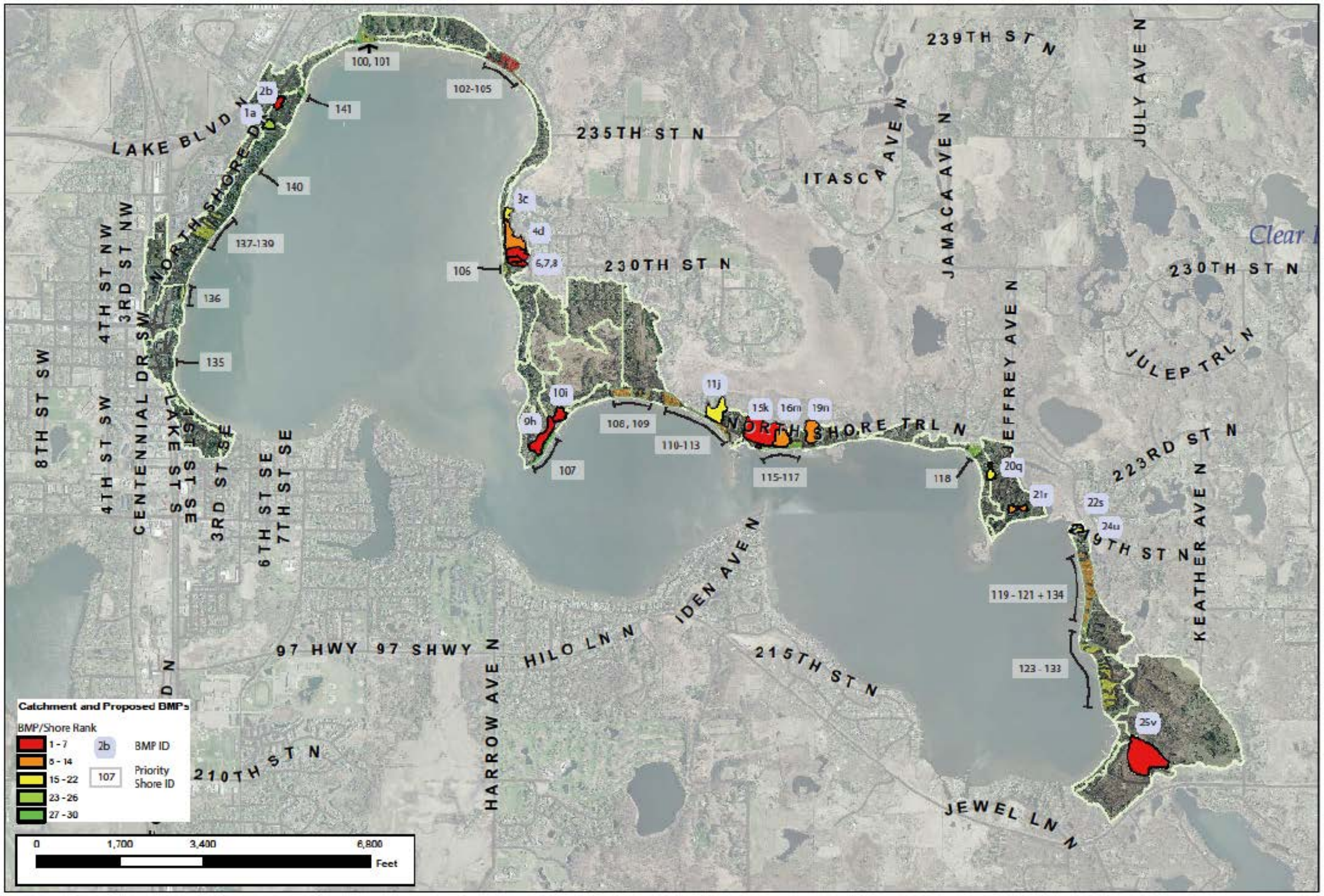


Figure 3-3. Location of North Shore Prioritized List of Retrofit projects (From page 8 of the WCD 2015 North Shore Stormwater Retrofit Analysis)

The grey circles represent the location of a potential BMP project. The numbers in the grey circles correspond with the BMP ID and the numbers in the grey rectangles correspond with the Shoreline project number listed in Table 3-4 of this report. The red yellow and green shading correspond to the BMP or shoreline restoration project rank, with red representing a higher rank.

Enhanced Street Sweeping

Street sweeping is the practice of removing particulates (salt, sand, soil) and organic matter (leaves, seeds, flowers) from streets using mechanical broom or vacuum street sweeping vehicles to reduce the amount of pollutants and sediment discharged to stormwater conveyance systems. Traditional municipal street sweeping programs typically involve mechanically sweeping all City streets once in the spring and once in the fall. Enhanced municipal street sweeping programs typically involve sweeping street with high efficiency sweepers (vacuum type or similar) sweeping streets at higher frequency, based on the variable generation of particulates and organic matter to streets.

The District received a $45,000 Clean Water Fund Accelerated Implementation grant in 2017 to develop an Enhanced Street Sweeping Plan for the City of Forest Lake. This project developed a Plan that identified road-specific street sweeping timing and frequency, quantified expected phosphorus load reductions, itemized costs of enhanced street sweeping (including purchase and subcontract options), and recommended funding options for an enhanced street sweeping program in the City of Forest Lake, MN.

The City currently sweeps approximately 240 curb miles twice annually (2016 sweeping contract). The most cost-effective street sweeping scenario for streets located within the direct drainage to Forest Lake was sweeping monthly (7 times; base priority) to 12 times (recommended) throughout the sweeping season with a regenerative air vacuum sweeper.

Summary

Phosphorus load reductions achieved from 7 sweeps per year (base priority) in the direct drainage area would achieve all of the phosphorus reductions needed for the Middle Basin, and 37% of the phosphorus reductions needed for the West Basin. Phosphorus reductions achieved from 12 (recommended) in the direct drainage area would achieve all of the phosphorus reductions needed for the Middle Basin, and 55% of the phosphorus reductions needed for the West Basin.

An additional 30-41 pounds per year of phosphorus reductions would be needed from stormwater retrofit projects identified as part of the South and North Shore Stormwater Retrofit Analysis projects to achieve the phosphorus reductions needed from the direct drainage area of Forest Lake.

Table 3-5. Phosphorus load reductions by basin from enhanced street sweeping

Lake Basin	Phosphorus Reduction Needed in Direct Drainage Area (lb/yr)	Phosphorus Load Reduction Achieved from Enhanced Street Sweeping (lb/yr)		Additional Load Reductions Needed from Stormwater Retrofits (lb/yr)
		Base Priority (7 sweeps per year)	Recommended (12 sweeps per year)	
Forest East	0	16.7	24.6	0
Forest Middle	7.7	7.9	11.6	0
Forest West	65.7	24.5	36.2	29.5 – 41.2

Table 3-6. Stormwater Retrofit projects identified in the Forest Lake West Basin Direct Drainage Area

Shaded rows illustrate the highest rank projects that achieve the additional 41 lb TP/yr reduction needed

Project Rank	Retrofit Type	Projects Identified	TP Reduction (lb/yr)	Total Project Cost	$Cost/ lb-TP/year (10-year)
South Shore Stormwater Retrofit Analysis					
4	6th St Dead End – IESF, Diversion + Pretreatment	1	9.1	$56,750	$850
5	Residential Raingardens	15	12.6	$73,554	$852
7	Residential Raingardens	10	7.9	$49,036	$906
8	Residential Raingardens	5	3.3	$24,518	$1,084
9	Woodland Drive – IESF with Pretreatment	1	4.4	$37,250	$1,102
17	10th Ave SE – Depavement, split flow, raingarden	1	1.8	$31,150	$2,335
18	7th Street Dead End – Water Quality Swale (Bioswale) with Pretreatment	1	1.1	$18,000	$3,629
19	Lakeside Woods – 3 raingardens	3	1.8	$47,036	$4,002
20	Swale with Pretreatment & stormsewer routing	1	0.7	$21,700	$5,365
21	5th St Dead End – Filter Strip with Pretreatment/ Level Spreader	1	0.4	$8,650	$6,043
25	Shoreline Buffers	180	19.8	$1,516,500	$11,295
26	Shoreline Buffers	120	13.2	$1,011,500	$11,299
27	Shoreline Buffers	60	6.6	$506,500	$11,311
North Shore Stormwater Retrofit Analysis					
19	Priority Shoreline 102,103,104,105	15	8.69	$96,850	$1,810
20	BMP 2b - Vegetated Swale	1	0.14	$1,620	$2,085
24	BMP 6g,7f,8e - Retention Swales and BioInfiltration Mod Complex	3	1.14	$21,022	$2,831
27	BMP 4d- BioInfiltration Simple	1	0.45	$9,049	$3,322
34	Priority Shoreline 101	3	1.12	$29,489	$4,296
35	Priority Shoreline 136-140	10	2.15	$61,600	$4,655
36	Priority Shoreline 106	3	0.97	$27,704	$4,674
39	BMP 3c - BioInfiltration Mod Complex	1	0.36	$14,305	$4,951
43	BMP 1a - Parking Lot Retrofit	1	0.44	$22,506	$6,082
51	Priority Shoreline 135	1	0.12	$7,375	$10,064
58	Priority Shoreline 100 & 141	10	0.87	$61,600	$11,490

3.2. Castlewood Subwatershed

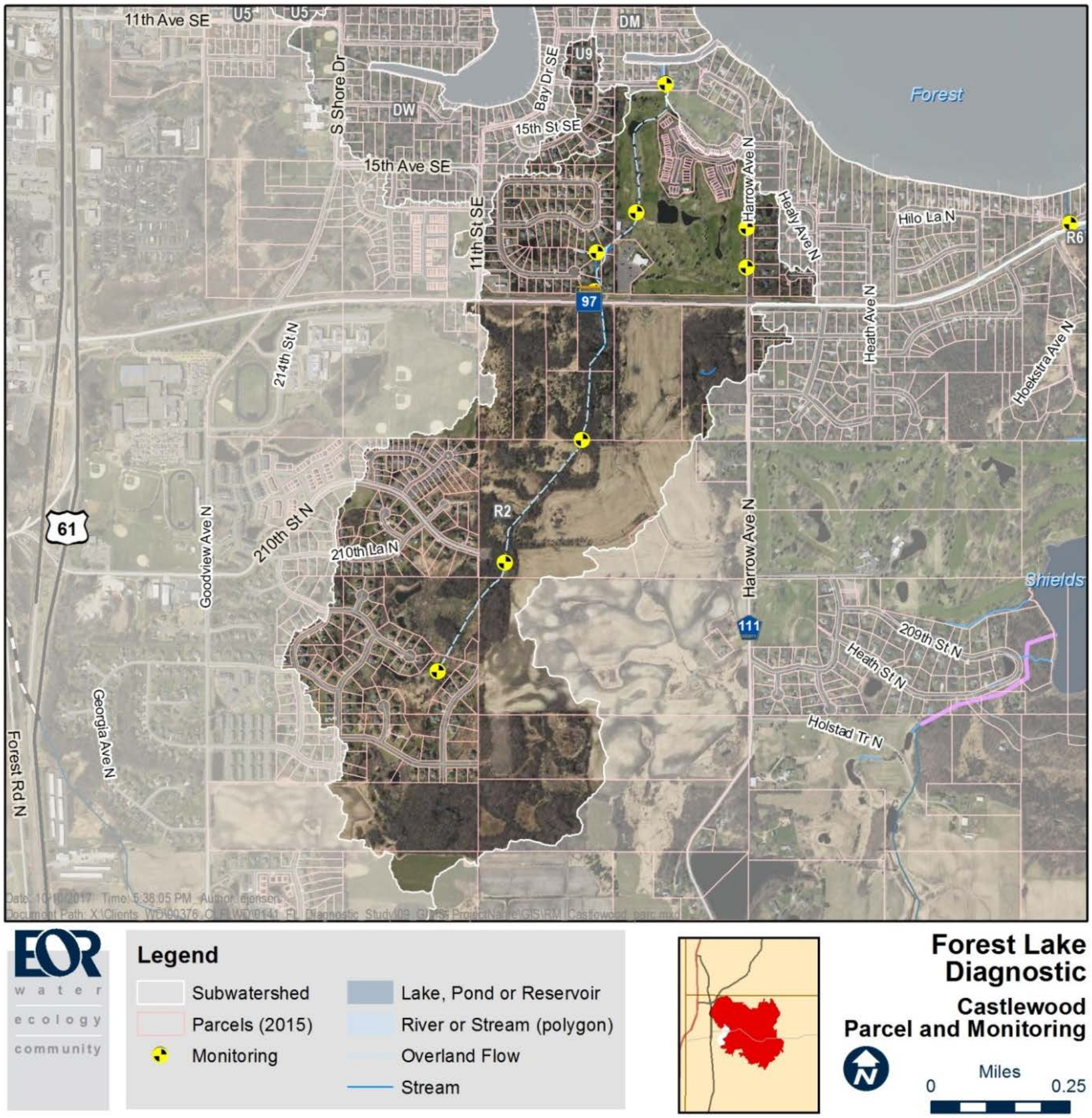


Figure 3-4. Castlewood Subwatershed Location, Parcels and 2017 Monitoring Locations

Diagnostic Summary

As a percent of the total for Forest Lake, the Castlewood subwatershed contributes:

- 5 percent of the total drainage area
- 6 percent of the total flow
- 5 percent of the total phosphorus load

The existing TP FWMC was 177 ppb, with a **15% reduction needed** to achieve the TP FWMC goal of less than 150 ug/L.

