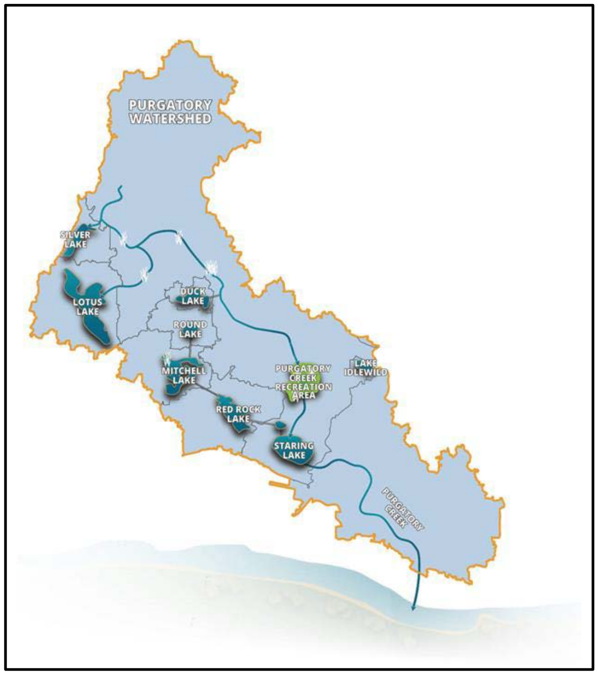
BARR



Lotus, Silver, Duck, Round, Mitchell, Red Rock Use Attainability Analysis Update; Lake Idlewild and Staring Lake Use Attainability Analysis; and Lower Purgatory Creek Stabilization Study

Prepared for
Riley-Purgatory-Bluff Creek Watershed District

RILEY
PURGATORY
BLUFF CREEK
WATERSHED DISTRICT November, 2016 (Revised March, 2017)

4300 MarketPointe Drive
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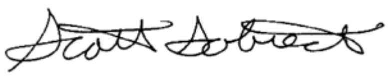
Minneapolis, MN 55435
Phone: 952.832.2600
Fax: 952.832.2601

Certifications

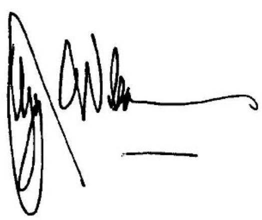
I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota.



11-8-2016

Scott Sobiech
PE #: MN 41338

Date



11-8-2016

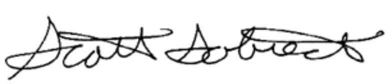
Gregory John Wilson
PE #: MN 25782

Date

Revisions:

- Updated Lotus Lake analysis (Chapter 4) to reflect updated ravine erosion information provided by RPBCWD staff, additional stormwater routing and recent project information from Chanhassen, updated engineer's opinion of probable cost for the iron enhanced sand filter.
- Revised Red Rock Lake BMP analysis for RRL_4 and RRL_6, corrected some stormwater routings, and updated cost estimates to reflect revisions.
- Corrected engineer's opinion of probable cost for the unit price iron enhanced sand.
- Revised executive summaries to show annual phosphorus load reduction and cost per pound at the respective lake rather than at each proposed BMP location.

I hereby certify that this revised plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the state of Minnesota.



3/16/2017

Scott Sobiech
PE #: MN 41338

Date

PURGATORY CREEK | LOTUS LAKE | SILVER LAKE | DUCK LAKE | ROUND LAKE | MITCHELL LAKE | RED ROCK LAKE | LAKE IDLEWILD | STARING LAKE

LOTUS, SILVER, DUCK, ROUND, MITCHELL, RED ROCK USE ATTAINABILITY ANALYSIS UPDATE; LAKE IDLEWILD AND STARING LAKE USE ATTAINABILITY ANALYSIS; AND LOWER PURGATORY CREEK STABILIZATION STUDY

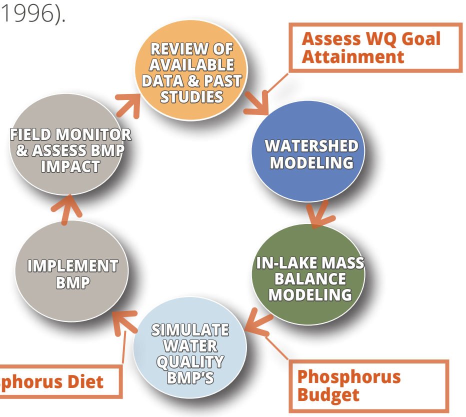
EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

PROJECT APPROACH

The assessment of the Lower Valley of Purgatory Creek incorporates the extensive efforts previously conducted as part of the RPBCWD Water Management Plan, (CH2M HILL, 2011), CRAS report (Barr and RPBCWD, 2015), creek inventories by District staff (RPBCWD 2014), city of Eden Prairie Purgatory Creek - 2006 to 2013 Erosion Changes (Wenck 2014), and 2005 Purgatory Creek Use Attainability Analysis (Barr 2005) to establish planning level streambank stabilization strategies. The assessment relied on existing information and did not involve the collection of any new field data. In addition, the focus was on Purgatory Creek downstream of Staring Lake and reserved the assessment of the creek and wetlands upstream of Valley View Road for future efforts. The geomorphic assessment generally followed guidelines and techniques included in the Rosgen classification system (Rosgen, 1996).



RPBCWD'S 2011 GOALS

The 2011 WMP indicates the following water quality goals for the resources in Purgatory Creek Watershed

Resource	RPBCWD Goals[1] TP (µg/l)	Chl a (µg/l)	SD (m)	MPCA Criteria
Lower Purgatory Creek [2]	-	-	-	Stream Eutrophication Standard
Silver Lake	≤60	≤20	≤1.0	non-degradation
Duck Lake	≤60	≤20	≤1.0	Shallow Lake Standard
Mitchell Lake	≤60	≤20	≤1.0	Shallow Lake Standard
Red Rock Lake	≤60	≤20	≤1.0	Shallow Lake Standard
Staring Lake	≤60	≤20	≤1.0	Shallow Lake Standard
Lotus Lake	≤40	≤14	≥1.4	Deep Lake Standard
Round Lake	≤40	≤14	≥1.4	Deep Lake Standard
Lake Idlewild	[3]	[3]	[3]	non-degradation

TP = Summer Average Total Phosphorus concentration
Chl a = Summer Average Chlorophyl a concentration
SD = Summer Average Secchi disc depth

[1] RPBCWD's 2011 Water Management Plan states the District "intends to achieve water quality that surpasses this minimum requirement. The result will be lakes with less pollution, better habitat, and more recreational opportunities than what would be afforded by using the water quality standards as the goal." The Plan also lists the water quality vision for all lakes to have a Secchi Depth ≥ 2.0 meters.

[2] The RPBCWD's Plan outlines goals aimed to protect and restore the creek (e.g. long-term goal 2,3,4, and 5).

[3] RPBCWD's 2011 Water Management Plan does not explicitly list water quality goals for Lake Idlewild. Therefore the resource should be managed to improve water quality to fully support its designated uses consistent with the District goals. This should include a non-degradation goal for water quality.

WATERSHED PHOSPHORUS LOADING TO LAKES

The distribution of phosphorus sources indicates the importance of managing both external and internal phosphorus sources.

Lake	2015 Nutrient (Phosphorus) Loading, Percent Contribution by Source: Direct external (watershed)[1]	Internal[2]	Indirect External[3]	Atmospheric
Silver Lake	64	31	0	5
Duck Lake	40	55	0	5
Mitchell Lake	45	51	<1	4
Red Rock Lake	48	3	45	4
Staring Lake	48	41	10	1
Lotus Lake	28	68	0	3
Round Lake	56	41	0	3
Lake Idlewild	84	15	0	1

[1] Direct external represents the estimated phosphorus loads from the lakes subwatershed and erosional sources such as ravine and streambank

[2] Internal represents the estimated phosphorus loads from the various sources including groundwater, sediment release, carp and curlyleaf pondweed.

[3] Indirect external represents the estimated phosphorus loads from upstream lakes.

The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for the resources.

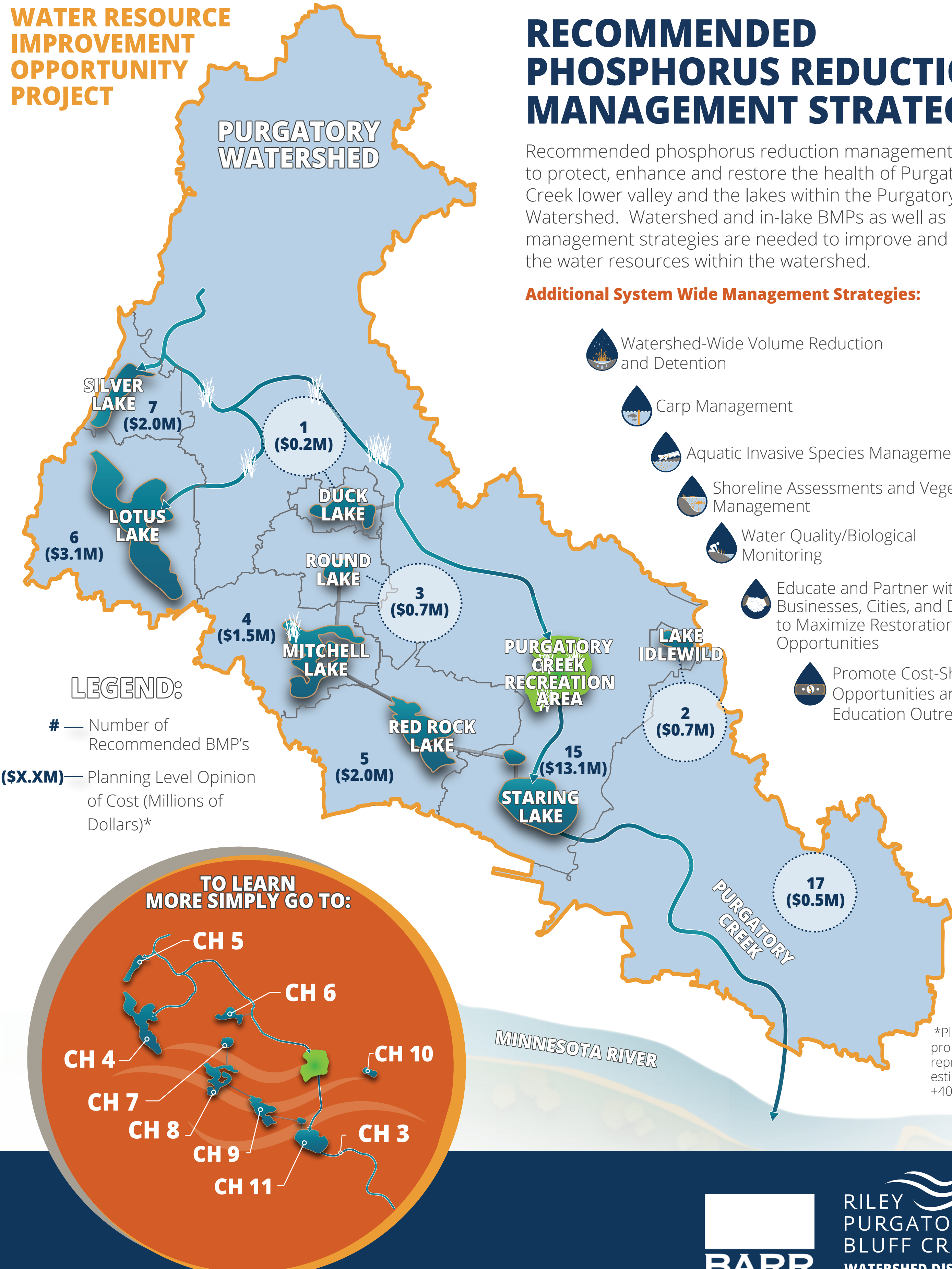
WATER RESOURCE IMPROVEMENT OPPORTUNITY PROJECT

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGY

Recommended phosphorus reduction management strategy to protect, enhance and restore the health of Purgatory Creek lower valley and the lakes within the Purgatory Creek Watershed. Watershed and in-lake BMPs as well as other management strategies are needed to improve and protect the water resources within the watershed.

Additional System Wide Management Strategies:

- Watershed-Wide Volume Reduction and Detention
- Carp Management
- Aquatic Invasive Species Management
- Shoreline Assessments and Vegetation Management
- Water Quality/Biological Monitoring
- Educate and Partner with Residents, Businesses, Cities, and Developers to Maximize Restoration and Protect Opportunities
- Promote Cost-Share Opportunities and Enhance Education Outreach



LEGEND:

\# — Number of Recommended BMP's

($X.XM) — Planning Level Opinion of Cost (Millions of Dollars)*

*Planning level probable costs represent a point estimate within a +40%/-20% range

TO LEARN MORE SIMPLY GO TO:

BARR

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

www.rpbcwd.org

Lotus, Silver, Duck, Round, Mitchell, Red Rock Use Attainability Analysis Update; Lake Idlewild and Staring Lake Use Attainability Analysis; and Lower Purgatory Creek Stabilization Study

Executive Summary | November 2016

LOWER PURGATORY CREEK STABILIZATION STUDY

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

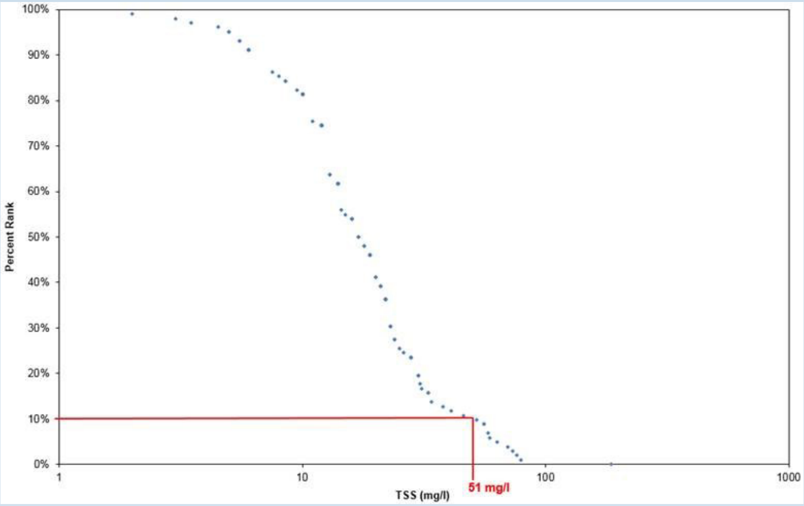
The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

PROJECT APPROACH

The assessment of the Lower Valley of Purgatory Creek incorporates the extensive efforts previously conducted as part of the RPBCWD Water Management Plan, (CH2M HILL, 2011), CRAS report (Barr and RPBCWD, 2015), creek inventories by District staff (RPBCWD 2014), city of Eden Prairie Purgatory Creek - 2006 to 2013 Erosion Changes (Wenck 2014), and 2005 Purgatory Creek Use Attainability Analysis (Barr 2005) to establish planning level streambank stabilization strategies. The assessment relied on existing information and did not involve the collection of any new field data. In addition, the focus was on Purgatory Creek downstream of Staring Lake and reserved the assessment of the creek and wetlands upstream of Valley View Road for future efforts.

The geomorphic assessment generally followed guidelines and techniques included in the Rosgen classification system (Rosgen, 1996).

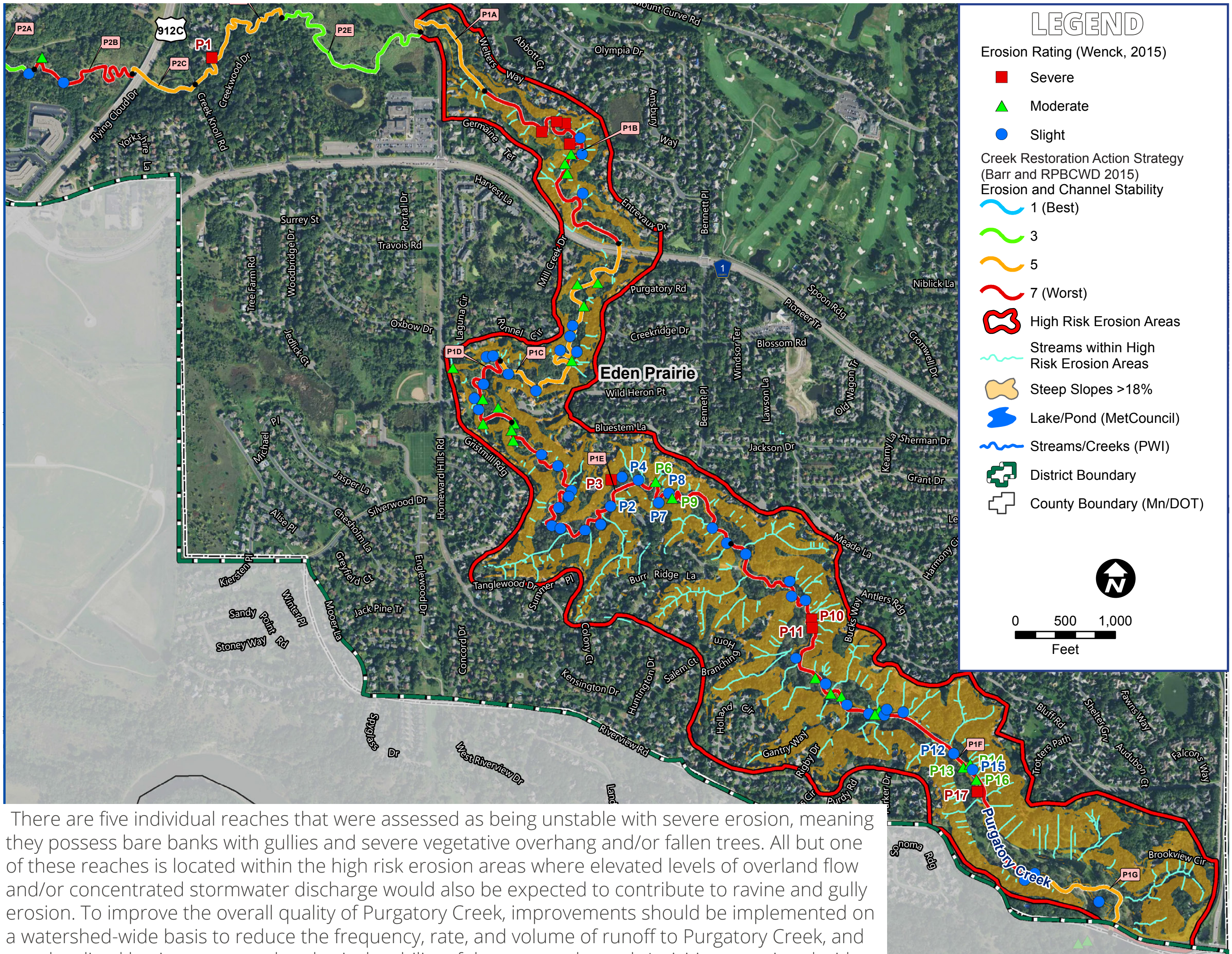
WATER QUALITY MONITORING DATA



The water quality monitoring data from Purgatory Creek shows that total suspended solids sample results only exceeded a concentration of 51 mg/L ten percent of the time. Since just 4% of the Purgatory Creek TSS samples exceeded the 65 mg/L, the standard is being achieved and Purgatory Creek will be considered for water quality protection in this study and will not be subject to total maximum daily load development by the MPCA. While the available TSS data for Purgatory Creek meets the standard, the results are limited in that most of the historic sampling has occurred upstream of significant near-channel sources of erosion and mass wasting (see photo below), including landslides. As a result, it is recommended that RPBCWD establish a monitoring station to measure continuous turbidity and collect TSS samples near the mouth of the creek, likely at the Riverview Road crossing. This would enable direct comparison of the continuous turbidity measurements with the data that is currently being collected at the Pioneer Trail WOMP station and allow RPBCWD to evaluate water quality improvements associated with the implementation of projects in the lower valley area.

LOWER PURGATORY CREEK

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES



There are five individual reaches that were assessed as being unstable with severe erosion, meaning they possess bare banks with gullies and severe vegetative overhang and/or fallen trees. All but one of these reaches is located within the high risk erosion areas where elevated levels of overland flow and/or concentrated stormwater discharge would also be expected to contribute to ravine and gully erosion. To improve the overall quality of Purgatory Creek, improvements should be implemented on a watershed-wide basis to reduce the frequency, rate, and volume of runoff to Purgatory Creek, and on a localized basis to restore the physical stability of the stream channel. Activities associated with reducing the frequency, rate and volume of runoff generally include storm water detention ponds or basins to reduce discharge rates and volumes from the urbanized area. Introduction of rainwater gardens can be used to infiltrate runoff, thereby reducing the volume and rate of runoff to the creek. Implementing these activities can reduce the frequency of bankfull flooding, and help maintain the stability of the stream. Every resident and business can play a vital role in the restoration and protection of the Lower Purgatory Creek through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.

SUMMARY OF RECOMMENDED BMPS

BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)[1]	30 Year Opinion of Planning Level Cost [2]	Annualized Cost per Pound Removed ($/lb)[3]
PC_1	Creek Restoration and Stabilization	3.8	$265,000 ($133,000 - $531,000)	$3,720 ($2,700 - $10,600)
PC_2	Creek Restoration and Stabilization	7.2	$185,000 ($93,000 - $730,000)	$1,370 ($690 - $2,740)

1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.

LOTUS LAKE

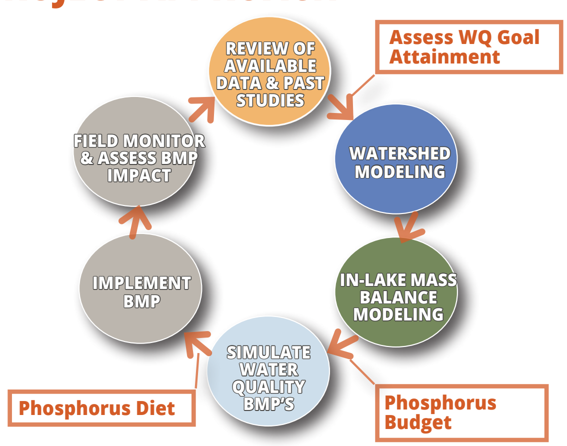
USE ATTAINABILITY UPDATE

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

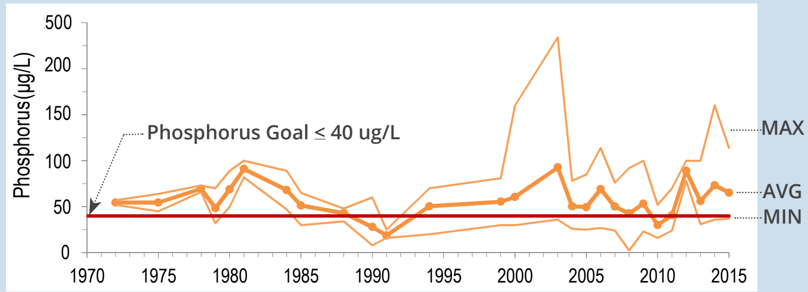
PROJECT APPROACH



The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for Lotus Lake.

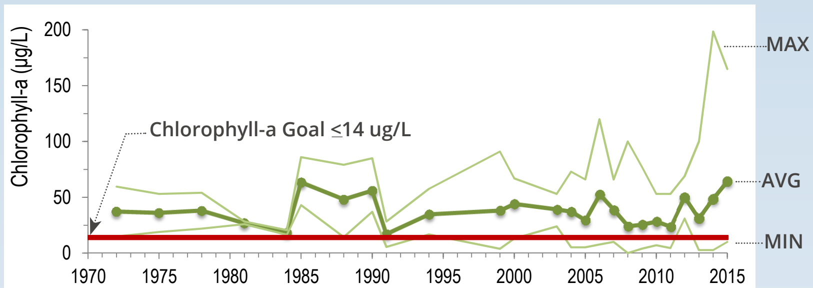
SUMMER AVERAGES WATER QUALITY

PHOSPHORUS LEVEL(S)



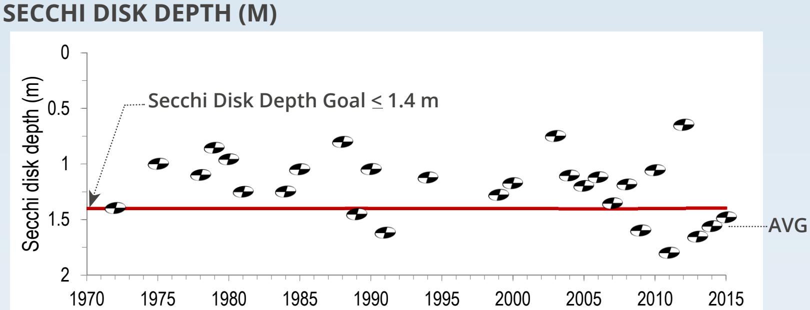
2015 average phosphorus concentration of 65 ug/L exceeded 40 ug/L goal.

CHLOROPHYLL-A LEVEL(S)



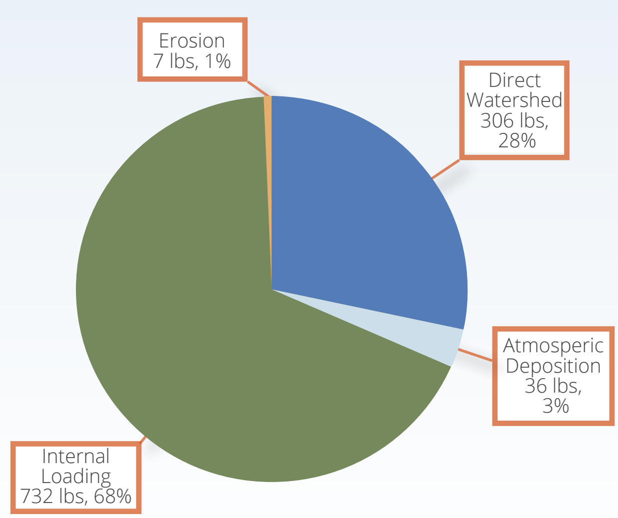
2015 average chlorophyll-a concentration of 64 ug/L exceeded 14 ug/L goal.

SECCHI DISK DEPTH (M)



2015 average transparency of 1.5 meters met the 1.4-meter goal.