Implementation Recommendations

Table 3-7. Castlewood Subwatershed Implementation Progress & Timeline

Adaptive Management Phase	Castlewood Subwatershed Implementation Progress	Timeline
Targeted Tributary Monitoring	Several water quality grab samples collected at Hwy 97 in 2017 Additional monitoring planned for 2018	2017-2018
Diagnostic Modeling Report	Scope development and Board approval by end of 2017	2018
Project Feasibility & Planning	Future activity	2018-2019
Project Design & Implementation	Future activity	2019-2020
Project Effectiveness Monitoring	Future activity	2021-2022

The Castlewood subwatershed is 414 acres of a mix of residential, forested, cropped, and golf course land uses (Figure 3-5). The area south of Highway 97 contains areas of active farming (including row crops), wetland areas, and residential development. A portion of the actively farmed area in the far southern portion of the watershed is currently under development (Chestnut Creek Development) and being converted to single family homes. The areas north of Highway 97 include Castlewood golf course with the remainder of the area being developed residential.

EOR and District staff took a site tour of the Castlewood East Golf Course with Golf Course staff and City of Forest Lake staff to look for opportunities for phosphorus reduction projects. The golf course has problems with flooding from water ponding on the greenways and sump pump discharge from neighboring homes. An in-depth feasibility study is needed, but there seemed opportunities for a small harvest and irrigation reuse system and several biofiltration features. Further feasibility study is needed in this subwatershed.

Some additional water quality grab sampling was conducted in 2017 to further refine phosphorus sources in the Castlewood Subwatershed. Four samples were collected between May and July following rainfall events at the R2 monitoring station (downstream of the golf course), and at the culvert under Highway 97 (upstream of the golf course). Preliminary results indicate that phosphorus concentrations were higher upstream of the golf course than downstream. A targeted monitoring and diagnostic study is needed in this subwatershed to spatially refine sources of phosphorus and identify the most cost-effective phosphorus reduction projects. Potential opportunities in the area south of Highway 97 would likely include wetland treatment systems and agricultural BMPs. Currently, the District is planning to fund this study in 2018.

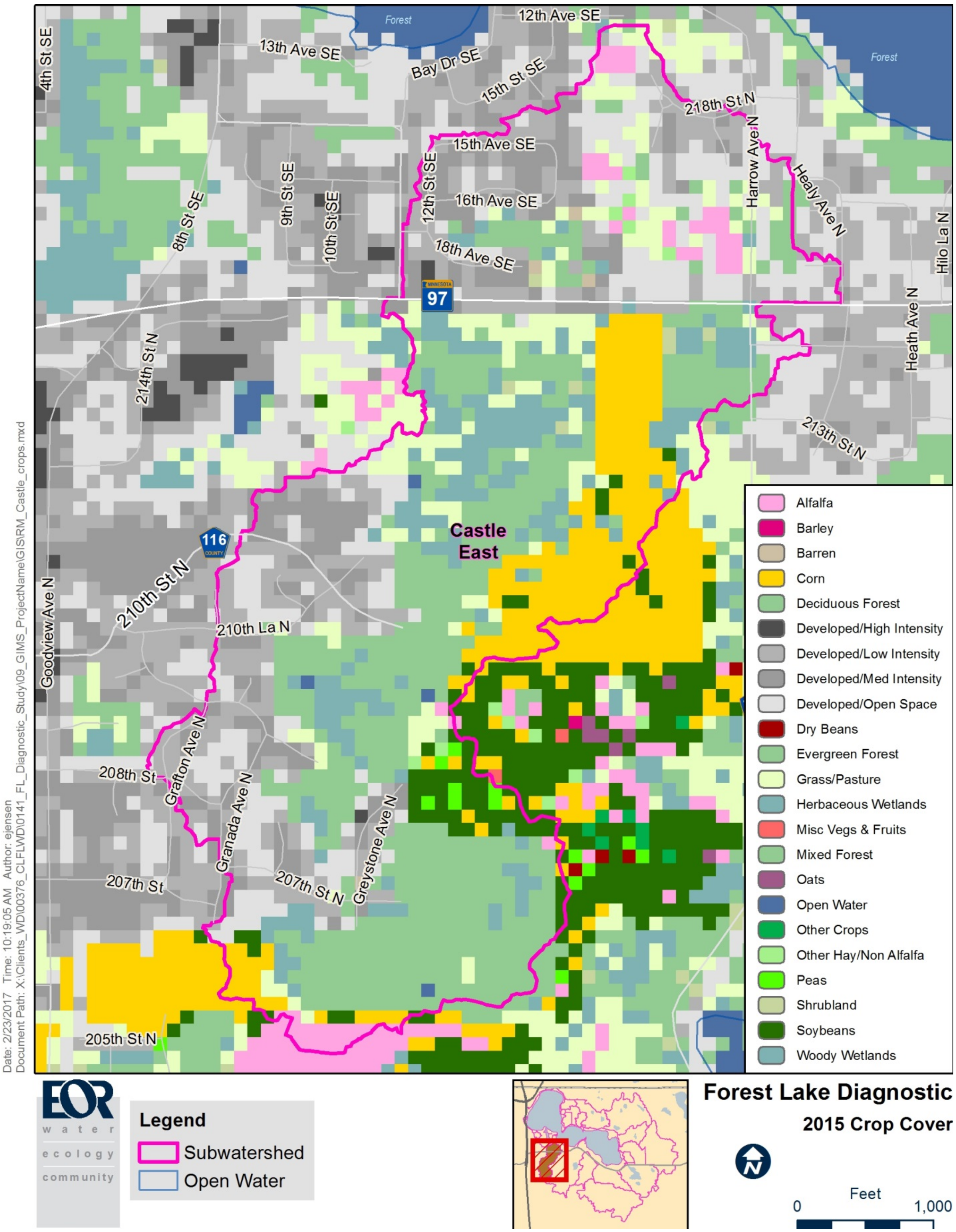


Figure 3-5. Castlewood Subwatershed 2015 Land Use

3.3. Shields Lake Subwatershed

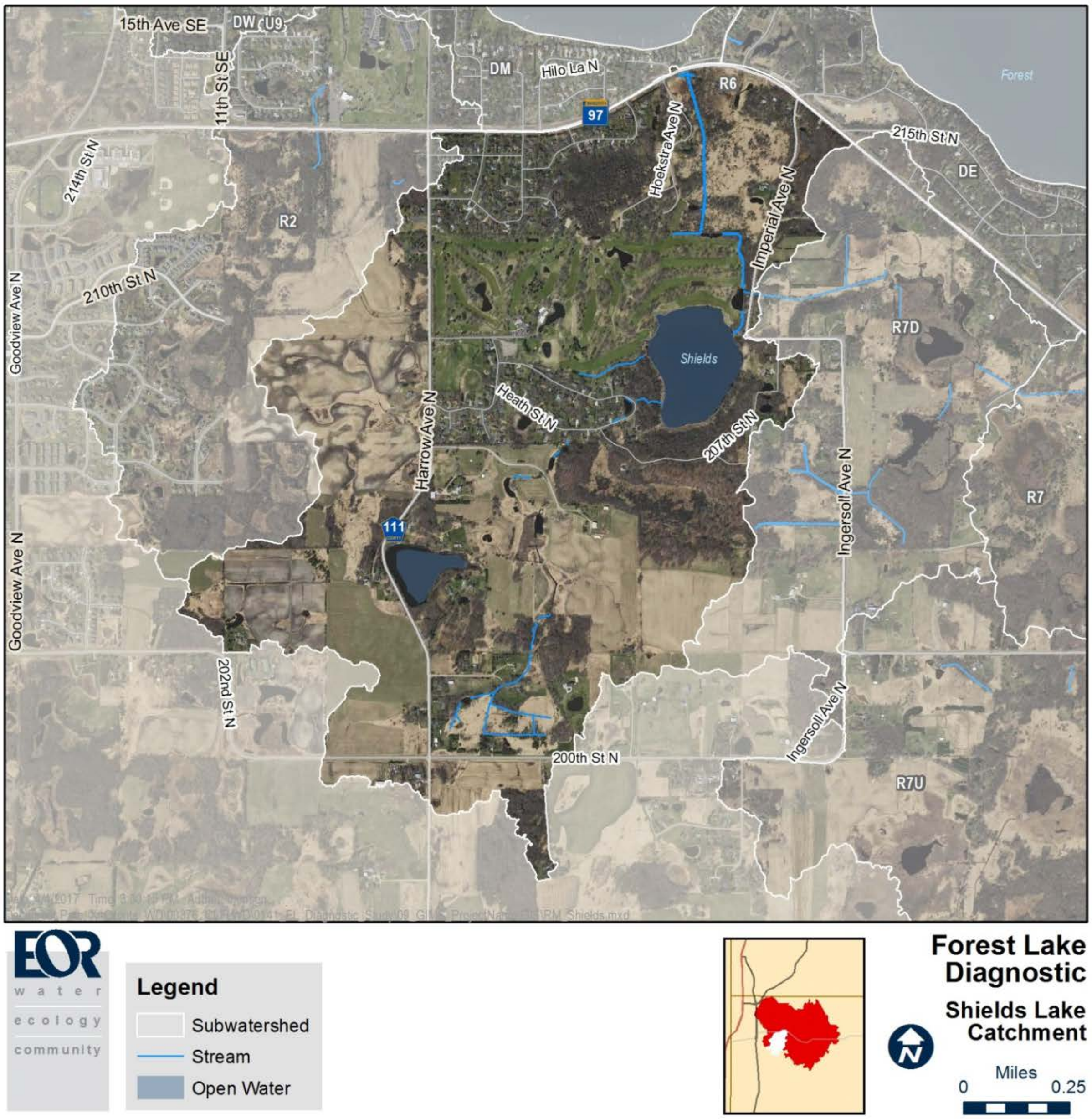


Figure 3-6. Shields Lake Subwatershed Location

Diagnostic Summary

As a percent of the total for Forest Lake, the Shields Lake subwatershed contributes:

- 12 percent of the total drainage area
- 21 percent of the total flow
- 28 percent of the total phosphorus load

The existing TP FWMC was 264 ppb, with a **77% reduction needed** to achieve the shallow lake in-lake phosphorus concentration goal for Shields Lake of less than 60 ug/L.

Implementation Recommendations

Table 3-8. Shields Lake Subwatershed Implementation Progress & Timeline

Adaptive Management Phase	Shields Lake Subwatershed Implementation Progress	Timeline
Targeted Tributary Monitoring	2016 Shields Lake Diagnostic Monitoring	Completed
Diagnostic Modeling Report	2015 Shields Lake Modeling 2016 Shields Lake Diagnostic Monitoring	Completed
Project Feasibility & Planning	2017 Shields Lake Stormwater Harvest and Irrigation Reuse Feasibility Report	Completed
Project Design & Implementation	Construction of harvest and reuse system planned for 2018 Shields Lake alum treatment planned for 2019	2018-2019
Project Effectiveness Monitoring	Future activity	2020

The 2015-2016 monitoring captured runoff from 755 acres of the total 851 acre watershed of Shields Lake. The total monitored watershed phosphorus load was 381 lb TP/year, nearly double the Six Lakes TMDL estimate of 187 lb TP/year based on literature unit area land cover values. The Shields Lake BATHTUB model was updated with 2015-2016 watershed monitoring data and recalibrated to the 2006-2015 growing season average in-lake phosphorus concentration of 241 µg TP/L. The updated BATHTUB model predicted a total lake load of 1,107 lb TP/year, with 35% of the load from the watershed and 65% of the load from lake internal loading. In contrast, the 2010 CLFLWD Six Lakes Total Maximum Daily Load study (https://www.pca.state.mn.us/sites/default/files/wq-iw6-03e.pdf) estimated that 18% of the total Shields lake load was from the watershed and 82% of the load was from internal loading.

In summary, the 2015-2016 monitoring data found higher than expected watershed phosphorus loads, particularly at Ditch West, compared to literature unit area land cover values which supports the need for some watershed phosphorus load reductions in addition to in-lake management of internal loads to improve the water quality of Shields Lake and ultimately reduce phosphorus loads to Forest Lake. Ditch West had the highest flow-weighted mean phosphorus concentration and highest phosphorus load for its drainage area compared to the other sites. Flows at Ditch West could be impounded to harvest stormwater for an irrigation reuse system for the golf course.

Preliminary estimates for stormwater harvest and irrigation use system could remove 67-94 lb TP/year at Ditch West. In addition, residential development of the agricultural lands west of Harrow Avenue under District rules will also reduce phosphorus loading to Shields Lake. For example, the

Chestnut Creek development (permit 16-008) includes proposed treatment features that will reduce loads by approximately 32 lb TP/year.

The District received an $824,000 Clean Water Fund grant in 2017 to implement a stormwater harvest and irrigation reuse system on the Forest Hills Golf Course, and complete an in-lake alum treatment in Shields Lake. The harvest and reuse system will impound water from the Ditch West tributary in a pond, which will be connected to the existing golf course irrigation system by a pipe and pump system.

The in-lake alum treatment is expected to achieve the rest of the phosphorus reductions needed for Shields Lake to meet its in-lake phosphorus goal (a total of 912 lb/yr). The predicted load reduction to Forest Lake from Shields Lake attaining an in-lake phosphorus concentration of 60 µg/L is 531 lb/yr reduction to the middle basin of Forest Lake. Other reports pertaining to this project and Shields Lake in general can be found on the CLFLWD webpage: http://www.clflwd.org/data.php.