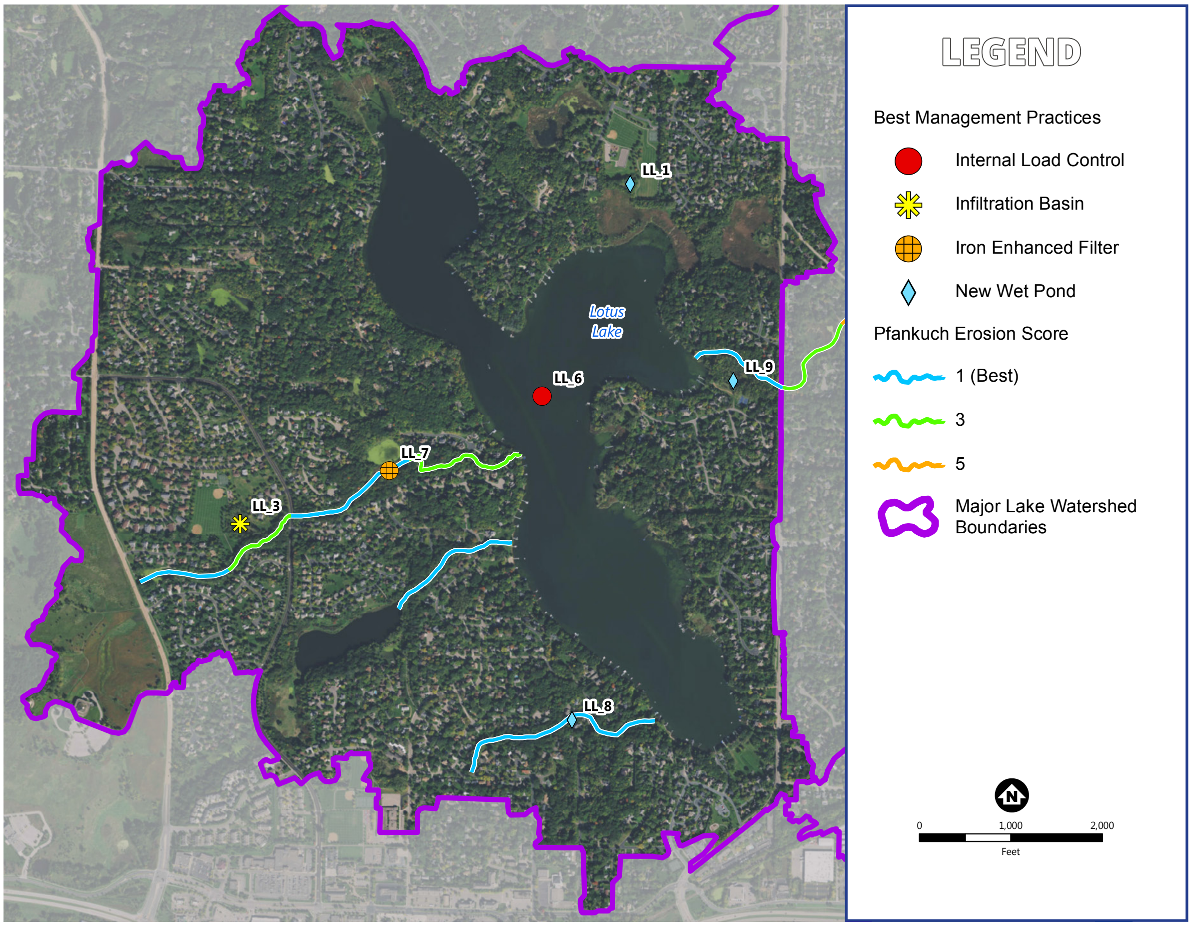
2015 ANNUAL PHOSPHORUS BUDGET



The pie chart above shows that approximately one-quarter of the phosphorus is coming from watershed runoff while two-thirds of the load is coming from internal sources. Internal represents phosphorus loads from various sources such as sediment release, carp, and curlyleaf pondweed. A 399 pound phosphorus load reduction is required to meet the phosphorus goal.

LOTUS LAKE

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES



Recommended phosphorus reduction management strategies to protect, enhance, and restore Lotus Lake include watershed and in-lake Best Management Practices (BMPs). Other management strategies, such as aquatic invasive species management, shoreline assessments, water quality/biological monitoring, and watershed-wide volume reduction and detention efforts are also needed to improve and protect the water quality in Lotus Lake and downstream resources (e.g. wetlands, lakes, and Purgatory Creek). The recommended BMPs are intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment phosphorus release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. Every resident and business can play a vital role in the restoration and protection of Lotus Lake through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.

SUMMARY OF RECOMMENDED BMPS

BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)[1]	30 Year Opinion of Planning Level Cost [2]	Annualized Cost per Pound Removed ($/lb)[3]
LL_1	New Wet Pond	6.4	$186,300 ($149,000 - $261,000)	$1,550 ($1,240 - $2,170)
LL_3	Infiltration Basin	48.5	$389,700 ($312,000 - $546,000)	$430 ($340 - $600)
LL_6	Internal Load Control (Two Whole Lake Alum Treatments)	586	$1,258,000 ($1,006,000 - $1,762,000)	$70 ($60 - $100)
LL_7	Iron Enhanced Sand Filter	58.7	$585,700 ($469,000 - $820,000)	$530 ($430 - $740)
LL_8	New Wet Pond	6.7	$142,400 ($114,000 - $199,000)	$1,130 ($900 - $1,580)
LL_9	New Wet Pond	10	$556,200 ($445,000 - $779,000)	$2,960 ($2,370 - $4,150)
LL_3&7	Infiltration Basin and Iron Enhanced Sand Filter	73.5	$975,400 ($780,000 - $1,366,000	$740 ($570 - $990)

1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.

SILVER LAKE

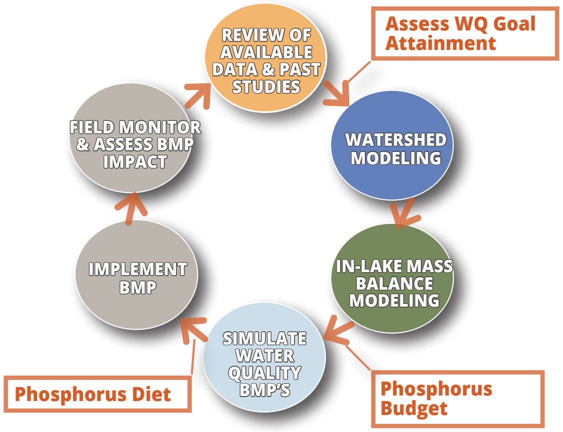
USE ATTAINABILITY UPDATE

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

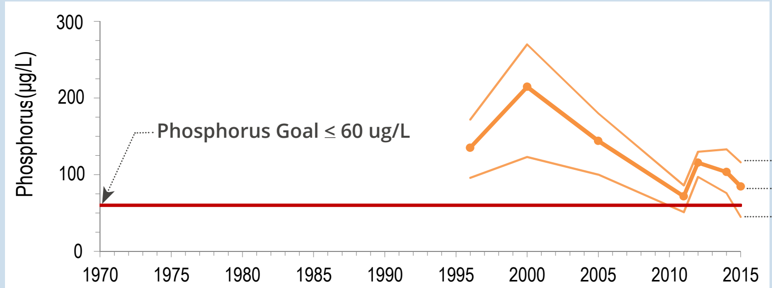
PROJECT APPROACH



The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for Silver Lake.

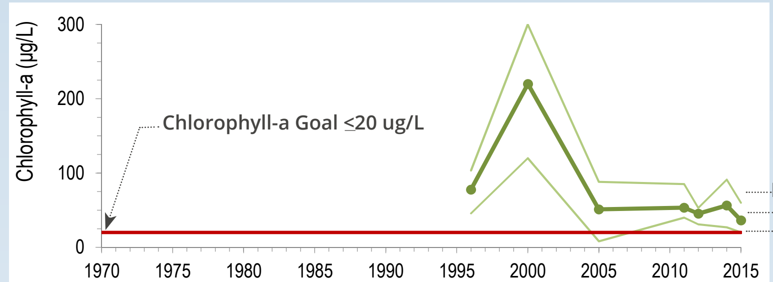
SUMMER AVERAGES WATER QUALITY

PHOSPHORUS LEVEL(S)



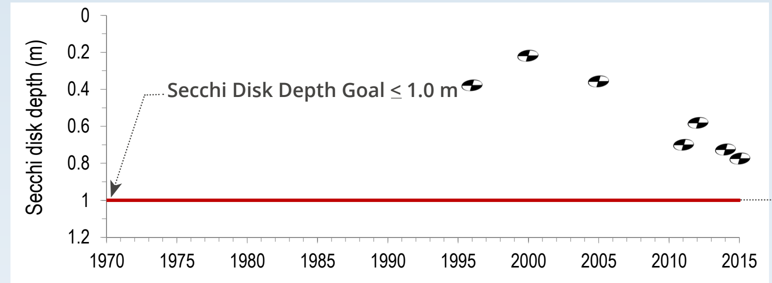
2015 average phosphorus concentration of 85 ug/L exceeded 60 ug/L goal.

CHLOROPHYLL-A LEVEL(S)



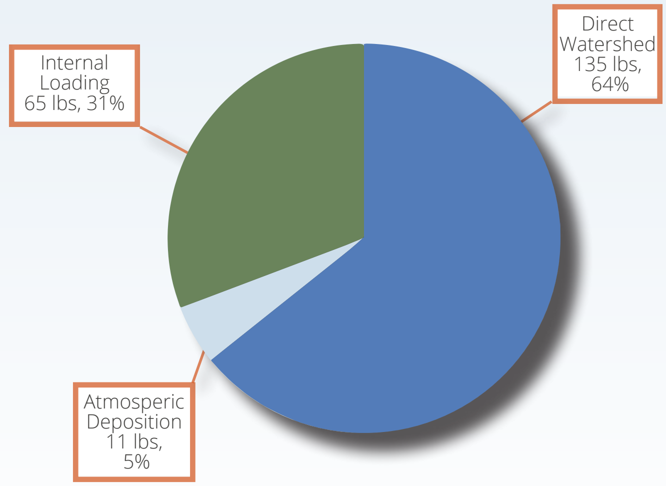
2015 average chlorophyll-a concentration of 36 ug/L exceeded 20 ug/L goal.

SECCHI DISK DEPTH (M)



2015 average transparency of 0.8 meters did not meet the 1.0-meter goal.

2015 ANNUAL PHOSPHORUS BUDGET

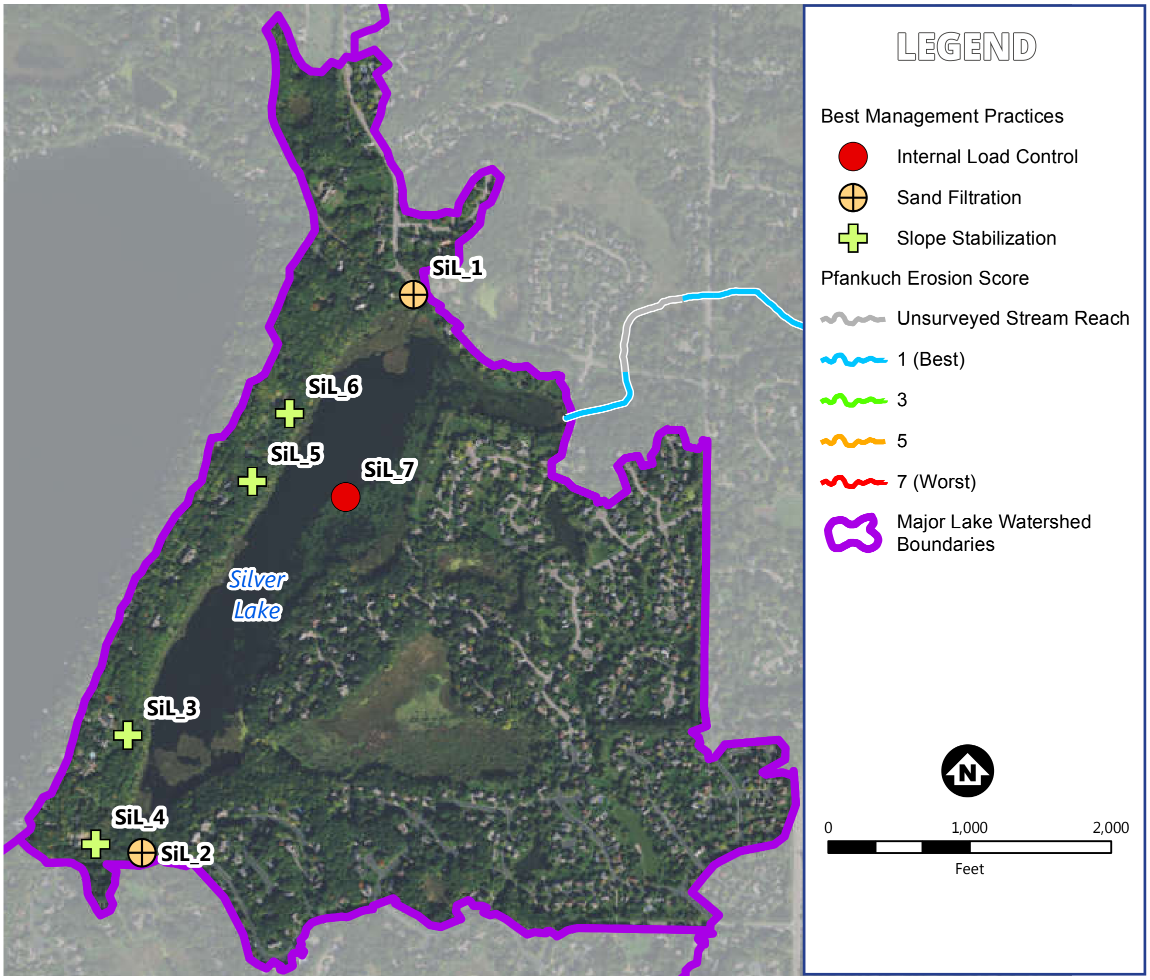


The pie chart above shows that approximately two-thirds of the phosphorus is coming from watershed runoff while one-third of the load is coming from internal sources. Internal represents phosphorus loads from various sources such as sediment release and curlyleaf pondweed. A 35 pound phosphorus load reduction is required to meet the phosphorus goal.