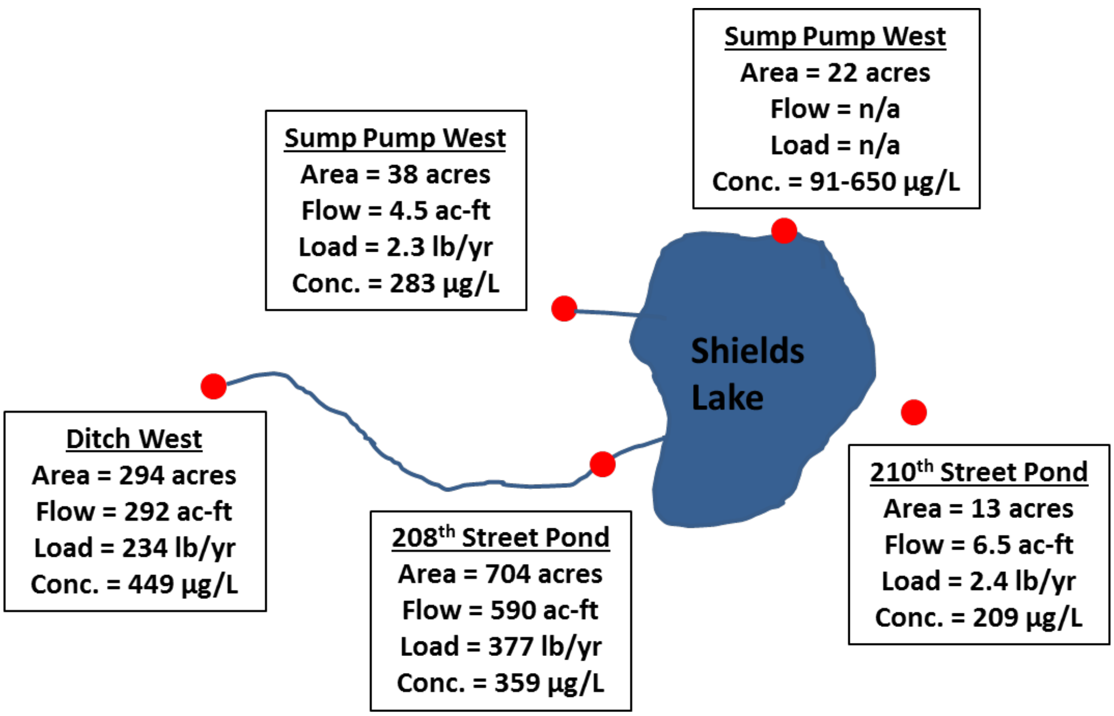


Figure 3-7. 2015-2016 Shields Lake monitoring site flow and total phosphorus loads and flow-weighted mean concentrations

3.4. JD6 Subwatershed

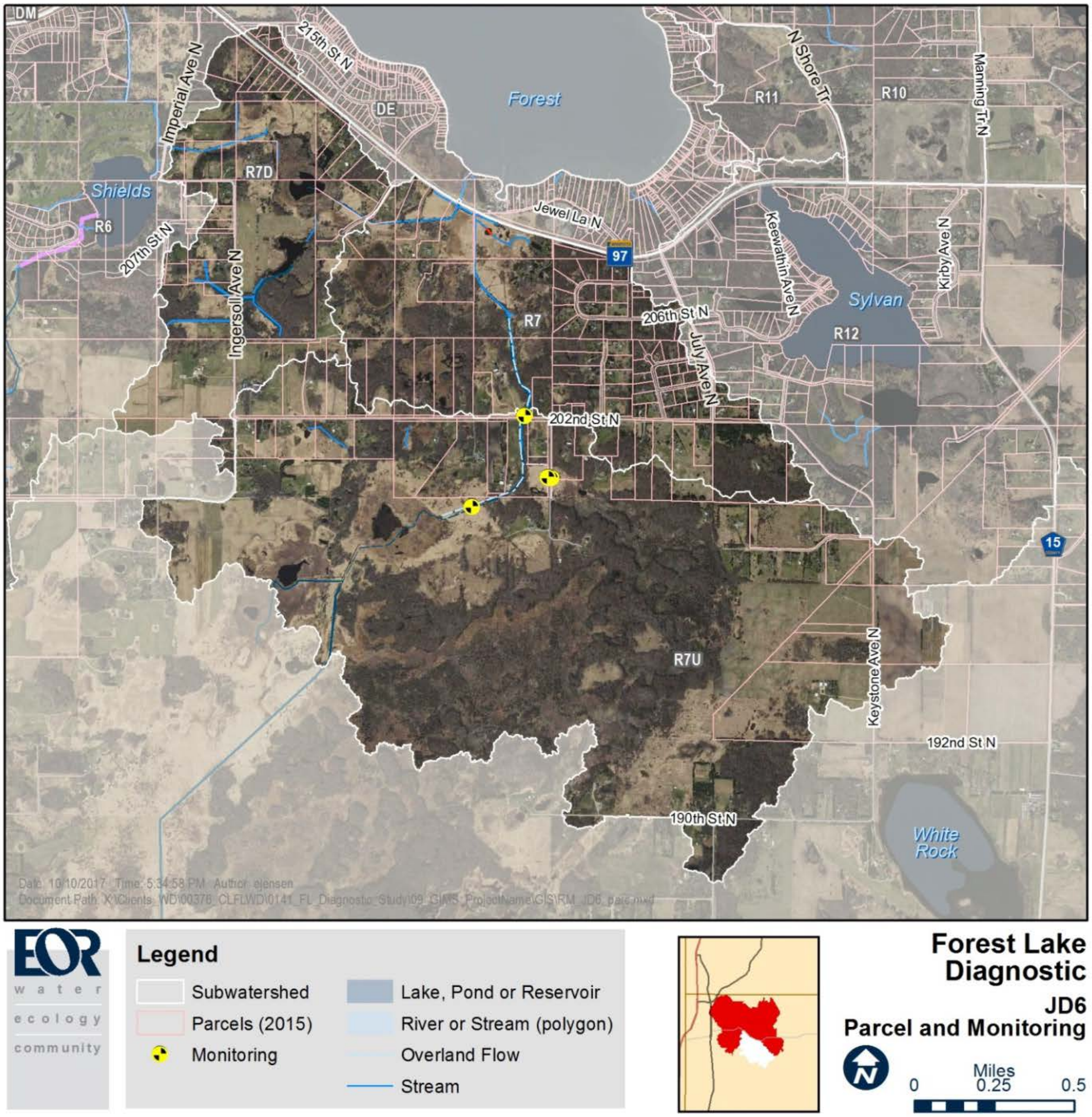


Figure 3-8. JD-6 Subwatershed Location, Parcels, and 2017 Monitoring Locations

Diagnostic Summary

As a percent of the total for Forest Lake, the JD6 subwatersheds (R7, R7d, and R7u) contribute:

- 26 percent of the total drainage area
- 30 percent of the total flow
- 30 percent of the total phosphorus load

The existing TP FWMCs were 171-201 ppb, with a **12-25% reduction needed** to achieve the TP FWMC goal of less than 150 ug/L.

Historic Conditions

From the 1921 Engineer's Report, the approximate area of wetlands benefitted by draintile [via construction of JD6] is 460 acres (Figure 3-9). According to the January 8, 2015 memorandum by the RCWD Engineer to the RCWD District Administrator:

"The WJD 6 pubic drainage system is in general disrepair, with many tiles clogged with sediment and tree roots. Much of the system is located in deep marshes and in forested areas which have accelerated the deterioration of the system. Several open channels have been excavated parallel to or crossing the historic alignment, presumably damaging portions of the tile systems (if the tiles were intact at the time of the excavation). Very few remnants of the historic tile system are visible at the surface, even at locations where the excavated channels cross the tile system."

WJD 6 was transferred from Rice Creek Watershed District to Comfort Lake – Forest Lake Watershed District in 2017.

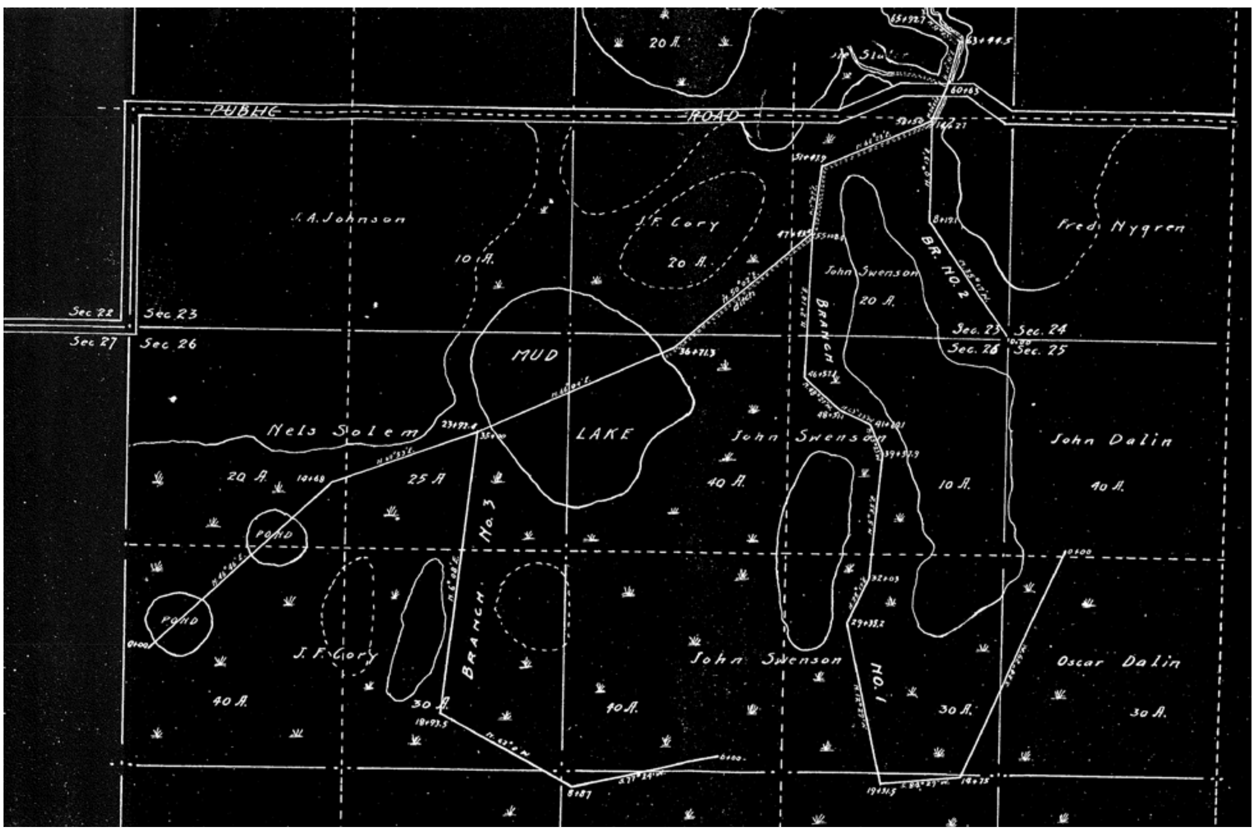


Figure 3-9. Proposed JD 6 alignment (RCWD 1921 Engineer's Report)

Implementation Recommendations

Table 3-9. Judicial Ditch 6 Subwatershed Implementation Progress & Timeline

Adaptive Management Phase	Judicial Ditch 6 Subwatershed Implementation Progress	Timeline
Targeted Tributary Monitoring	Several water quality grab samples collected at 202nd St and Jeffrey Avenue in 2017 Additional monitoring planned for 2018	2017-2018
Diagnostic Modeling Report	Scope development and Board approval by end of 2017	2018
Project Feasibility & Planning	Future activity	2018-2019
Project Design & Implementation	Future activity	2019-2024
Project Effectiveness Monitoring	Future activity	2020-2026

The JD6 Subwatershed largely consists of wetland areas and large lot residential development (Figure 3-10). Based on aerial photos it appears that very little active farming still occurs along the ditch system and the ditch system is largely in disrepair. A portion the ditch system also runs through the DNR owned Hardwood Creek Wetland Management Area (WMA).

Implementation planning based on current land uses may miss phosphorus hotspots and therefore result in identification of practices with low cost-effectiveness. Therefore, targeted monitoring and field reconnaissance is needed in this subwatershed to identify legacy phosphorus hotspots and develop non-structural management practices to address these phosphorus hotspots. The subcatchment assessments will consist of the following tasks and methods:

1. Desktop analysis of LiDAR topography, soil type, wetland delineations, and land use
2. Wetland water level and phosphorus monitoring using piezometers to characterize subsurface flow and phosphorus quality
3. Soil testing of phosphorus and organic matter content in targeted wetlands and ponds based on the wetland pore water or sequential tributary monitoring results
4. Field reconnaissance and survey work to identify types and locations of projects

Depending on the desired future land use along the JD-6 system, the ditch system could potentially be abandoned and converted back to a more natural wetland/channel system. This would likely require acquisition of property or easements along the drainage way. This would potentially be a good location for a greenway corridor connecting Hardwood Creek WMA and Forest Lake. If this is a desired outcome for this subwatershed, comprehensive planning is recommended, such that property/easement acquisition could occur when future opportunities arise.