SILVER LAKE

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES

Recommended phosphorus reduction management strategies to protect, enhance, and restore Silver Lake include watershed and in-lake Best Management Practices (BMPs). Other management strategies, such as aquatic invasive species management, shoreline assessments, water quality/biological monitoring, and watershed-wide volume reduction and detention efforts are also needed to improve and protect the water quality in Silver Lake and downstream resources (e.g. wetlands, lakes, and Purgatory Creek). Wild rice is a unique feature in the lake that warrants protection and/or enhancement. The recommended BMPs are intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment phosphorus release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. Every resident and business can play a vital role in the restoration and protection of Silver Lake through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.



SUMMARY OF RECOMMENDED BMPS

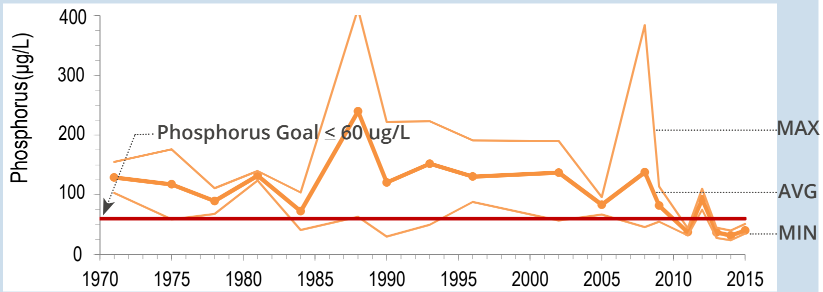
BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)[1]	30 Year Opinion of Planning Level Cost [2]	Annualized Cost per Pound Removed ($/lb)[3]
SiL_1	Underground Filtration	16.3	$810,700 ($649,000 - $1,135,000)	$2,650 ($2,120 - $3,710)
SiL_2	Sand Filter	6.3	$534,700 ($428,000 - $749,000)	$4,530 ($3,620 - $6,340)
SiL_3	Slope Stabilization	10	$86,000 ($43,000 - $172,000)	$460 ($230 - $910)
SiL_4	Slope Stabilization	3	$80,000 ($40,000 - $160,000)	$1,420 ($710 - $2,840)
SiL_5	Slope Stabilization	4	$80,000 ($40,000 - $160,000)	$1,070 ($530 - $2,130)
SiL_6	Slope Stabilization	3	$52,000 ($26,000 - $104,000)	$910 ($460 - $1,820)
SiL_7	Internal Load Control [4] (Two Sediment - Phosphorus Precipitant Treatments)	52	$332,000 ($266,000 - $464,000)	$210 ($170 - $300)

1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.
4. Due to the unique presence of wild rice, which warrants protection, various alternatives for phosphorus precipitants need testing to avoid adverse impacts on the wild rice.

DUCK LAKE

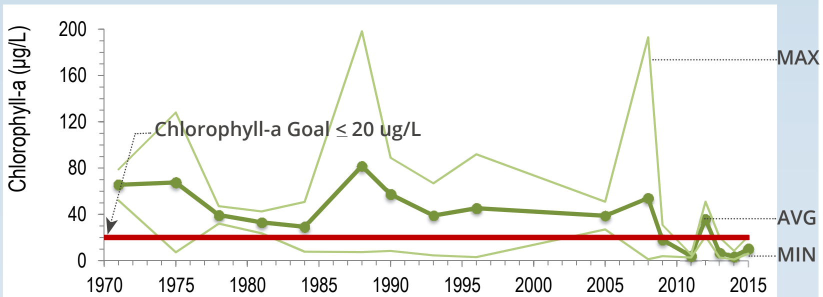
SUMMER AVERAGES WATER QUALITY

PHOSPHORUS LEVEL(S)



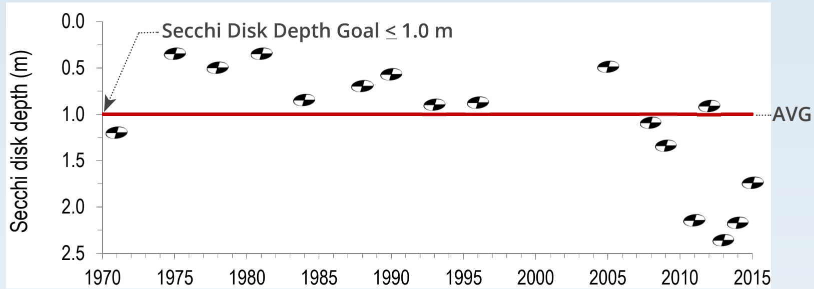
2015 average phosphorus concentration of 40 ug/L met the 60 ug/L goal.

CHLOROPHYLL-A LEVEL(S)



2015 average chlorophyll-a concentration of 10 ug/L met the 20 ug/L goal.

SECCHI DISK DEPTH (M)



2015 average transparency of 1.7 meters met the 1.0-meter goal.

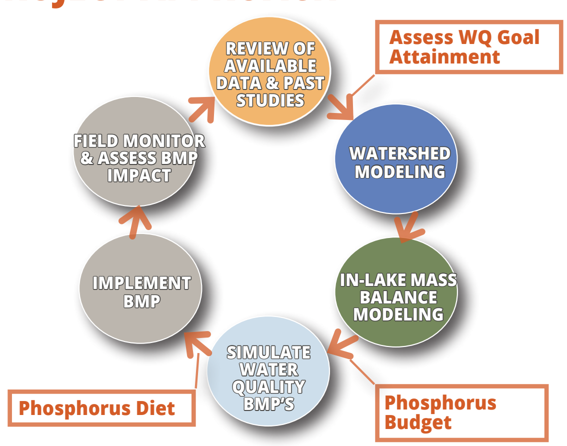
USE ATTAINABILITY UPDATE

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

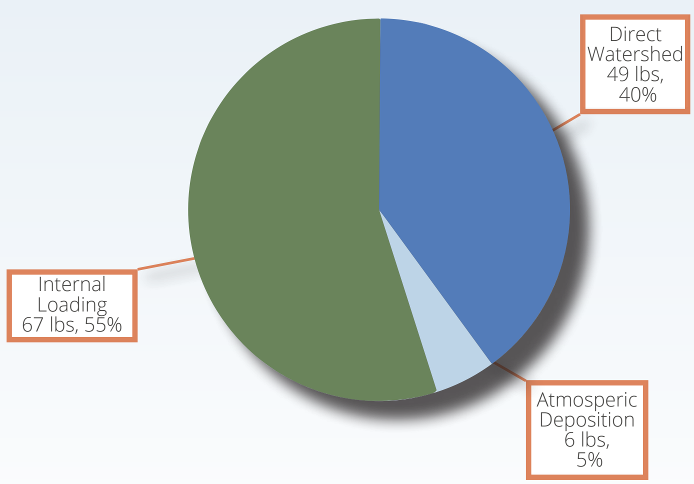
The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

PROJECT APPROACH



The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for Duck Lake.

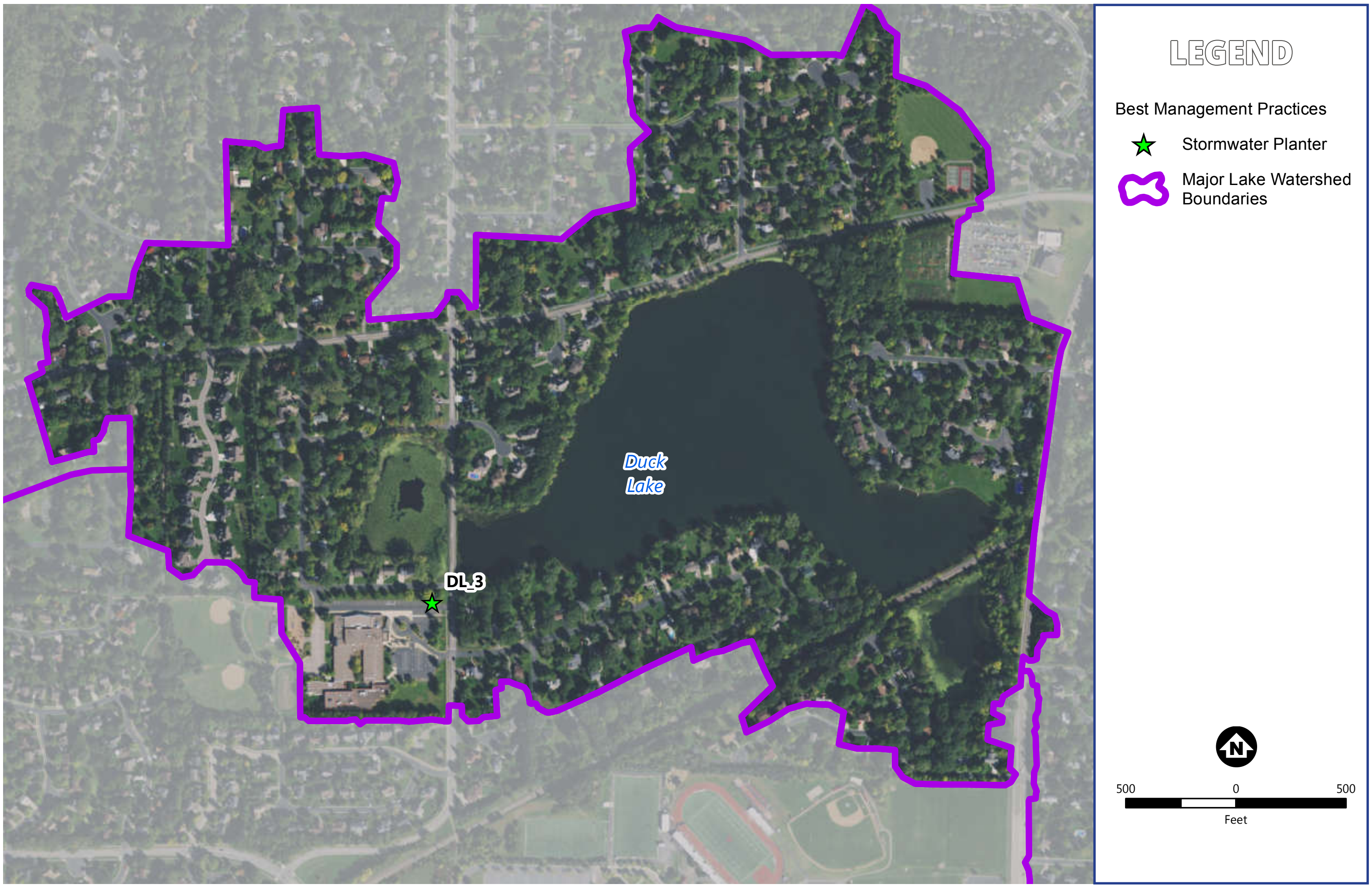
2015 ANNUAL PHOSPHORUS BUDGET



The pie chart above shows that 40% of the phosphorus is coming from watershed runoff while 55% of the load is coming from internal sources. Internal represents phosphorus loads from various sources such as sediment release and curlyleaf pondweed. No phosphorus load reduction is required to meet the phosphorus goal.

DUCK LAKE

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES



Recommended phosphorus reduction management strategies to protect, enhance, and restore Duck Lake include watershed and in-lake Best Management Practices (BMPs). Other management strategies, such as aquatic invasive species management, shoreline assessments, water quality/biological monitoring, and watershed-wide volume reduction and detention efforts are also needed to improve and protect the water quality in Duck Lake and downstream resources (e.g. wetlands, lakes, and Purgatory Creek). The recommended BMPs are intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed. Every resident and business can play a vital role in the restoration and protection of Duck Lake through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.

SUMMARY OF RECOMMENDED BMPS

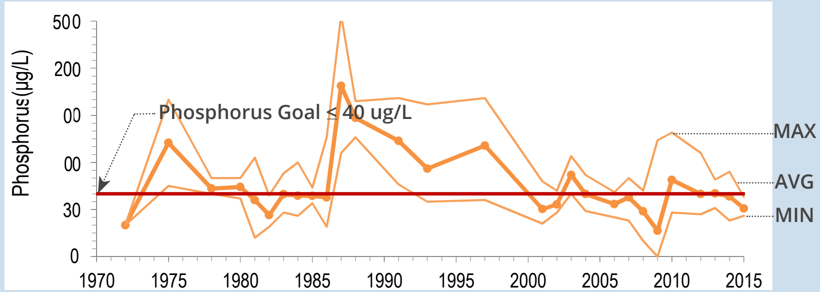
BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)[1]	30 Year Opinion of Planning Level Cost [2]	Annualized Cost per Pound Removed ($/lb)[3]
DL_3	Rainwater Gardens	2.4	$213,400 ($171,000 - $299,000)	$4,760 ($3,800 - $6,660)

1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.