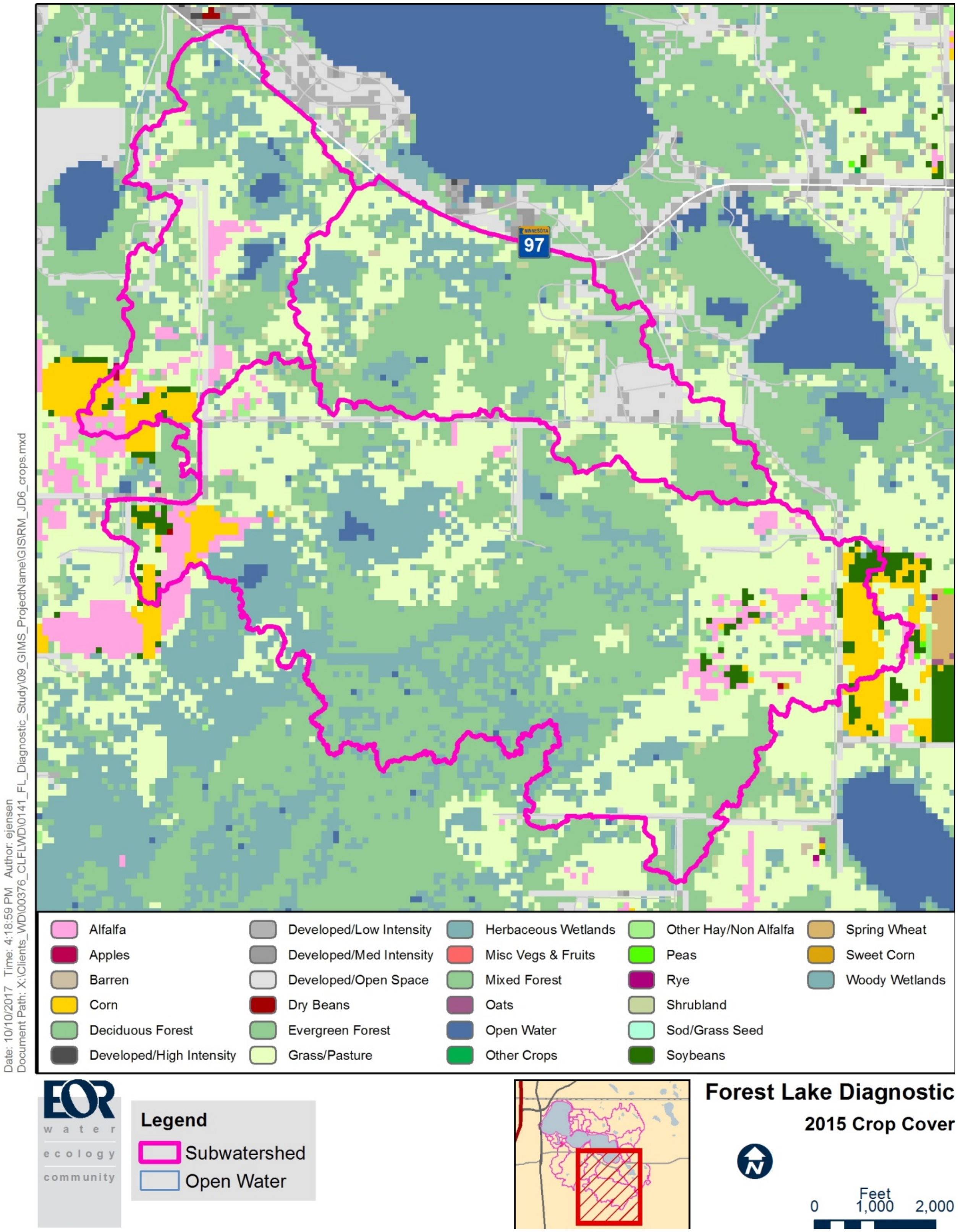


Figure 3-10. JD-6 Subwatershed 2015 Land Use

3.5. 3rd Lake Pond

Figure 3-11. 3rd Lake Pond Subwatershed Location

Diagnostic Summary

As a percent of the total for Forest Lake, the 3rd Lake Pond subwatershed contributes:

- 4 percent of the total drainage area
- 1.4 percent of the total flow
- 1.3 percent of the total phosphorus load

The existing TP FWMCs were 188 ppb, with a **20% reduction needed** to achieve the TP FWMC goal of less than 150 ug/L.

Implementation Recommendations

Table 3-10. 3rd Lake Pond Subwatershed Implementation Progress & Timeline

Adaptive Management Phase	3rd Lake Pond Subwatershed Implementation Progress	Timeline
Targeted Tributary Monitoring	Forest Lake East Shore Algae Investigation – September 20, 2012	Completed
Diagnostic Modeling Report		
Project Feasibility & Planning	3rd Lake Pond Feasibility Study – August 20,2015	Completed
Project Design & Implementation	2016 Project Design Plans	2017-2018
Project Effectiveness Monitoring	Several water quality grab samples collected in 2017 Additional monitoring planned for 2018	2017-2018

The 3rd Lake Pond (currently a regulated wetland) is located on a 3.53 acre City of Forest Lake parcel located west of North Shore Trail and north of 215th Street on the east shore of Forest Lake. An algae investigation was completed along the east shore of 3rd Lake in 2012. One conclusion of the investigation was that the pond/wetland was a source of phosphorous and potentially contributing to the algae blooms in this area of the lake. The investigation also recommended possible actions, in order of priority, to reduce nutrient and algae loading to Forest Lake. The actions included:

1. Evaluation of proper sizing and expansion of the wetland to increase phosphorus removal capacity (most expensive option, but less ongoing maintenance and most likely to be a successful long-term solution).
2. Summer aeration to increase oxygen concentrations and reduce anoxic release of phosphorus from pond sediments (requires ongoing operation and maintenance).
3. Annual barley straw treatments to control algae growth and export of phosphorus and algae (less expensive but requires hiring a subcontractor to apply the barley straw every spring).

The 2015 feasibility study focused on the 1st priority action item – the feasibly of enlarging and dredging the pond and/or creating a wetland treatment facility. The feasibility study recommended that a wetland treatment system be constructed and the design should remove the impacted wetland soils, increase storage, and incorporate a skimming structure.

The feasibility study was used to obtain a clean water grant from BWSR. The project was designed in 2016 and constructed in the winter of 2016/2017. Based on surveying and soil boring, the wetland area was very shallow and filled with nutrient-rich material that has accumulated over time. By excavating out some of this accumulated material there is a longer retention time in the wetland to allow more time for sediments coming from upstream to settle out more efficiently before discharging to Forest Lake. Because the project is located within a historic wetland area and must maintain wetland characteristics the amount of excavation is limited. The wetland conservation act prohibits converting this wetland to a deep pond. The wetland also has a skimmer structure intended to prevent floating debris from getting into Forest Lake.

The shallow benches created along the perimeter of the pond will support the growth of rooted aquatic plants along with a wetland fringe vegetation buffer. The buffer area around the wetland should be left un-mowed. This will allow for filtering of nutrients and sediment from adjacent lawns and the wetland fringe area should assist in uptake of phosphorus during storm events. The intent of the basin is to capture suspended sediments and phosphorus thus reducing the amount of pollutants entering Forest Lake. Although the quality of the water in the wetland is expected to be cleaner initially, wetlands have high nutrients and support aquatic plant and algae growth. The purpose of the project was not to improve the water quality of the wetland, but improve the pollutant removal ability of the wetland with the goal of improving water quality in Forest Lake.

Effectiveness monitoring is planned for 2017/2018. This monitoring will assess the effectiveness of the system and determine if addition actions are need in this watershed.

3.6. Hayward Avenue

Figure 3-12. Hayward Avenue Subwatershed Location and Parcels

Diagnostic Summary

As a percent of the total for Forest Lake, the Hayward Avenue subwatersheds (R4W, R4C, R3, R5, R14, and R15) contribute:

- 7 percent of the total drainage area
- 5 percent of the total flow
- 9 percent of the total phosphorus load

The existing TP FWMC were 237-363 ppb, with a **37-62% reduction needed** to achieve the TP FWMC goal of less than 150 ug/L.

Implementation Recommendations

Table 3-11. Hayward Avenue Subwatershed Implementation Progress & Timeline

Adaptive Management Phase	Hayward Avenue Subwatershed Implementation Progress	Timeline
Targeted Tributary Monitoring	Scope development and Board approval by end of 2017	2018
Diagnostic Modeling Report	Scope development and Board approval by end of 2017	2018
Project Feasibility & Planning	Future activity	2018-2019
Project Design & Implementation	Future activity	2019-2021
Project Effectiveness Monitoring	Future activity	2020-2023

The Hayward Avenue subcatchments contain large areas of wetlands with small areas of residential development (Figure 3-13) making the source of high phosphorus loading not obvious based on current land use alone. Legacy loading from past land uses (such as intensive agriculture and feedlots) in these systems may be hidden. Particularly since the Forest Lake Area was once a large Creamery producer. For example, the Moody Lake Diagnostic Study (completed in 2014), located just north and west of the Forest Lake watershed, found that a small, degraded wetland was discharging a disproportionately high phosphorus load to Moody Lake compared to other wetland complexes in the watershed. This wetland was characterized by higher ortho phosphorus and lower iron levels compared to the other wetlands. The CLFLWD utilized targeted tributary monitoring and wetland soil chemical analyses to identify a large legacy load in this small wetland from past grazing of over 100 cattle in the wetland. These past livestock practices led to the accumulation of phosphorus rich sediment in the wetland over several decades that is now discharging phosphorus to the lake even though only a handful of cattle are currently raised on this property.

Targeted monitoring will identify legacy phosphorus hotspots that may otherwise be hidden based on existing land uses and practices. Implementation planning based on current land uses may miss phosphorus hotspots and therefore result in identification of practices with low cost-effectiveness. Therefore, targeted monitoring and field reconnaissance is needed in this subwatershed to identify legacy phosphorus hotspots and develop non-structural management practices to address these phosphorus hotspots. The subcatchment assessments will consist of the following tasks and methods:

1. Desktop analysis of LiDAR topography, soil type, wetland delineations, and land use
2. Wetland water level and phosphorus monitoring using piezometers to characterize subsurface flow and phosphorus quality

3. Soil testing of phosphorus and organic matter content in targeted wetlands and ponds based on the wetland pore water or sequential tributary monitoring results
4. Field reconnaissance and survey work to identify types and locations of projects

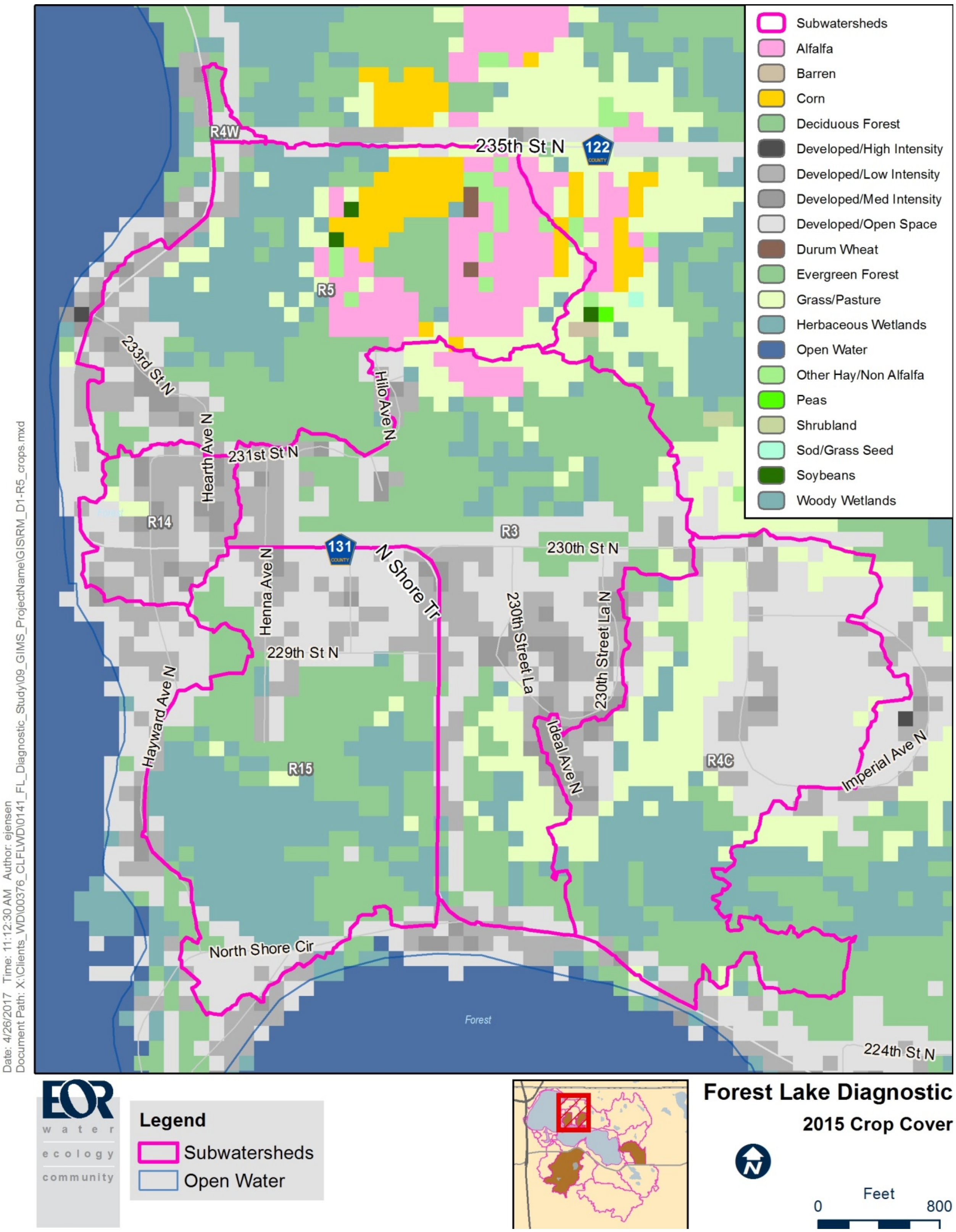


Figure 3-13. Hayward Avenue Subwatershed 2015 Land Use

3.7. Previously Identified BMPs

As part of this study, we considered previously identified BMPs in the Forest Lake Watershed from the 1987 Forest Lake Diagnostic Study and 2008 CLFLWD Capital Improvement Plan. Many of these projects are no longer relevant, have been completed, or are incorporated in our implementation recommendations. Table 3-12 lists these previously identified BMPs for reference.