ROUND LAKE

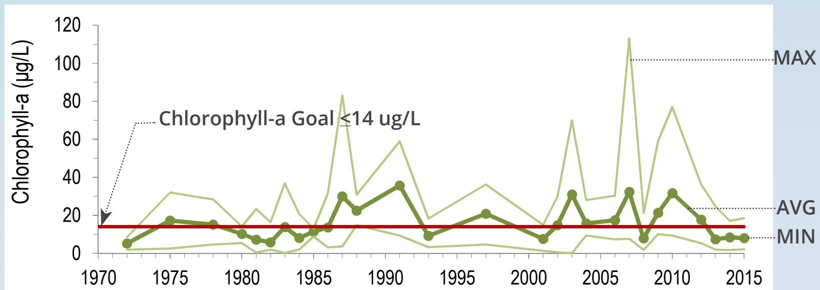
SUMMER AVERAGES WATER QUALITY

PHOSPHORUS LEVEL(S)



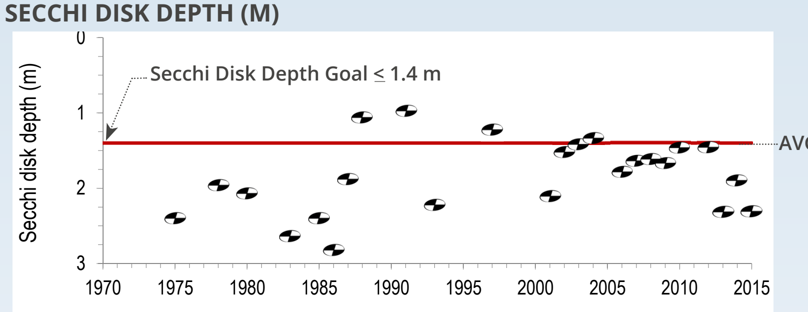
2015 average phosphorus concentration of 30 ug/L met the 40 ug/L goal.

CHLOROPHYLL-A LEVEL(S)



2015 average chlorophyll-a concentration of 8 ug/L met the 14 ug/L goal.

SECCHI DISK DEPTH (M)



2015 average transparency of 2.3 meters met the 1.4-meter goal.

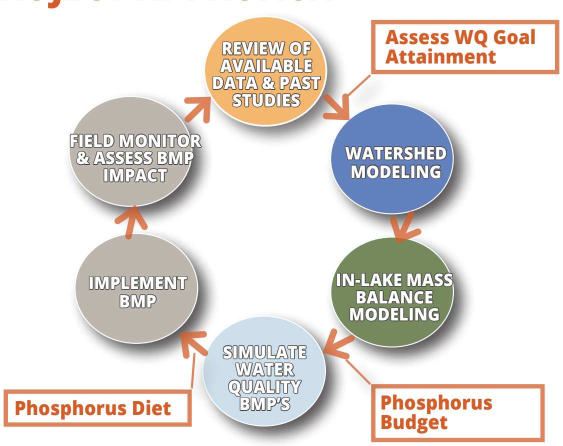
USE ATTAINABILITY UPDATE

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

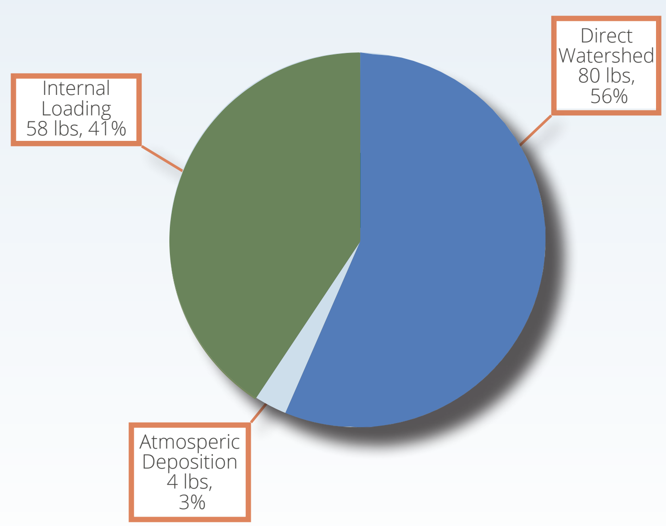
The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

PROJECT APPROACH



The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for Round Lake.

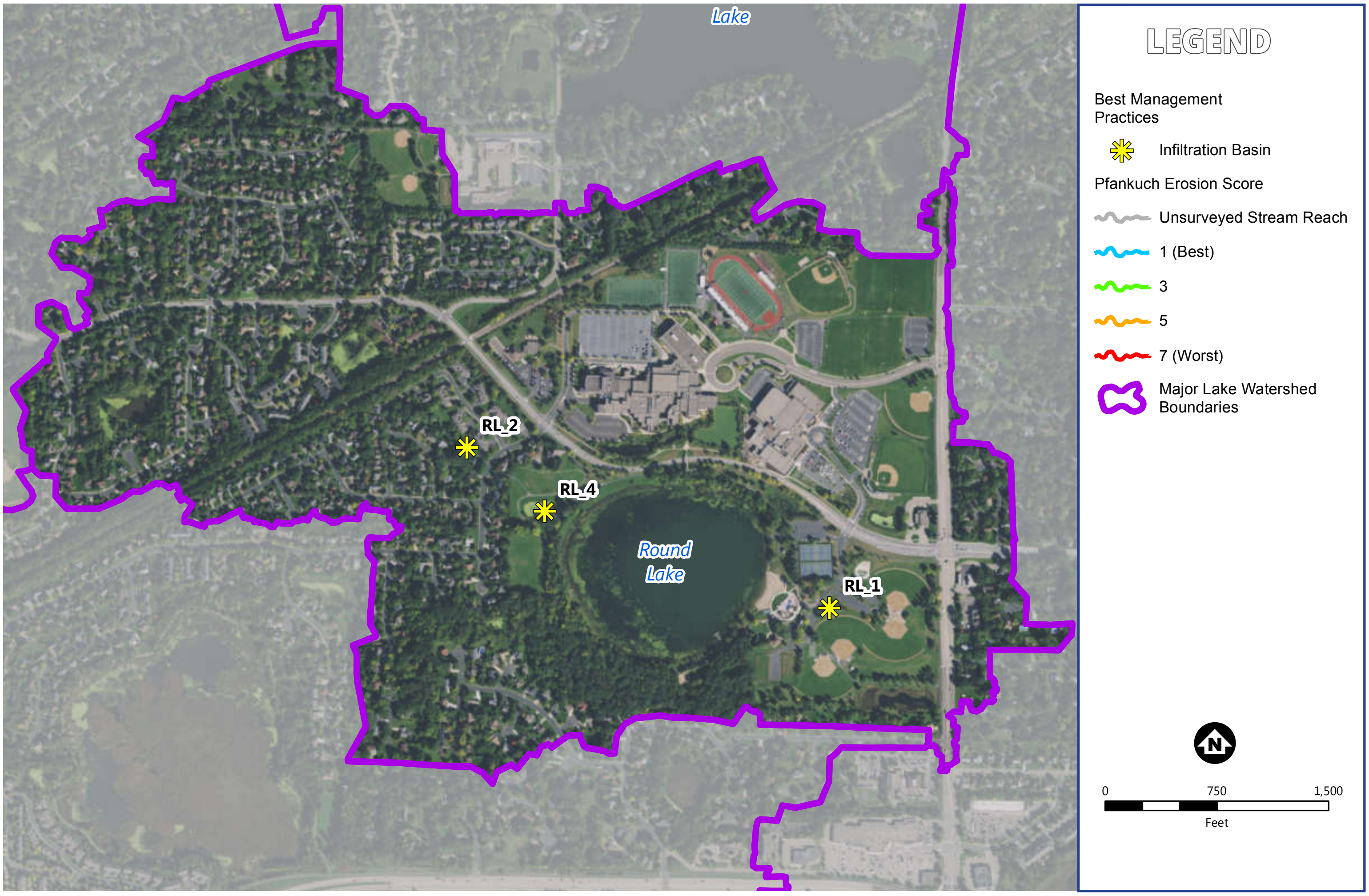
2015 ANNUAL PHOSPHORUS BUDGET



The pie chart above shows that more than half of the phosphorus is coming from watershed runoff while approximately 40% of the load is coming from internal sources. Internal represents phosphorus loads from various sources such as sediment release and curlyleaf pondweed. No phosphorus load reduction is required to meet the phosphorus goal.

ROUND LAKE

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES



Recommended phosphorus reduction management strategies to protect, enhance, and restore Round Lake include watershed and in-lake Best Management Practices (BMPs). Other management strategies, such as aquatic invasive species management, shoreline assessments, water quality/biological monitoring, and watershed-wide volume reduction and detention efforts are also needed to improve and protect the water quality in Round Lake and downstream resources (e.g. wetlands, lakes and Purgatory Creek). The recommended BMPs are intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed. Every resident and business can play a vital role in the restoration and protection of the [insert lake/creek name here] through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.

SUMMARY OF RECOMMENDED BMPS

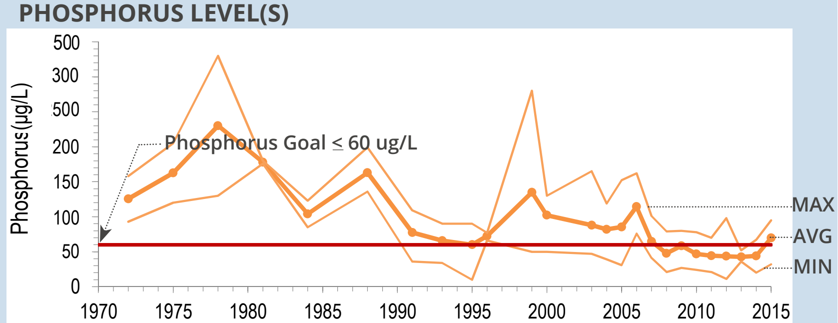
BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)¹	30 Year Opinion of Planning Level Cost ²	Annualized Cost per Pound Removed ($/lb)³
RL_1	Infiltration Basin	6.8	$118,300 ($95,000 - $166,000)	$930 ($750 - $1,310)
RL_2	Underground Infiltration Basin	24.4	$245,300 ($196,000 - $343,000)	$540 ($430 - $750)
RL_4	Infiltration Basin	20.6	$361,700 ($289,000 - $506,000)	$930 ($750 - $1,310)

1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.

MITCHELL LAKE

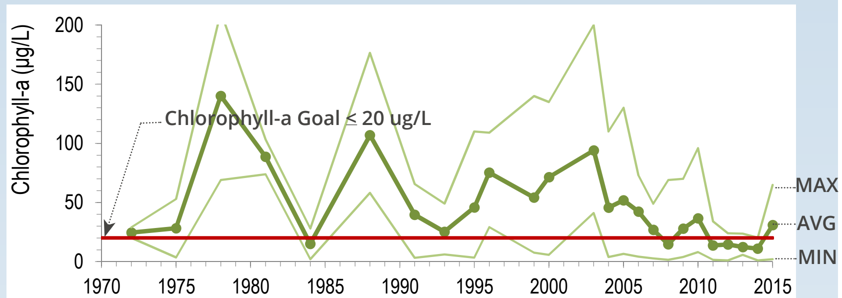
SUMMER AVERAGES WATER QUALITY

PHOSPHORUS LEVEL(S)



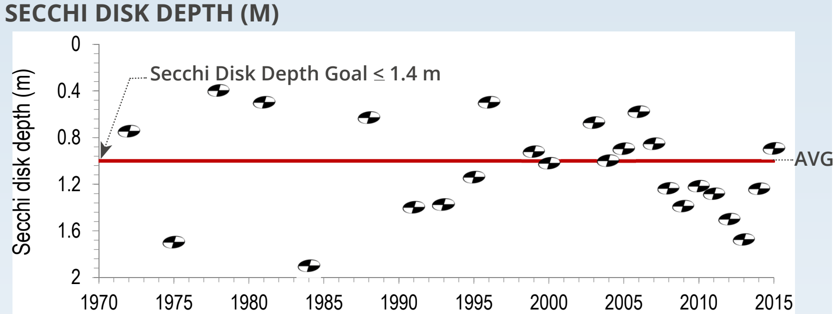
2015 average phosphorus concentration of 70 ug/L exceeded 60 ug/L goal.

CHLOROPHYLL-A LEVEL(S)



2015 average chlorophyll-a concentration of 31 ug/L exceeded 20 ug/L goal.

SECCHI DISK DEPTH (M)



2015 average transparency of 0.9 meters did not meet the 1.0-meter goal.