Table 3-12. Previously identified BMPs in the Forest Lake Watershed

Study	Subshed	BMP	Load Reduction (lb/yr)	2015 Total 10-year Annual Cost ($/yr)
Wenck 1987	Wetlands	Load Prevention	2,040	
Wenck 1987	Golf courses	Golf Course Fertilizer Mgmt Plans	200	
Wenck 1987	R-7	Wetland Treatment System for R-7	470	$182,574
Wenck 1987	R-6	Wetland Treatment System for R-6	70	
Wenck 1987	In-lake	Weed Harvesting	0	
Wenck 1987	All city streets	Street Sweeping	5	
Wenck 1987	All ag land	Farm Conservation Plans	330	
Wenck 1987	In-lake	Hypolimnetic Aeration	--	$1,014,300
Wenck 1987	In-lake	Dilution	--	$124,362
Wenck 1987	In-lake	Fishery Management	--	
Wenck 1987	In-lake	Small-scale dredging	0	
Wenck 1987	Urban outfalls	Sedimentation Basins	0	
Wenck 2008	FL3	Watershed BMPs (FL3)	21	$564
Wenck 2008	FL2	Watershed BMPs (FL2)	1	$564
Wenck 2008	FL1	Watershed BMPs (FL1)	5	$564
Wenck 2008	FL1	Shoreline Restoration (FL1)	0	$753
Wenck 2008	FL2	Shoreline Restoration (FL2)	0	$753
Wenck 2008	FL3	Shoreline Restoration (FL3)	0	$753
Wenck 2008	In-lake	Alum treatment (FL3)	176	$1,128,960
Wenck 2008	In-lake	Alum treatment (FL2)	68	$539,392
Wenck 2008	44	FL44 Wetland Restoration	156	$99,098

3.8. Cost-Benefit Ranking

Table 3-13. Preliminary cost-benefit ranking for priority implementation subwatersheds

Implementation Subwatershed	Phosphorus Reductions Needed (lb/yr)	Project	Project P Reduction (lb/yr)	Total Project Cost	$/lb TP-yr (10-year)*
Shields Lake	531	Stormwater harvest and irrigation reuse + Shields Lake alum treatment	531	$1,030,000	$194
JD-6	169	To be determined			
Hayward Ave	123	To be determined			
Direct Drainage Area	73	Street Sweeping	33-48	n/a	n/a
		6th St Dead End – IESF, Diversion + Pretreatment	9.1	$56,750	$850
		Residential Raingardens	12.6	$73,554	$852
		Residential Raingardens	7.9	$49,036	$906
		Residential Raingardens	3.3	$24,518	$1,084
		Woodland Drive – IESF with Pretreatment	4.4	$37,250	$1,102
		Priority Shoreline 102,103,104,105	8.69	$96,850	$1,810
Castlewood	20	To be determined			
3rd Lake Pond	6	Treatment Wetland	56	$234,000	$418
1st Lake	0	Alum Treatment (to be determined)	392		
TOTAL	**932**	**All projects**	**1,058-1,103**		

* Cost-benefit estimates are preliminary and for planning purposes only. They may not account for all project costs (such as O&M). Cost-benefit estimates for street sweeping are not applicable as the total cost is based on City-wide implementation of a street sweeping program, with phosphorus reductions to multiple waterbodies. Cost-benefit estimates for the direct drainage area stormwater retrofit projects are from the North and South Shore Stormwater Retrofit Analysis reports.

APPENDIX A. 2016 MONITORING DATA

Appendix A.1. Monitoring Locations

Field reconnaissance was conducted on Dec. 11, 2015 of the 1987 diagnostic study monitoring sites (Figure 3-15), stormsewer outfall locations provided by the City (Figure 3-16), and other outfall locations provided by Forest Lake Lake Association members (Table 3-14). A total of 16 monitoring sites were originally identified as suitable for monitoring and representative of the total Forest Lake drainage area load. During the monitoring season, one site was removed due to lack of flow (R4W) and 4 additional sites were added (R14, R15, R2, and U9), for a total of 19 monitoring sites. Continuous flow and water quality grabs were collected at 12 of these sites, and water quality grabs only at the remaining 7 sites. A photo and description of each monitoring site is included in Table 3-15 below, beginning with the Forest Lake Outlet and moving counter clockwise around the lake as shown in Figure 3-14. Site names were chosen to be consistent with the 1987 diagnostic study.

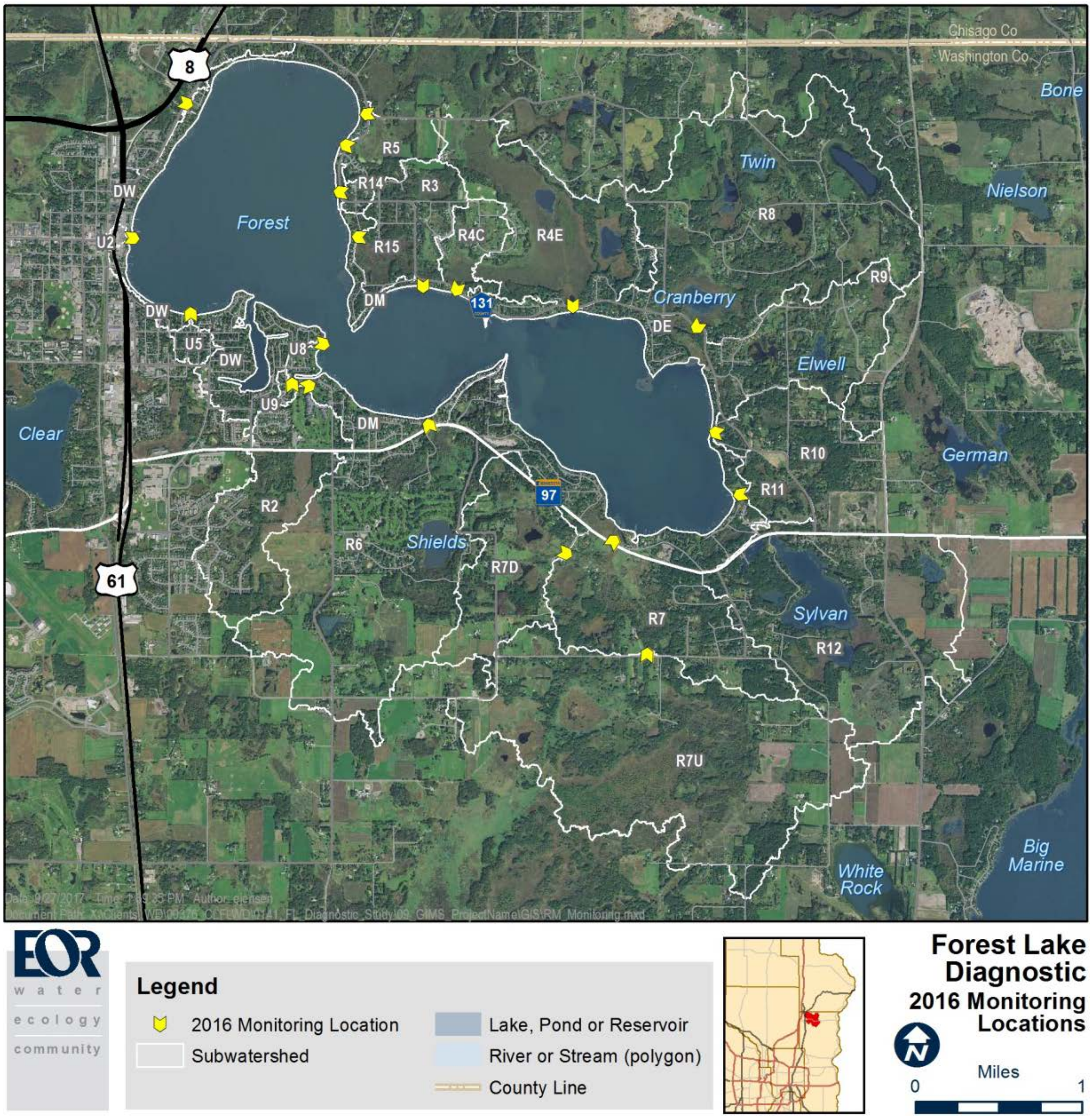


Figure 3-14. 2016 Monitoring Locations

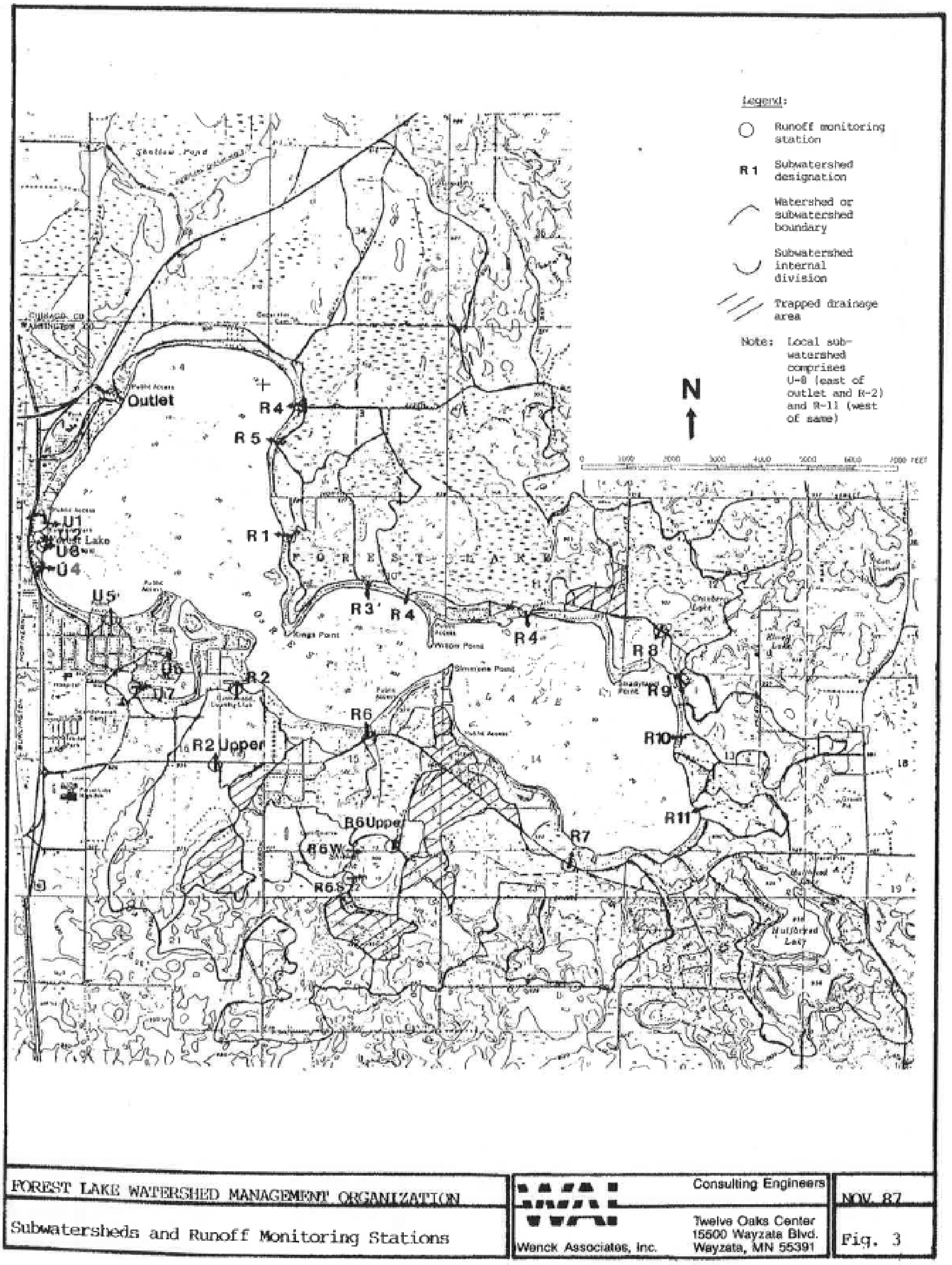


Figure 3-15. 1987 Forest Lake Diagnostic Monitoring Locations

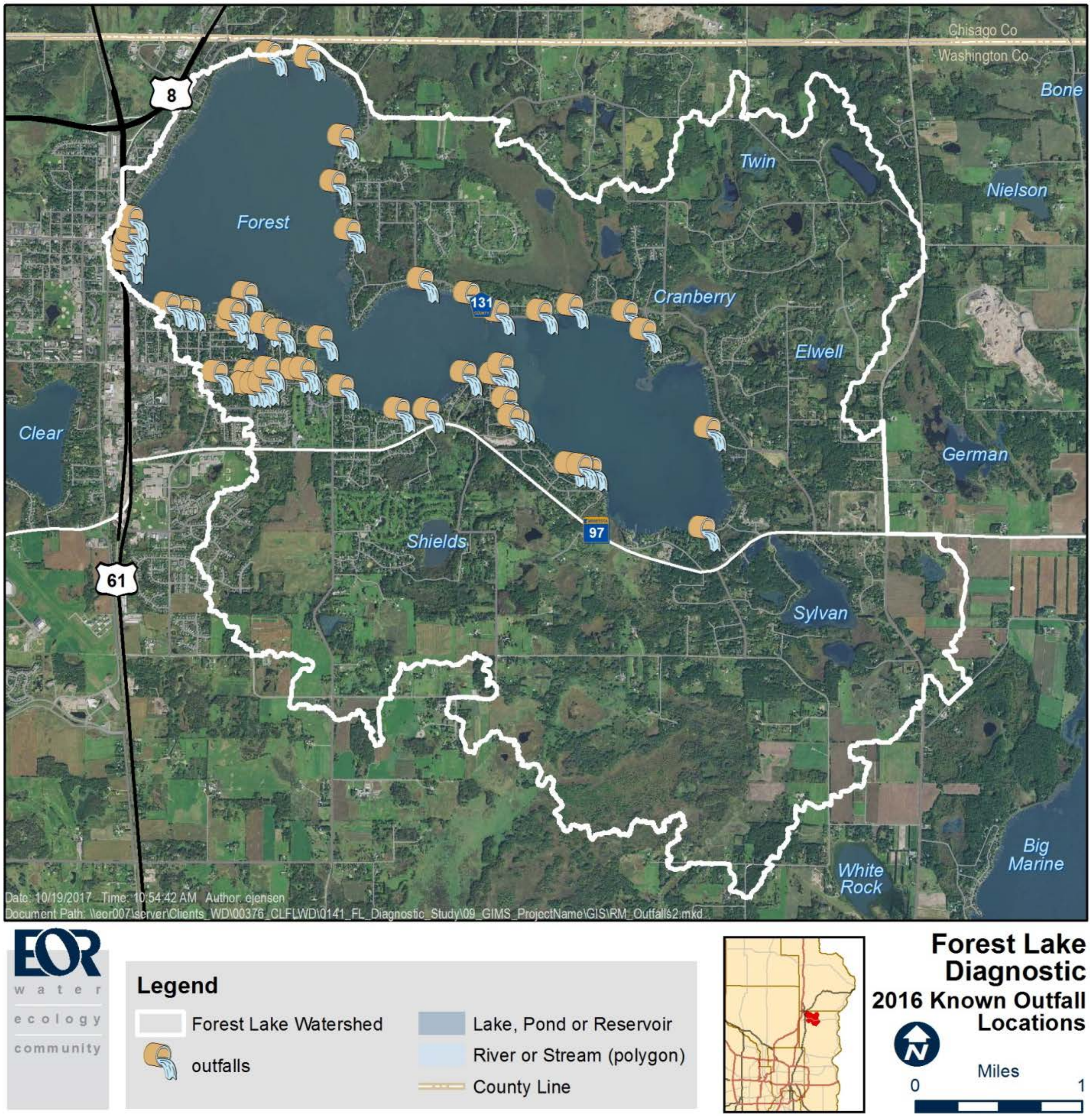


Figure 3-16. City of Forest Lake known stormsewer outfall locations (2016)

Table 3-14. Forest Lake Lake Association member known outfall locations (2015)

Address	Description
7149 N Shore Trail	Big Drainage
Between 7411-7415 N Shore Trail	Small
Between 7480-7485 N Shore Trail	Very large…drains big sub division
22800 Hayward Ave N	Drains a very large wetland
Between 7841-7871 N Shore Trail	
8789? N Shore Trail between 8739 and 8769	48 inch culvert
Between 21910-21920 Ideal Ave N	
9089 N Shore Trail	Ditch goes into culvert which disappears
9591 N Shore Trail on Log Lane	
20996 Juno Ave N…	Right down from the Log Cabin Rest
21431 Iverson Ave N	
@ end of Iverson	Another culvert 1 block west of 21431 Iverson Ave N on lake easement
Between 21421-21431 Iverson Ave N	May be same property as above
East side of 907 19th St SE	
1605 12th Ave SE	Golf course culvert
A few houses to the right of 1605 12th Ave SE	Very large drainage from Castlewood Golf Course
22156 Jason Ave N	Culvert drains into a bay channel
343 South Shore Dr.	I have a storm water culvert next to my property at 343 South Shore Drive in Forest Lake. The catch basin is in the street is located at the corner of South Shore Drive and SE 4th Street and the culvert runs along side my property and flows into the lake.
808 12th Ave SE	There is a culvert on our property 808 12th Ave SE , Forest Lake, MN. We live on a channel on Forest Lake off of the bay. The culvert flows into the channel. When the rains are heavy you can see the water flowing when standing by the culvert. The culvert is not visible from the windows in our house as we are uphill from the channel.
907 9th St. SE	Culvert with heavy flow during rain events

Address	Description
1630 11th Ave SE	There is a storm water outlet to Forest Lake between the following 2 addresses: 1630 11th Av SE, Forest Lake & 1706 11th Av SE, Forest Lake
1856 Beach Dr. SE	Culvert with heavy flow during rain events
6921 North Shore Trl N	Reported via telephone: Ditch runs from North Shore Trail to Forest Lake along west side of lot. Ditch contains cattails and other “natural vegetation”. Flow reportedly runs from street or driveway culvert through vegetated area, into a culvert that dumps directly into the lake. Heavy flow reported during springtime with low water clarity and brown color.
7411 North Shore Trl N	It is a large [runoff] and it drains from across the street, into culvert, turns into a small creek between two houses and then directly into the lake. A lot of water goes directly into lake from swamp across street. I am not good a measuring, but looks like a culvert that is used to go under driveways
7880 Scandia Trl N	There is a storm water stream running into FL on the East side of the property at 7880 Scandia Trail N. (Shields Lake outlet through electric fish barrier, culvert under 97, into FL)
8330 216th Street N & 21703 Imperial Ave N	During heavy rains the water runs down the hill from the east on 216th Street to the driveway of 8330 216st N and then down the drive into our yard at 21703 Imperial Ave North and turns directly into the lake. This is almost a river of water and it is completely washing out the gutters missing the sewer drain by just 25 feet or so and taking the most direct route to Forest Lake. Root cause it that the drain is too far to the west to handle the flow.
8571 North Shore Trl	During heavy rains we have a huge runoff through our property and our neighbors from the street
21319 Iverson Ave N	Driveway floods during heavy rains such as the event on 11/11/15 (~.5 inches). Eventually drains to lake. Reported a culvert near the road. Culvert not shown on City of Forest Lake's storm sewer inventory. Field recon possibly necessary.
21363 Iverson Ave N	Where we live storm water flows down a hill, into our back lot, under the road, through a neighbors back lot and then into a "pond" and into the lake. In a heavy rain storm, it's A LOT [of flow]. The water runs down a hill that that follows the road and flows from at least 4 different lots before it gets to mine. I have no idea how large the pond is - not very big - it's swampy even when it's not rainy and it is pre-existing.

Table 3-15. 2016 monitoring sites for the Forest Lake Diagnostic Study

	**Forest Lake Outlet** Estimated Dimensions: Concrete weir Notes: • Continuous flow • Water quality grab samples
	**Urban Site #2 (U2)** Estimated Dimensions: 18x28" arch Reinforced Concrete Pipe (RCP) Notes: • Water quality grab samples and instantaneous flow
	**Urban Site #5 (U5)** Estimated Dimensions: 18x28" arched RCP Notes: • Continuous flow inside pipe • ISCO composite water quality sampler

Urban Site #8 (U8)

<u>Estimated Dimensions</u>:

18" Corrugated Metal Pipe (CMP) under driveway, 75 feet of open channel to Forest Lake

<u>Notes</u>:

- Water quality grab samples and instantaneous flow

Castlewood West (U9)

<u>Estimated Dimensions</u>:

12" Reinforced Concrete Pipe (RCP)

<u>Notes</u>:

- Water quality grab samples and instantaneous flow

Castlewood East (R2)

<u>Estimated Dimensions</u>:

24" High Density Polyethylene (HDPE)

<u>Notes</u>:

- Continuous flow inside pipe
- Water quality grab samples

Rural Site #6 (R6)
(Shields Lake Outlet)

<u>Estimated Dimensions</u>:

48" Reinforced Concrete Pipe (RCP)

<u>Notes</u>:

- Continuous flow in ditch downstream of culvert
- Water quality grab samples
- Lake backwater occurs at this site when Forest Lake levels are high

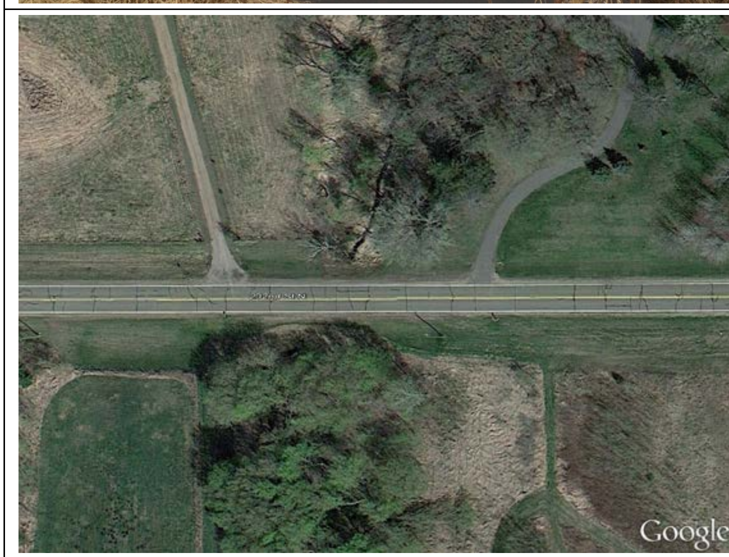
Rural Site #7 (R7)
(JD6 drainage outlet)

<u>Estimated Dimensions</u>:

Open ditch. Culvert underwater – need to monitor upstream of 97.

<u>Notes</u>:

- Water quality grab samples and instantaneous flow in ditch upstream of culvert
- Lake backwater occurs at this site when Forest Lake levels are high



Rural Site #7u (R7u)
(JD6 drainage)

<u>Estimated Dimensions</u>:

36" Reinforced Concrete Pipe (RCP)

<u>Notes</u>:

- Continuous flow in ditch downstream of culvert
- Water quality grab samples

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<tr>
<td>
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<td>Rural Site #7d (R7d)
(JD6 drainage)
Estimated Dimensions:
TBD
Notes:

Continuous flow in ditch downstream of culvert
Water quality grab samples
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<td>Rural Site #11 (R11)
Estimated Dimensions:
Open channel
Notes:

Continuous flow in open channel
Water quality grab samples
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<td>Rural Site #10 (R10)
Estimated Dimensions:
15” High Density Polyethylene (HDPE)
Notes:

3rd Lake Pond outlet where EOR has monitored in the past
Continuous flow in pipe
Water quality grab samples
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	**Cranberry Lake Outlet (R8)** Estimated Dimensions: 36” Reinforced Concrete Pipe (RCP) Notes: • Continuous flow in ditch downstream of culvert • Water quality grab samples
	**Rural Site #4 East (R4E)** Estimated Dimensions: 30” Corrugated Metal Pipe (CMP) Notes: • Continuous flow in ditch downstream of culvert • Water quality grab samples
	**Rural Site #4 Central (R4C)** Estimated Dimensions: 24” CMP Notes: • Continuous flow in ditch downstream of culvert • Water quality grab samples

	**Rural Site #3 (R3)** Estimated Dimensions: 24” Corrugated Metal Pipe (CMP) Notes: • Continuous flow in ditch downstream of culvert • Water quality grab samples
	**Rural Site #5 (R5)** Estimated Dimensions: 15” Corrugated Metal Pipe (CMP) – in very poor condition and partially plugged with sediment Notes: • Continuous flow in ditch downstream of culvert • Water quality grab samples
	**Rural Site #15 (R15)** Estimated Dimensions: 8” High Density Polyethylene (HDPE) Notes: • Continuous flow in pipe • Water quality grab samples

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Rural Site #14 (R14)

<u>Estimated Dimensions</u>:

8” High Density Polyethylene

<u>Notes</u>:

- Continuous flow in ditch upstream of culvert
- Water quality grab samples

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Rural Site #4 West (R4W)

<u>Estimated Dimensions</u>:

15” CMP. Two-thirds plugged with debris.

<u>Notes</u>:

- Continuous flow attempted in ditch immediately upstream of culvert
- Very low stage and flow, few water quality grabs collected

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Appendix A.2. Water Quality Data

Site	Date	Time	TP [mg/L]	Ortho P [mg/L]	TSS [mg/L]	Fe [mg/L]	Ortho:TP	Fe:TP	Notes
Castle East	4/28/2016	11:00	0.083	0.052	4.60	0.280	63%	3.4	Rain event sample
Castle East	5/24/2016	13:10	0.101	0.049	2.40	0.340	48%	3.4	Rain event sample
Castle East	6/15/2016	12:20	0.242	0.178	19.7	0.62	74%	2.6	Rain event sample
Castle East	7/24/2016	11:25	0.233			0.550		2.4	Rain event sample
Castle East	8/4/2016	12:10	0.370	0.288	18.67	0.680	78%	1.8	Rain event sample
Castle East	8/11/2016	13:50	0.327	0.285	42.4	1.400	87%	4.3	Rain event sample
Castle East	9/5/2016	10:25	0.290	0.217	24.75	1.00	75%	3.4	Rain event sample
Castle East	9/22/2016	8:50	0.248	0.192	6.40	0.440	77%	1.8	Rain event sample
Castle West	4/28/2016	10:48	0.171	0.118	5.80	0.560	69%	3.3	Rain event sample
Castle West	6/15/2016	11:55	0.568	0.471	5.67	0.98	83%	1.7	Rain event sample
Castle West	7/24/2016	11:15	1.024	0.652	25.3	2.00	64%	2.0	Rain event sample
Castle West	8/4/2016	12:00	0.302	0.183	5.67	0.730	61%	2.4	Rain event sample
Castle West	8/11/2016	13:45	0.319	0.267	4.62	0.80	84%	2.5	Rain event sample
Castle West	9/5/2016	10:15	0.224	0.164	6.40	0.610	73%	2.7	Rain event sample
Castle West	9/22/2016	8:40	0.316	0.211	22.20	1.00	67%	3.2	Rain event sample
Cranberry Outlet	3/11/2016	9:22	0.149	0.009	4.00	0.620	6%	4.2	Snowmelt sample
Cranberry Outlet	3/16/2016	10:50	0.221	0.010	3.20	0.99	5%	4.5	Rain event sample
Cranberry Outlet	3/30/2016	12:27	0.031	0.008	4.60	0.96	25%	30.7	Rain event sample
Cranberry Outlet	4/25/2016	11:42	0.024	0.006	3.00	0.320	26%	13.5	Rain event sample
Cranberry Outlet	5/24/2016	10:37	0.025	0.007	4.00	0.450	26%	18.1	Rain event sample
Cranberry Outlet	6/15/2016	9:43	0.024	0.008	13.3	0.66	34%	27.8	Rain event sample
Cranberry Outlet	7/24/2016	8:30	0.055	0.018	5.33	1.40	32%	25.6	Rain event sample
Cranberry Outlet	8/4/2016	14:00	0.031	0.012	1.00	0.610	38%	19.8	Rain event sample
Cranberry Outlet	8/11/2016	12:25	0.037	0.018	17.0	0.670	49%	18.2	Rain event sample
Cranberry Outlet	9/5/2016	12:30	0.031	0.007	4.60	1.00	23%	32.1	Rain event sample