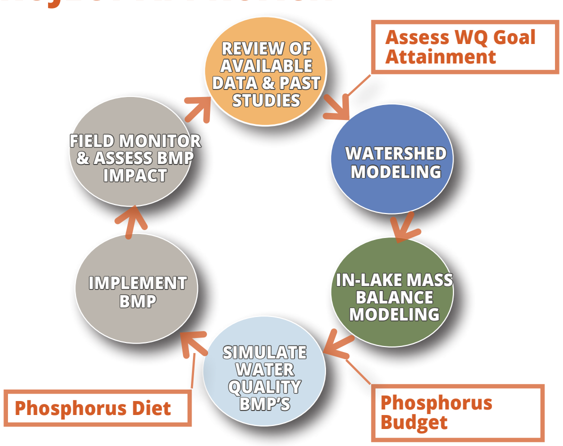
USE ATTAINABILITY UPDATE

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

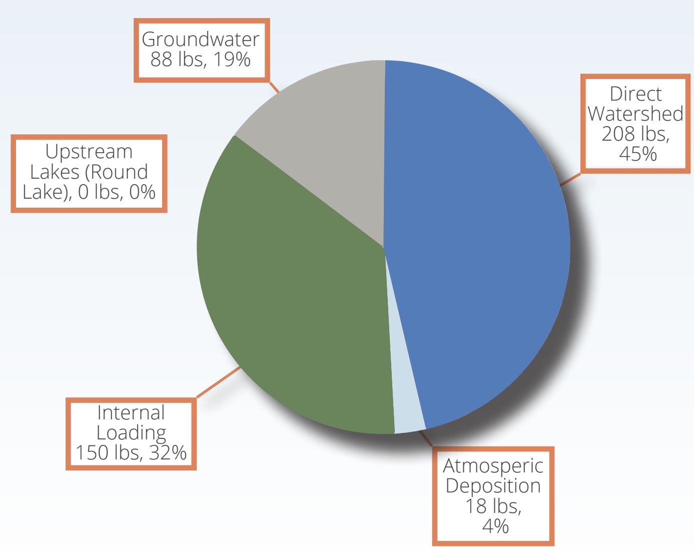
The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

PROJECT APPROACH



The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for Lotus Lake.

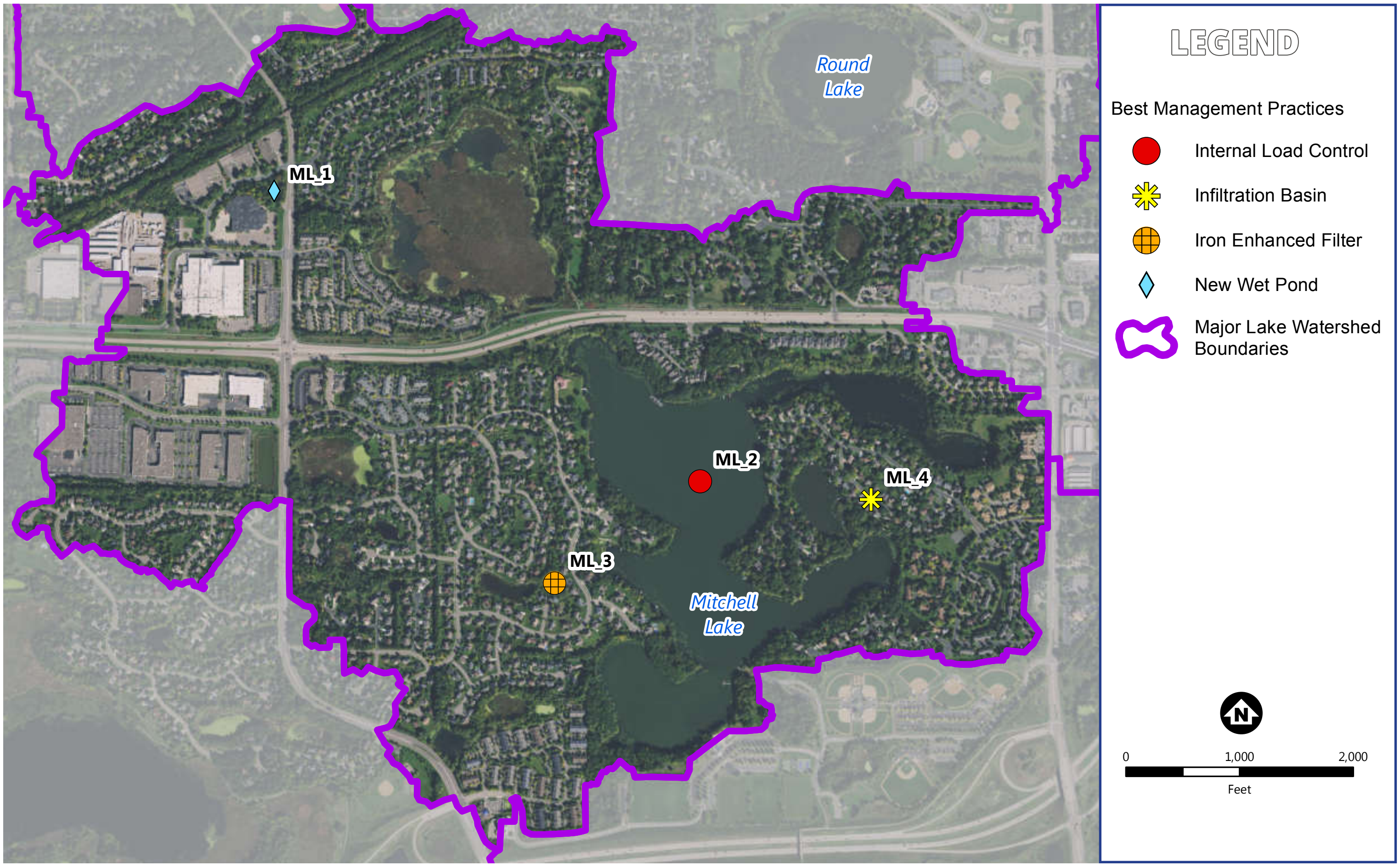
2015 ANNUAL PHOSPHORUS BUDGET



The pie chart above shows that 45% of the phosphorus is coming from watershed runoff while more than 30% of the load is coming from internal sources. Internal represents phosphorus loads from various sources such as sediment release and curlyleaf pondweed. A 59 pound phosphorus load reduction is required to meet the phosphorus goal.

MITCHELL LAKE

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES

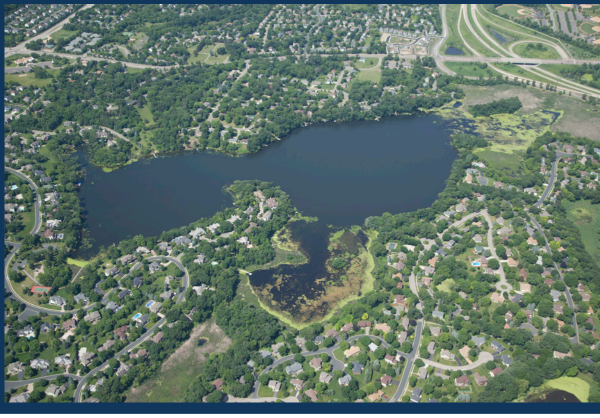


Recommended phosphorus reduction management strategies to protect, enhance, and restore Mitchell Lake include watershed and in-lake Best Management Practices (BMPs). Other management strategies, such as aquatic invasive species management, shoreline assessments, water quality/biological monitoring, and watershed-wide volume reduction and detention efforts are also needed to improve and protect the water quality in Mitchell Lake and downstream resources (e.g. wetlands, lakes, and Purgatory Creek). The recommended BMPs are intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment phosphorus release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. Every resident and business can play a vital role in the restoration and protection of Mitchell Lake through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.

SUMMARY OF RECOMMENDED BMPS

BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)[1]	30 Year Opinion of Planning Level Cost [2]	Annualized Cost per Pound Removed ($/lb)[3]
ML_1	New Wet Pond	7.5	$132,900 ($106,000 - $186,000)	$950 ($760 - $1,330)
ML_2	Internal Load Control (Two Whole Lake Alum Treatments)	120	$518,800 ($463,000 - $810,000)	$140 ($120 - $200)
ML_3	Iron Enhanced Sand Filter	21.1	$578,000 ($463,000 - $810,000)	$1,460 ($1,170 - $2,050)
ML_4	Underground Filtration	7.7	$314,500 ($252,000 - $440,000)	$2,180 ($1,740 - $3,050)

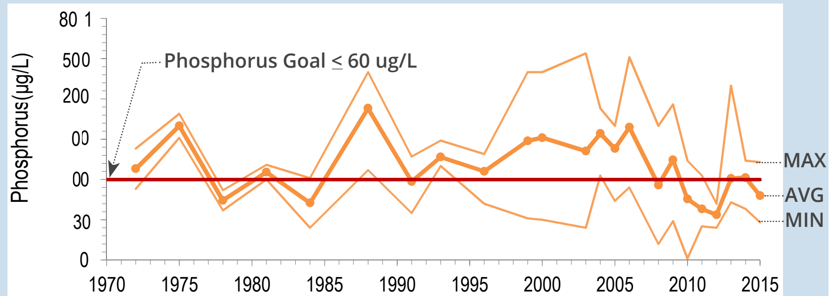
1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.



RED ROCK LAKE

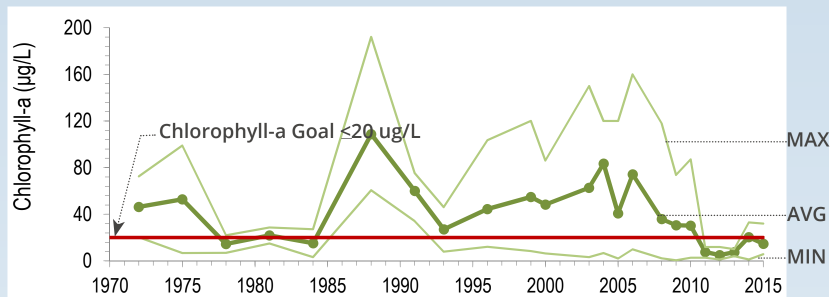
SUMMER AVERAGES WATER QUALITY

PHOSPHORUS LEVEL(S)



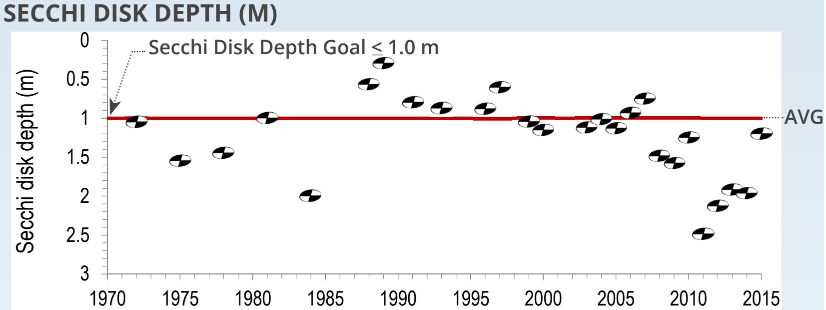
2015 average phosphorus concentration of 48 ug/L met the 60 ug/L goal.

CHLOROPHYLL-A LEVEL(S)



2015 average chlorophyll-a concentration of 15 ug/L met the 20 ug/L goal.

SECCHI DISK DEPTH (M)



2015 average transparency of 1.2 meters met the 1.0-meter goal.

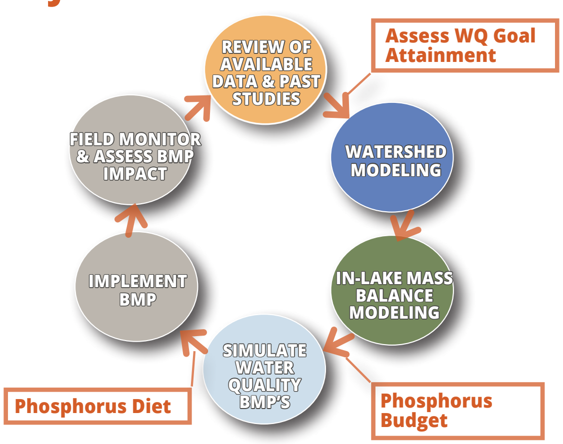
USE ATTAINABILITY UPDATE

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

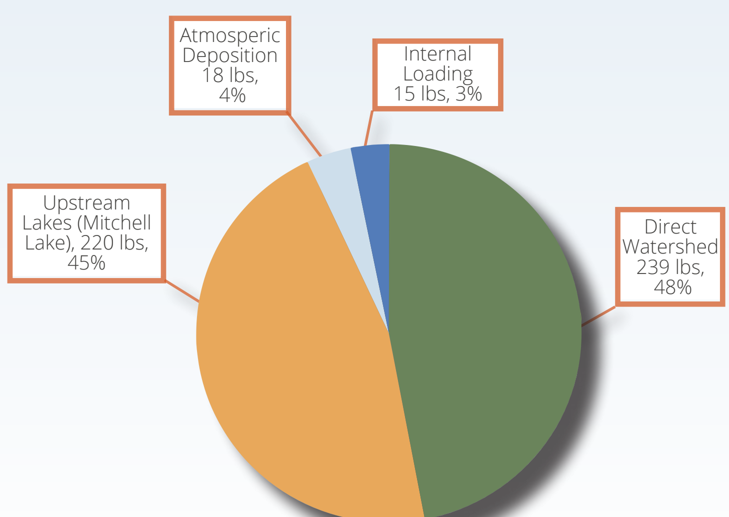
The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

PROJECT APPROACH



The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for Red Rock Lake.