Site	Date	Time	TP [mg/L]	Ortho P [mg/L]	TSS [mg/L]	Fe [mg/L]	Ortho:TP	Fe:TP	Notes
Cranberry Outlet	9/22/2016	11:00	0.033	0.009	8.80	0.940	26%	28.7	Rain event sample
D1	3/30/2016	9:30	0.298	0.282	23.0	1.80	95%	6.0	Rain event sample
D1	4/28/2016	11:40	0.121	0.125	11.2	0.700	103%	5.8	Rain event sample
D1	6/30/2016	12:10	0.371	0.263	20.0	0.58	71%	1.6	Rain event sample
D1	7/24/2016	7:30	0.167	0.115	2.80	0.092	69%	0.6	Rain event sample
D1	8/11/2016	11:30	0.134	0.092	1.00	0.210	69%	1.6	Rain event sample
Duplicate from IRI	5/24/2016		0.054	0.016	1.60	0.210	30%	3.9	Duplicate collected at R4E
Duplicate from Pace	5/24/2016		0.038	0.010	N/A	0.214	26%	5.6	Lab lost TSS sample, no result
R10	3/9/2016	16:00	0.118	0.023	3.6	0.460	19%	3.9	Snowmelt sample
R10	3/16/2016	10:30	0.257	0.150	33.4	0.42	58%	1.6	Rain event sample
R10	3/30/2016	12:10	0.089	0.030	8.20	0.26	34%	2.9	Rain event sample
R10	4/25/2016	11:25	0.085	0.055	16.4	0.360	65%	4.2	Rain event sample
R10	5/24/2016	10:20	0.197	0.141	7.20	0.900	71%	4.6	Rain event sample
R10	6/15/2016	10:08	0.112	0.073	9.00	0.60	65%	5.4	Rain event sample
R10	8/4/2016	13:50	0.193	0.108	179	0.500	56%	2.6	Rain event sample
R10	8/11/2016	12:35	0.256	0.178	14.2	0.45	70%	1.8	Rain event sample
R10	9/5/2016	12:25	0.241	0.174	10.80	0.530	72%	2.2	Rain event sample
R10	9/22/2016	10:51	0.202	0.135	11.40	0.340	67%	1.7	Rain event sample
R11	3/11/2016	8:45	0.139	0.027	4.27	0.870	19%	6.3	Snowmelt sample
R11	3/16/2016	10:00	0.215	0.131	39.2	3.50	61%	16.3	Rain event sample
R11	3/30/2016	11:45	0.163	0.107	23.4	2.70	66%	16.6	Rain event sample
R11	4/25/2016	11:08	0.139	0.105	24.4	2.70	76%	19.4	Rain event sample
R11	5/24/2016	10:00	0.042	0.024	4.40	0.560	56%	13.3	Rain event sample
R11	6/15/2016	10:30	0.120	0.043	93.3	1.30	36%	10.9	Rain event sample
R11	7/24/2016	10:35	0.141	0.081	20.7	3.50	57%	24.8	Rain event sample
R11	8/4/2016	13:35	0.132	0.112	10.3	1.60	85%	12.1	Rain event sample

Site	Date	Time	TP [mg/L]	Ortho P [mg/L]	TSS [mg/L]	Fe [mg/L]	Ortho:TP	Fe:TP	Notes
R11	8/11/2016	12:50	0.096	0.062	4.60	3.00	64%	31.1	Rain event sample
R11	9/5/2016	12:00	0.144	0.112	17.80	1.80	78%	12.5	Rain event sample
R11	9/22/2016	10:30	0.092	0.065	5.60	1.00	71%	10.9	Rain event sample
R3	3/11/2016	11:25	0.145	0.040	1.60	0.310	28%	2.1	Snowmelt sample
R3	3/16/2016	12:15	0.774	0.057	2.60	0.26	7%	0.3	Rain event sample
R3	3/30/2016	13:15	0.052	0.023	1.60	0.24	45%	4.6	Rain event sample
R3	4/25/2016	12:25	0.198	0.076	1.60	0.360	39%	1.8	Rain event sample
R3	6/15/2016	9:02	0.263	0.207	3.00	0.57	78%	2.2	Rain event sample
R3	7/24/2016	7:50	0.354	0.292	5.33	0.240	82%	0.7	Rain event sample
R3	8/4/2016	14:25	0.555	0.447	7.67	2.60	81%	4.7	Rain event sample
R3	8/11/2016	12:00	0.429	0.375	1.00	0.860	87%	2.0	Rain event sample
R3	9/5/2016	13:30	0.327	0.282	2.60	1.00	86%	3.1	Rain event sample
R3	9/22/2016	11:23	0.318	0.281	3.40	1.20	88%	3.8	Rain event sample
R4C	3/11/2016	10:35	0.194	0.081	1.7	0.310	42%	1.6	Snowmelt sample
R4C	3/16/2016	11:55	0.249	0.103	2.80	0.28	41%	1.1	Rain event sample
R4C	3/30/2016	13:09	0.083	0.048	<1.00	0.27	58%	3.3	Rain event sample
R4C	4/25/2016	12:20	0.176	0.128	2.40	0.410	73%	2.3	Rain event sample
R4C	5/24/2016	11:25	0.270	0.205	8.80	1.40	76%	5.2	Rain event sample
R4C	6/15/2016	9:15	0.370	0.287	4.67	0.99	77%	2.7	Rain event sample
R4C	7/24/2016	8:00	0.523	0.468	68.0	0.580	90%	1.1	Rain event sample
R4C	8/4/2016	14:20	0.500	0.395	5.67	1.30	79%	2.6	Rain event sample
R4C	8/11/2016	12:05	0.345	0.289	3.40	0.800	84%	2.3	Rain event sample
R4C	9/5/2016	13:15	0.248	0.201	3.20	0.840	81%	3.4	Rain event sample
R4C	9/22/2016	11:15	0.204	0.169	2.60	1.10	83%	5.4	Rain event sample
R4E	3/11/2016	9:57	0.128	0.013	1.1	0.480	10%	3.7	Snowmelt sample
R4E	3/16/2016	11:10	0.069	0.028	1.60	0.66	40%	9.6	Rain event sample

Site	Date	Time	TP [mg/L]	Ortho P [mg/L]	TSS [mg/L]	Fe [mg/L]	Ortho:TP	Fe:TP	Notes
R4E	3/30/2016	12:50	0.028	0.008	1.00	0.20	29%	7.1	Rain event sample
R4E	4/25/2016	12:08	0.040	0.019	1.20	0.230	46%	5.7	Rain event sample
R4E	5/24/2016	10:52	0.034	0.015	0.80	0.210	45%	6.1	Rain event sample + duplicate
R4E	6/15/2016	9:25	0.083	0.043	3.67	0.82	51%	9.8	Rain event sample
R4E	7/24/2016	8:15	0.106	0.044	5.67	1.40	41%	13.2	Rain event sample
R4E	8/4/2016	14:10	0.176	0.140	4.67	1.40	80%	8.0	Rain event sample
R4E	8/11/2016	12:15	0.142	0.111	3.40	1.000	78%	7.1	Rain event sample
R4E	9/5/2016	13:00	0.153	0.114	3.20	1.40	75%	9.2	Rain event sample
R4E	9/22/2016	11:08	0.075	0.046	4.40	0.820	61%	10.9	Rain event sample
R4W	3/16/2016	13:00	0.211	0.090	10.2	0.58	43%	2.7	Rain event sample
R4W	4/25/2016	13:05	0.184	0.098	7.20	0.580	53%	3.1	Rain event sample
R5	3/11/2016	13:15	0.214	0.056	4.00	0.240	26%	1.1	Snowmelt sample
R5	3/16/2016	12:40	0.919	0.042	8.60	0.26	5%	0.3	Rain event sample
R5	3/30/2016	13:50	0.070	0.042	8.20	0.28	60%	4.0	Rain event sample
R5	4/25/2016	12:50	0.165	0.116	6.80	0.810	70%	4.9	Rain event sample
R5	5/24/2016	11:45	0.164	0.113	2.14	1.80	69%	11.0	Rain event sample
R5	6/15/2016	8:35	0.358	0.280	8.00	1.20	78%	3.4	Rain event sample
R5	8/4/2016	14:50	0.492	0.396	8.33	1.10	80%	2.2	Rain event sample
R5	8/11/2016	11:20	0.537	0.209	6.00	1.40	39%	2.6	Rain event sample
R5	9/5/2016	13:50	0.396	0.317	10.00	1.90	80%	4.8	Rain event sample
R5	9/22/2016	11:50	0.311	0.237	4.60	0.930	76%	3.0	Rain event sample
R5	7/24/2016	7:15	0.468	0.410	8.00	0.360	88%	0.8	Rain event sample
R5 South	3/11/2016	12:15	0.256	0.088	2.80	0.160	34%	0.6	Snowmelt sample
R5 South	3/16/2016	12:25	0.269	0.166	4.80	0.31	62%	1.2	Rain event sample
R5 South	3/30/2016	13:30	0.091	0.044	9.20	0.38	48%	4.2	Rain event sample
R5 South	4/25/2016	12:40	0.207	0.156	3.40	0.390	76%	1.9	Rain event sample

Site	Date	Time	TP [mg/L]	Ortho P [mg/L]	TSS [mg/L]	Fe [mg/L]	Ortho:TP	Fe:TP	Notes
R5 South	5/24/2016	12:05	0.182	0.113	11.60	2.00	62%	11.0	Rain event sample
R5 South	6/15/2016	8:50	0.425	0.336	4.33	0.73	79%	1.7	Rain event sample
R5 South	8/4/2016	14:35	0.379	0.278	3.00	0.47	74%	1.2	Rain event sample
R5 South	8/11/2016	11:45	0.563	0.470	<1.00	0.38	83%	0.7	Rain event sample
R5 South	9/5/2016	13:40	0.399	0.329	3.00	0.970	83%	2.4	Rain event sample
R5 South	9/22/2016	11:35	0.359	0.284	3.20	0.570	79%	1.6	Rain event sample
R6	3/9/2016	14:55	3.400	0.036	6.20	0.510	1%	0.1	Snowmelt sample
R6	3/16/2016	8:30	0.306	0.148	9.33	0.63	49%	2.1	Rain event sample
R6	3/30/2016	10:23	0.088	0.040	5.00	0.34	46%	3.9	Rain event sample
R6	4/25/2016	8:20	0.109	0.072	2.40	0.460	67%	4.2	Rain event sample
R6	5/24/2016	8:30	0.230	0.166	6.40	0.910	72%	4.0	Rain event sample
R6	7/24/2016	11:00	0.370	0.284	7.00	0.870	77%	2.4	Rain event sample
R6	8/4/2016	12:25	0.464	0.324	5.00	1.30	70%	2.8	Rain event sample
R6	8/11/2016	13:30	0.322	0.267	2.00	0.41	83%	1.3	Rain event sample
R6	9/5/2016	10:40	0.307	0.228	7.60	0.840	74%	2.7	Rain event sample
R6	9/22/2016	9:00	0.342	0.235	20.20	0.830	69%	2.4	Rain event sample
R7	3/9/2016	12:50	0.226	0.071	14.2	2.10	31%	9.3	Snowmelt sample
R7	3/16/2016	8:55	0.157	0.103	12.0	1.90	66%	12.1	Rain event sample
R7	3/30/2016	10:47	0.113	0.087	15.2	1.70	77%	15.1	Rain event sample
R7	4/25/2016	10:16	0.413	0.072	10.6	1.20	17%	2.9	Rain event sample
R7	5/24/2016	9:08	0.096	0.067	2.40	1.40	70%	14.6	Rain event sample
R7	6/15/2016	10:15	0.241	0.140	13.0	2.60	58%	10.8	Rain event sample
R7	7/24/2016	10:00	0.154	0.118	2.33	1.70	77%	11.0	Rain event sample
R7	8/4/2016	13:05	0.260	0.192	22.0	2.40	74%	9.2	Rain event sample
R7	8/11/2016	13:15	0.178	0.173	24.0	1.000	97%	5.6	Rain event sample
R7	9/5/2016	11:10	0.260	0.201	20.60	3.00	77%	11.6	Rain event sample

Site	Date	Time	TP [mg/L]	Ortho P [mg/L]	TSS [mg/L]	Fe [mg/L]	Ortho:TP	Fe:TP	Notes
R7	9/22/2016	9:40	0.177	0.132	5.00	1.20	75%	6.8	Rain event sample
R7D	3/9/2016	12:25	0.140	0.064	5.2	2.30	46%	16.5	Snowmelt sample
R7D	3/16/2016	9:20	0.148	0.075	8.40	1.90	51%	12.8	Rain event sample
R7D	3/30/2016	10:32	0.102	0.047	5.60	1.50	46%	14.8	Rain event sample
R7D	4/25/2016	10:00	0.184	0.064	6.20	2.00	35%	10.9	Rain event sample
R7D	5/24/2016	8:50	0.150	0.109	5.60	3.30	73%	22.1	Rain event sample
R7D	6/15/2016	11:25	0.220	0.161	12.0	5.80	73%	26.3	Rain event sample
R7D	7/24/2016	9:45	0.374	0.290	15.00	11.0	78%	29.4	Rain event sample
R7D	8/4/2016	12:55	0.241	0.192	7.00	3.20	80%	13.3	Rain event sample
R7D	8/11/2016	13:30	0.196	0.142	6.40	2.60	73%	13.3	Rain event sample
R7D	9/5/2016	10:50	0.188	0.142	7.43	2.20	76%	11.7	Rain event sample
R7D	9/22/2016	9:21	0.161	0.111	5.60	1.70	69%	10.5	Rain event sample
R7U	3/9/2016	14:00	0.164	0.070	12.0	1.70	43%	10.4	Snowmelt sample
R7U	3/16/2016	9:40	0.137	0.091	8.20	1.20	66%	8.8	Rain event sample
R7U	3/30/2016	11:08	0.086	0.057	14.8	0.88	67%	10.3	Rain event sample
R7U	4/25/2016	10:40	0.105	0.074	14.6	0.950	71%	9.0	Rain event sample
R7U	5/24/2016	9:30	0.099	0.070	4.00	1.10	70%	11.1	Rain event sample
R7U	6/15/2016	10:42	0.310	0.188	28.0	3.40	61%	11.0	Rain event sample
R7U	7/24/2016	10:20	0.404	0.360	11.0	3.20	89%	7.9	Rain event sample
R7U	8/4/2016	13:20	0.308	0.254	19.0	3.60	82%	11.7	Rain event sample
R7U	8/11/2016	13:05	0.325	0.261	19.2	2.40	80%	7.4	Rain event sample
R7U	9/5/2016	11:35	0.332	0.270	16.22	3.20	81%	9.6	Rain event sample
R7U	9/22/2016	10:02	0.267	0.210	10.80	1.60	79%	6.0	Rain event sample
U2	3/15/2016	9:25	0.232	0.117	63.0	1.80	50%	7.8	Post rain event- low flow
U2	3/30/2016	9:10	0.126	0.094	56.6	1.70	74%	13.5	Rain event sample
U2	4/25/2016	9:15	0.289	0.127	206	3.50	44%	12.1	Rain event sample