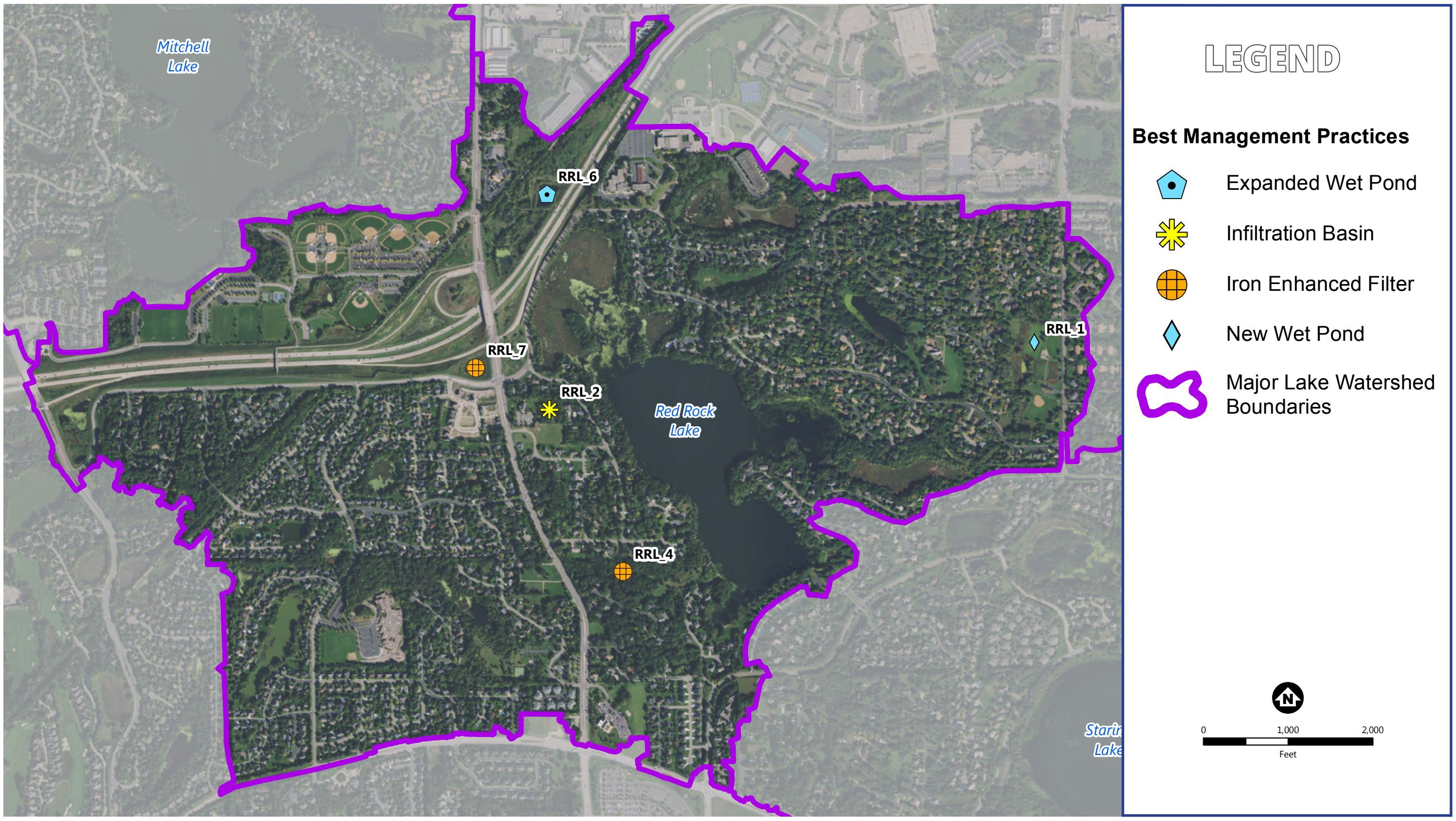
2015 ANNUAL PHOSPHORUS BUDGET



The pie chart above shows that approximately one-half of the phosphorus is coming from watershed runoff while 45% of the load is coming from upstream sources. Internal represents phosphorus loads from various sources such as sediment release and curlyleaf pondweed. No phosphorus load reduction is required to meet the phosphorus goal.

RED ROCK LAKE

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES



Recommended phosphorus reduction management strategies to protect, enhance, and restore Red Rock Lake include watershed and in-lake Best Management Practices (BMPs). Other management strategies, such as aquatic invasive species management, shoreline assessments, water quality/biological monitoring, and watershed-wide volume reduction and detention efforts are also needed to improve and protect the water quality in Red Rock Lake and downstream resources (e.g. wetlands, lakes, and Purgatory Creek). The recommended BMPs are intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed for BMP implementation. Every resident and business can play a vital role in the restoration and protection of Red Rock Lake through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.

SUMMARY OF RECOMMENDED BMPS

BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)[1]	30 Year Opinion of Planning Level Cost [2]	Annualized Cost per Pound Removed ($/lb)[3]
RRL_1	New Wet Pond	9.5	$305,900 ($245,000 - $428,000)	$1,720 ($1,370 - $2,400)
RRL_2	Infiltration Basin	2.0	$89,700 ($72,000 - $126,000)	$2,400 ($1,920 - $3,350)
RRL_4	Iron Sand Filter Chamber	24.5	$979,500 ($284,000 - $1,372,000)	$2,130 ($1,710 - $2,990)
RRL_6	Expanded Wet Pond	2.9	$194,000 ($155,000 - $272,000)	$3,570 ($2,860 - $5,000)
RRL_7	Iron Enhanced Sand Filter Benches	10	$440,500 ($352,000 - $617,000)	$2,350 ($1,880 - $3,290)
RRL_9	Assume Mitchell Lake meets load and quality goals	37	See Table 12.1 for the cost for Mitchell Lake BMPs	See Table 12.1 for the cost for Mitchell Lake BMPs

1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.

LAKE IDLEWILD

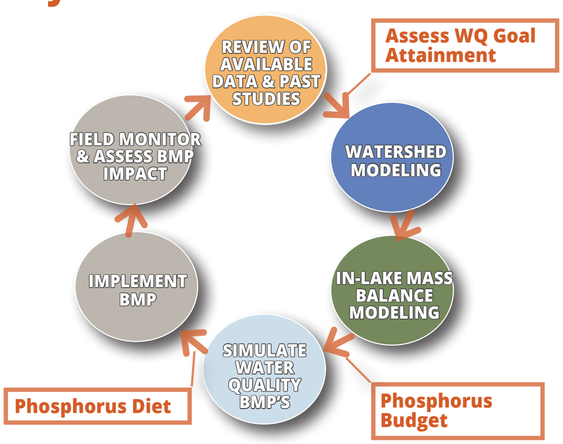
USE ATTAINABILITY ANALYSIS

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

PROJECT APPROACH



The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for Lake Idlewild.

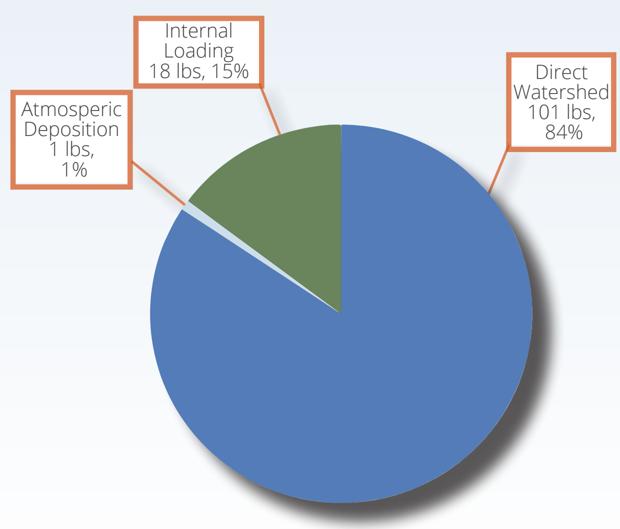
PHYSICAL CHARACTERISTICS

Lake Characteristic	Lake Idlewild
Lake MDNR ID	--
MPCA Lake Classification	Not Classified
Water Level Control Elevation (feet MSL)	853.5
Average Water Elevation (feet MSL)	853.7
Surface Area (acres)	12
Mean Depth (feet)	4
Maximum Depth (feet)	8.2
Littoral Area (acres)	12
Volume (at normal water elevation) (acre-feet)	51
Thermal Stratification Pattern	polymictic
Estimated Residence Time (years) - 2014-2015 climatic conditions	0.3
Watershed Area Tributary to Upstream Lake	0
Total Watershed Area (acres, including lake area)	89
Subwatershed Area (acres)	89
Trophic Status Based on 2015 Growing Season Average Water Data	hypereutrophic

2015 GROWING SEASON AVERAGE WATER QUALITY

Parameter	2015 growing season average	2015 max value	2015 min value
TP (µg/L)	71	102	36
Chl-a (µg/L)	16	28	4
Secchi Depth (m)	1.7	2.3	1.1

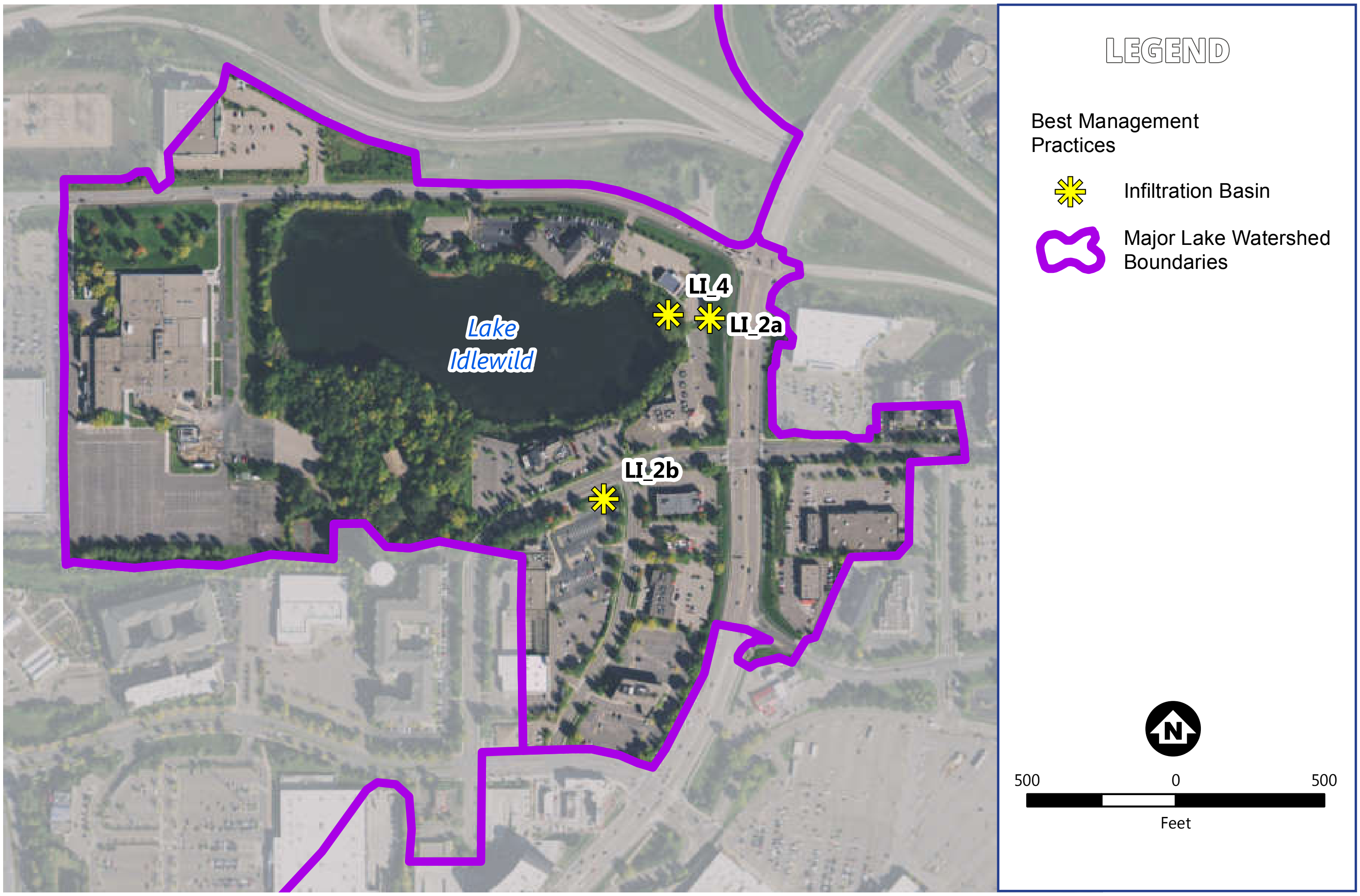
2015 ANNUAL PHOSPHORUS BUDGET



The pie chart above shows that approximately 85% of the phosphorus is coming from watershed runoff while 15% of the load is coming from internal sources. Internal represents phosphorus loads from various sources such as sediment release. No phosphorus load reduction is required.

LAKE IDLEWILD

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES



Recommended phosphorus reduction management strategies to protect, enhance, and restore Lake Idlewild include watershed and in-lake Best Management Practices (BMPs). Other management strategies, such as watershed-wide volume reduction and detention efforts, aquatic invasive species management, shoreline assessments, water quality/biological monitoring, and watershed-wide volume reduction and detention efforts are also needed to improve and protect the water quality in Lake Idlewild and downstream resources (e.g. Purgatory Creek and wetlands). The recommended BMPs are intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed for BMP implementation. Every resident and business can play a vital role in the restoration and protection of Lake Idlewild through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.