Site	Date	Time	TP [mg/L]	Ortho P [mg/L]	TSS [mg/L]	Fe [mg/L]	Ortho:TP	Fe:TP	Notes
U2	6/30/2016	11:50	0.292	0.059	9.00	1.80	20%	6.2	Rain event sample
U2	7/5/2016	18:55	0.386	0.118	93.3	0.550	31%	1.4	Rain event sample
U2	7/24/2016	6:55	0.272	0.236	23.0		87%	0.0	Rain event sample
U2	8/4/2016	11:25	0.419	0.310	5.00	0.520	74%	1.2	Rain event sample
U2	9/5/2016	9:25	0.173	0.125	16.00	0.520	73%	3.0	Rain event sample
U5	3/15/2016	9:37	0.381	0.127	52.3	1.90	33%	5.0	Post rain event- low flow
U5	3/30/2016	10:05	0.206	0.155	47.4	1.20	75%	5.8	Composite sample
U5	4/21/2016	15:00	0.333	0.210	38.4	0.880	63%	2.6	Composite sample
U5	4/25/2016	15:10	0.170	0.121	93.6	1.40	71%	8.2	Composite sample
U5	5/24/2016	12:25	0.664	0.162	59.20	0.980	24%	1.5	Composite sample
U5	6/15/2016	10:00	0.143	0.084	521	0.41	58%	2.9	Composite sample
U5	7/1/2016	12:30	0.450	0.255	8.67	1.00	57%	2.2	Composite sample
U5	7/8/2016	11:30	0.460	0.306	33.3	2.80	66%	6.1	Composite sample
U5	7/24/2016	11:35	0.445			0.350		0.8	Composite sample
U5	8/4/2016	11:40	0.213	0.171	1.67	0.140	80%	0.7	Grab sample
U5	8/19/2016	14:00	0.220	0.140	20.4	0.360	64%	1.6	Composite sample
U5	9/16/2016	9:50	0.274	0.152	29.4	0.430	55%	1.6	Composite sample
U5	9/26/2016	7:55	0.187	0.113	24.2	0.860	61%	4.6	Composite sample
U7	3/15/2016	9:52	0.176	0.135	16.3	0.38	77%	2.2	Post rain event- low flow
U7	3/30/2016	8:45	0.090	0.078	3.00	0.22	87%	2.4	Rain event sample
U7	4/25/2016	9:42	0.203	0.112	35.40	0.840	55%	4.1	Rain event sample

Appendix B.3. Existing Segment Mass Balance Based Upon Predicted Concentrations

Segment Mass Balance Based Upon Predicted Concentrations

Component:	**TOTAL P**			**Segment:**	**1**	**East**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
1	1	DD-E	0.3533	4.8%	50.2	6.1%	142
2	1	CLO	0.3603	4.9%	28.5	3.5%	79
3	1	R4E	0.3847	5.2%	33.7	4.1%	88
4	1	R7	0.3545	4.8%	66.9	8.2%	189
5	1	R7d	0.2265	3.1%	38.8	4.7%	171
6	1	R7u	1.1460	15.5%	230.2	28.1%	201
7	1	R9	0.0826	1.1%	4.6	0.6%	56
8	1	R10	0.0768	1.0%	14.4	1.8%	188
9	1	R11	0.0678	0.9%	9.6	1.2%	142
10	1	Keewahtin (Sylvan) GW	0.8094	11.0%	24.3	3.0%	30
11	1	Regional GW	0.3763	5.1%	21.0	2.6%	56
PRECIPITATION			3.1505	42.6%	85.1	10.4%	27
TRIBUTARY INFLOW			4.2382	57.4%	522.2	63.8%	123
NET DIFFUSIVE INFLOW			0.0000	0.0%	211.7	25.9%	
***TOTAL INFLOW			7.3887	100.0%	819.0	100.0%	111
ADVECTIVE OUTFLOW			5.4984	74.4%	178.0	21.7%	32
***TOTAL OUTFLOW			5.4984	74.4%	178.0	21.7%	32
***EVAPORATION			1.8903	25.6%	0.0	0.0%	
***RETENTION			0.0000	0.0%	641.0	78.3%	

Hyd. Residence Time =	2.1945	yrs
Overflow Rate =	1.7	m/yr
Mean Depth =	3.8	m

Component:	**TOTAL P**			**Segment:**	**2**	**Middle**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm³/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m³**
12	1	DD-M	0.1292	1.5%	22.9	3.5%	177
13	1	Castle E	0.3270	3.7%	57.9	8.9%	177
14	1	Castle W	0.0104	0.1%	1.8	0.3%	177
15	1	R3	0.0701	0.8%	27.6	4.2%	393
16	1	R4C	0.0119	0.1%	2.8	0.4%	237

17	1	Shields	1.1778	13.3%	311.4	47.7%	264
18	1	Regional GW	0.1775	2.0%	9.9	1.5%	56
PRECIPITATION			1.4864	16.7%	40.1	6.2%	27
TRIBUTARY INFLOW			1.9039	21.4%	434.3	66.6%	228
ADVECTIVE INFLOW			5.4984	61.9%	178.0	27.3%	32
***TOTAL INFLOW			8.8887	100.0%	652.5	100.0%	73
ADVECTIVE OUTFLOW			7.9969	90.0%	285.1	43.7%	36
NET DIFFUSIVE OUTFLOW			0.0000	0.0%	101.1	15.5%	
***TOTAL OUTFLOW			7.9969	90.0%	386.2	59.2%	48
***EVAPORATION			0.8918	10.0%	0.0	0.0%	
***RETENTION			0.0000	0.0%	266.3	40.8%	

Hyd. Residence Time = 0.6301 yrs
Overflow Rate = 5.4 m/yr
Mean Depth
= 3.4 m

Component:		**TOTAL P**		**Segment:**	**3**	**West**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
19	1	DD-W	0.4549	3.4%	95.0	9.3%	209
20	1	D1	0.0109	0.1%	4.0	0.4%	363
21	1	R4W	0.0699	0.5%	25.4	2.5%	363
22	1	R5	0.0593	0.4%	21.5	2.1%	363
23	1	R5S	0.0554	0.4%	18.4	1.8%	332
24	1	U2	0.0112	0.1%	2.3	0.2%	209
25	1	U5	0.0395	0.3%	8.2	0.8%	209
26	1	U7	0.0020	0.0%	0.4	0.0%	209
27	1	Regional GW	0.5190	3.8%	29.0	2.8%	56
PRECIPITATION			4.3455	32.0%	117.3	11.5%	27
INTERNAL LOAD			0.0000	0.0%	415.8	40.7%	
TRIBUTARY INFLOW			1.2221	9.0%	204.3	20.0%	167
ADVECTIVE INFLOW			7.9969	59.0%	285.1	27.9%	36
***TOTAL INFLOW			13.5645	100.0%	1022.6	100.0%	75
ADVECTIVE OUTFLOW			10.9572	80.8%	402.8	39.4%	37
NET DIFFUSIVE OUTFLOW			0.0000	0.0%	110.6	10.8%	
***TOTAL OUTFLOW			10.9572	80.8%	513.4	50.2%	47
***EVAPORATION			2.6073	19.2%	0.0	0.0%	
***RETENTION			0.0000	0.0%	509.1	49.8%	

Hyd. Residence Time = 1.1937 yrs
Overflow Rate = 2.5 m/yr
Mean Depth
= 3.0 m

Appendix B.4. Existing Predicted & Observed Values Ranked Against CE Model Development Dataset

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 4 Area-Wtd Mean

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	35.0	0.35	36.4%	35.1	0.05	36.4%

Segment: 1 East

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	32.4	0.37	33.2%	32.4	0.10	33.2%

Segment: 2 Middle

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	35.7	0.34	37.1%	35.6	0.10	37.1%

Segment: 3 West

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	36.8	0.34	38.4%	36.8	0.01	38.5%

Appendix B.5. Goal Segment Mass Balance Based Upon Predicted Concentrations

Segment Mass Balance Based Upon Predicted Concentrations

Component:		TOTAL P		Segment:	1	East	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	DD-E	0.3533	4.8%	50.2	7.9%	142
2	1	CLO	0.3603	4.9%	28.5	4.5%	79
3	1	R4E	0.3847	5.2%	33.7	5.3%	88
4	1	R7	0.3545	4.8%	53.2	8.4%	150
5	1	R7d	0.2265	3.1%	34.0	5.3%	150
6	1	R7u	1.1460	15.5%	171.9	27.1%	150
7	1	R9	0.0826	1.1%	4.6	0.7%	56
8	1	R10	0.0768	1.0%	11.5	1.8%	150
9	1	R11	0.0678	0.9%	9.6	1.5%	142
10	1	Sylvan GW	0.8094	11.0%	24.3	3.8%	30
11	1	Regional GW	0.3763	5.1%	21.0	3.3%	56
PRECIPITATION			3.1505	42.6%	85.1	13.4%	27
TRIBUTARY INFLOW			4.2382	57.4%	442.5	69.7%	104
NET DIFFUSIVE INFLOW			0.0000	0.0%	107.7	16.9%	
***TOTAL INFLOW			7.3887	100.0%	635.2	100.0%	86
ADVECTIVE OUTFLOW			5.4984	74.4%	151.5	23.9%	28
***TOTAL OUTFLOW			5.4984	74.4%	151.5	23.9%	28
***EVAPORATION			1.8903	25.6%	0.0	0.0%	
***RETENTION			0.0000	0.0%	483.7	76.1%	

Hyd. Residence Time =	2.1945	yrs
Overflow Rate =	1.7	m/yr
Mean Depth =	3.8	m

Component:		TOTAL P		Segment:	2	Middle	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
12	1	DD-M	0.1292	1.5%	19.4	4.5%	150
13	1	Castle E	0.3270	3.7%	49.0	11.5%	150
14	1	Castle W	0.0104	0.1%	1.6	0.4%	150
15	1	R3	0.0701	0.8%	10.5	2.5%	150
16	1	R4C	0.0119	0.1%	1.8	0.4%	150
17	1	Shields	1.1778	13.3%	70.7	16.5%	60
18	1	Regional GW	0.1775	2.0%	9.9	2.3%	56
PRECIPITATION			1.4864	16.7%	40.1	9.4%	27
TRIBUTARY INFLOW			1.9039	21.4%	162.9	38.1%	86
ADVECTIVE INFLOW			5.4984	61.9%	151.5	35.5%	28

NET DIFFUSIVE INFLOW	0.0000	0.0%	72.7	17.0%	
***TOTAL INFLOW	8.8887	100.0%	427.2	100.0%	48
ADVECTIVE OUTFLOW	7.9969	90.0%	233.7	54.7%	29
***TOTAL OUTFLOW	7.9969	90.0%	233.7	54.7%	29
***EVAPORATION	0.8918	10.0%	0.0	0.0%	
***RETENTION	0.0000	0.0%	193.5	45.3%	

Hyd. Residence Time = 0.6301 yrs
Overflow Rate = 5.4 m/yr
Mean Depth
= 3.4 m

Component: TOTAL P **Segment: 3 West**

Trib	Type	Location	Flow hm³/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m³
19	1	DD-W	0.4549	3.4%	68.2	7.6%	150
20	1	D1	0.0109	0.1%	1.6	0.2%	150
21	1	R4W	0.0699	0.5%	10.5	1.2%	150
22	1	R5	0.0593	0.4%	8.9	1.0%	150
23	1	R5S	0.0554	0.4%	8.3	0.9%	150
24	1	U2	0.0112	0.1%	1.7	0.2%	150
25	1	U5	0.0395	0.3%	5.9	0.7%	150
26	1	U7	0.0020	0.0%	0.3	0.0%	150
27	1	Regional GW	0.5190	3.8%	29.0	3.2%	56
PRECIPITATION			4.3455	32.0%	117.3	13.0%	27
INTERNAL LOAD			0.0000	0.0%	415.8	46.1%	
TRIBUTARY INFLOW			1.2221	9.0%	134.5	14.9%	110
ADVECTIVE INFLOW			7.9969	59.0%	233.7	25.9%	29
***TOTAL INFLOW			13.5645	100.0%	901.4	100.0%	66
ADVECTIVE OUTFLOW			10.9572	80.8%	340.1	37.7%	31
NET DIFFUSIVE OUTFLOW			0.0000	0.0%	180.3	20.0%	
***TOTAL OUTFLOW			10.9572	80.8%	520.4	57.7%	47
***EVAPORATION			2.6073	19.2%	0.0	0.0%	
***RETENTION			0.0000	0.0%	381.0	42.3%	

Hyd. Residence Time = 1.1937 yrs
Overflow Rate = 2.5 m/yr
Mean Depth
= 3.0 m

Appendix B.6. Goal Predicted & Observed Values Ranked Against CE Model Development Dataset

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 4 Area-Wtd Mean

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	29.5	0.34	29.5%	35.1	0.05	36.4%

Segment: 1 East

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	27.6	0.36	27.0%	32.4	0.10	33.2%

Segment: 2 Middle

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	29.2	0.34	29.2%	35.6	0.10	37.1%

Segment: 3 West

		Predicted Values--->			Observed Values--->		
Variable		**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P	MG/M3	31.0	0.33	31.5%	36.8	0.01	38.5%