SUMMARY OF RECOMMENDED BMPS

BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)[1]	30 Year Opinion of Planning Level Cost [2]	Annualized Cost per Pound Removed ($/lb)[3]
LI_2a & LI_2b	Infiltration	20	$667,300 ($534,000 - $934,000)	$1,780 ($1,420 - $2,490)
LI_4	Infiltration	2.5	$0[4]	$0[4]

1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.
4. BMP proposed to be implemented by developer as required to achieve conformance with RPBCWD stormwater management rule.

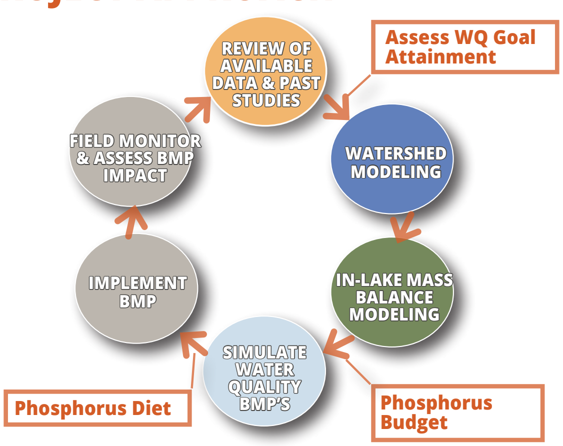
USE ATTAINABILITY ANALYSIS

EXECUTIVE SUMMARY

STUDY PURPOSE AND GOALS

The goal of this study is to provide updated and consistent information about the water quality and biological integrity of the receiving waters in the Purgatory Creek watershed with a focus on the lower valley of purgatory creek and major lakes in the watershed. The assessment of the lower valley of purgatory creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study includes trend analyses and comparisons of water quality monitoring with state standards and District goals, water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.•

PROJECT APPROACH

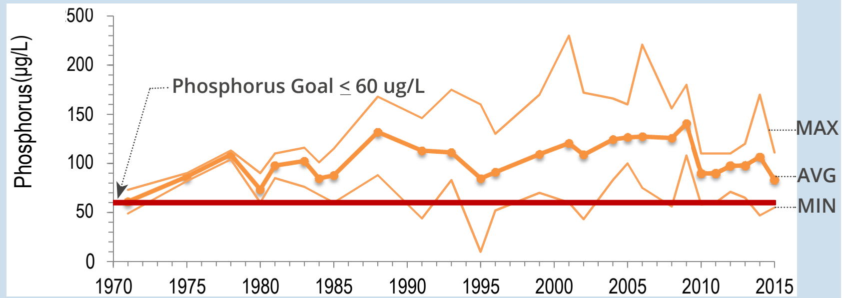


The project approach utilized in this study includes four main steps of an adaptive management approach. After analyzing available water quality data and past studies, watershed modeling estimated total phosphorus loads reaching the lake while an in-lake phosphorus concentration model simulated the lake's response to various loading sources. With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to improve or protect water quality levels for Staring Lake.

STARING LAKE

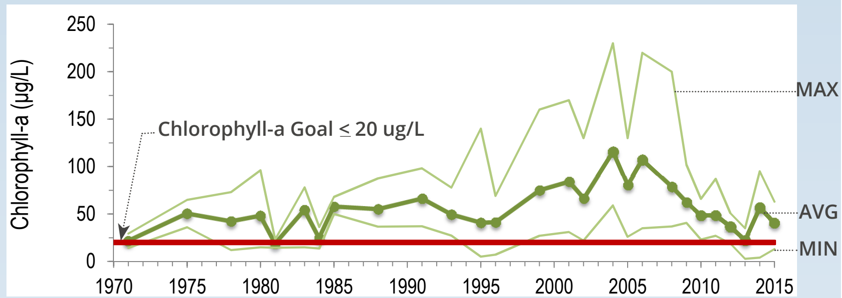
SUMMER AVERAGES WATER QUALITY

PHOSPHORUS LEVEL(S)



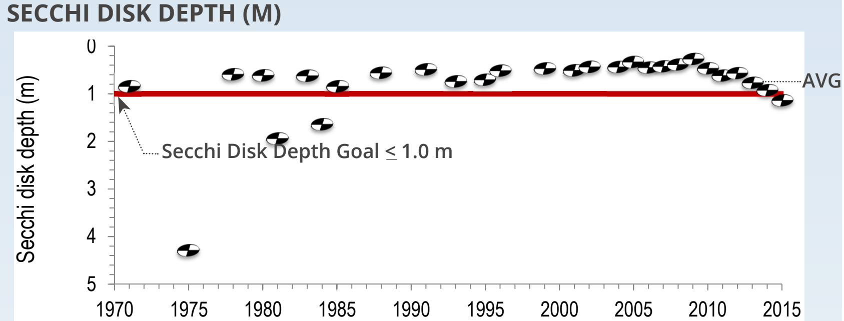
2015 average phosphorus concentration of 83 ug/L exceeded 60 ug/L goal.

CHLOROPHYLL-A LEVEL(S)



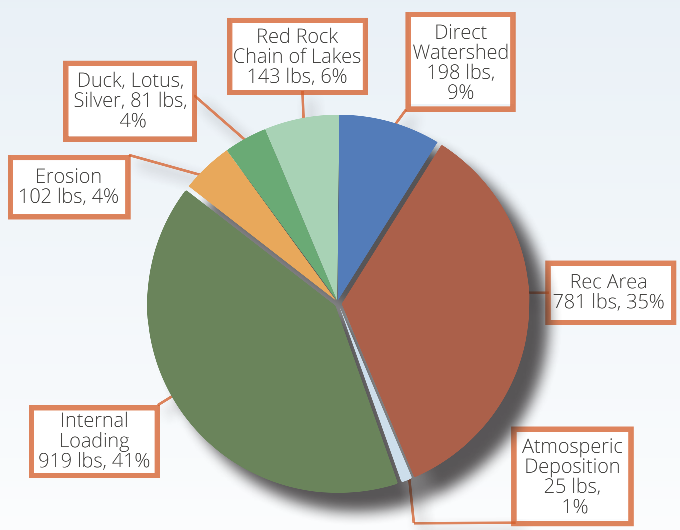
2015 average chlorophyll-a concentration of 41 ug/L exceeded 20 ug/L goal.

SECCHI DISK DEPTH (M)



2015 average transparency of 1.1 meters met the 1.0-meter goal.

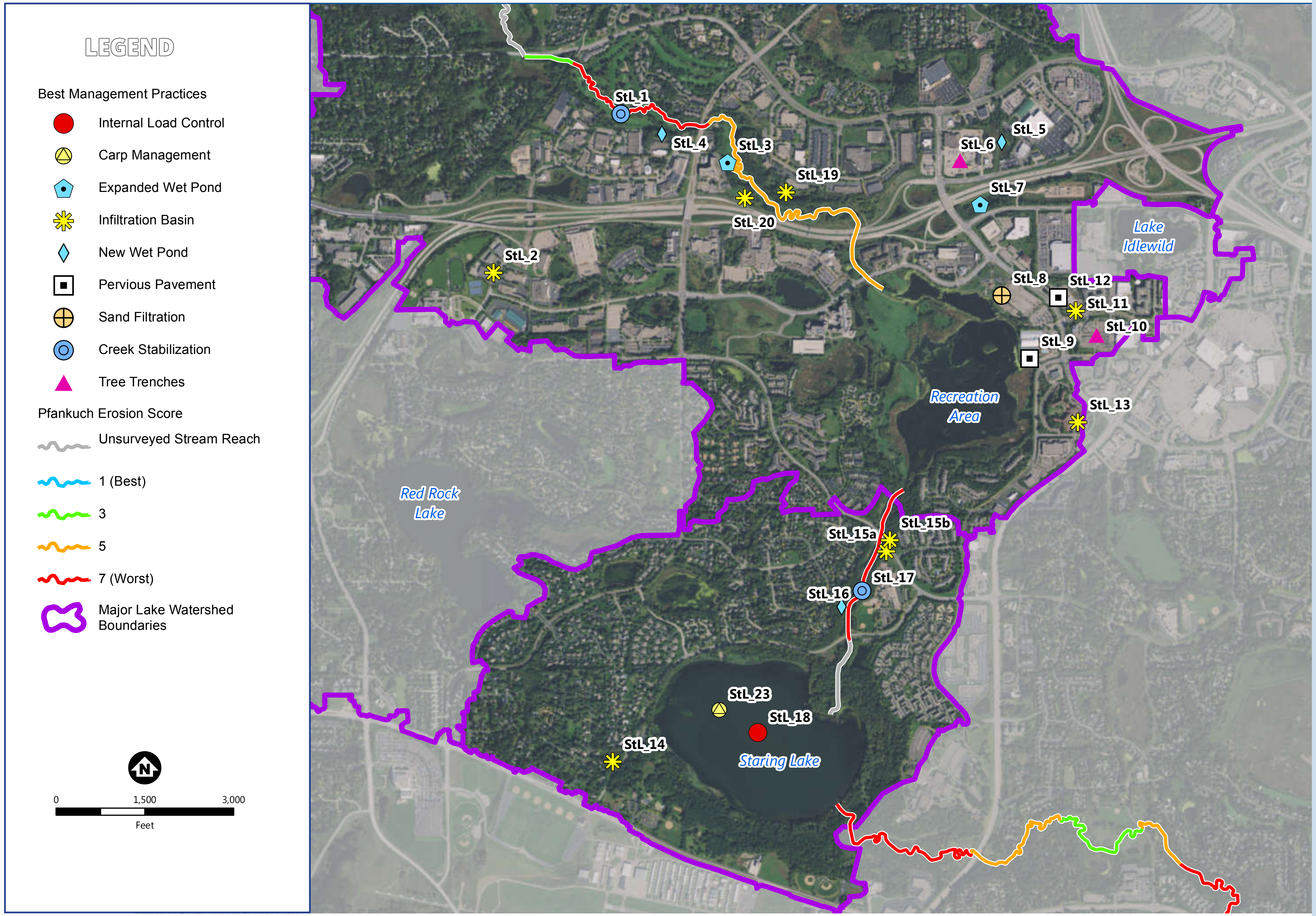
2015 ANNUAL PHOSPHORUS BUDGET



The pie chart above shows that approximately one-third of the phosphorus is coming from the recreation area while about 40% of the load is coming from internal sources. Internal represents phosphorus loads from various sources such as sediment release, carp, and curlyleaf pondweed. A 500 pound phosphorus load reduction is required to meet the phosphorus goal.

STARING LAKE

RECOMMENDED PHOSPHORUS REDUCTION MANAGEMENT STRATEGIES



Recommended phosphorus reduction management strategies to protect, enhance, and restore Staring Lake include watershed and in-lake Best Management Practices (BMPs). Other management strategies, such as watershed-wide volume reduction and detention efforts, aquatic invasive species management, shoreline assessments, water quality/biological monitoring, and watershed-wide volume reduction and detention efforts are also needed to improve and protect the water quality in Staring Lake and downstream resources (e.g. Purgatory Creek and wetlands). The recommended BMPs are intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment phosphorus release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. Every resident and business can play a vital role in the restoration and protection of Staring Lake through self-implementation of small scale non-structural measures such as keeping leaves, grass clippings, and fertilizers off impervious surfaces; establishing riparian buffers; educating neighbors; cleaning catch basins; installing individual rainwater gardens; and reducing impervious cover on lots (i.e., promote infiltration). Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources.

SUMMARY OF RECOMMENDED BMPS

BMP ID	BMP Type	Annual Phosphorus Load Reduction (lbs/yr)[1]	30 Year Opinion of Planning Level Cost[2]	Annualized Cost per Pound Removed ($/lb)[3]
StL_1	Creek Restoration and Stabilization	52	$1,173,000 ($586,500 - $2,346,000)	$1,200 ($600 - $2,410)
StL_2	Infiltration Basin	8.9	$253,000 ($202,000 - $354,000)	$1,520 ($1,220 - $2,130)
StL_3	Expanded Wet Pond	7.2	$269,700 ($216,000 - $378,000)	$2,000 ($1,600 - $2,800)
StL_4	New Wet Pond	3.5	$203,400 ($163,000 - $285,000)	$3,110 ($2,490 - $4,350)
StL_5	New Wet Pond	18.6	$925,700 ($741,000 - $1,296,000)	$2,650 ($2,120 - $3,720)
StL_7	Expanded Wet Pond	11.7	$207,200 ($166,000 - $290,000)	$940 ($750 - $1,320)
StL_8	Filtration Basins	8.4	$628,600 ($502,900 - $880,000)[8]	$3,990 ($3,200 - $5,590)
StL_10	Stormwater Planters and Tree Trenches	11.4	$851,500 ($681,200 - $1,192,100)[8]	$3,980 ($3,180 - $5,570)
StL_11	Infiltration Basins and Tree Trenches	37.2	$5,099,800 ($4,080,000 - $7,140,000)[8]	$7,310 ($5,860 - $10,245)
StL_12	Pervious Pavement	7.9	$270,000 ($216,000 - $378,000)[8]	$1,820 ($1,460 - $2,550)
StL_15a& StL_15b	Infiltration Basins	12.3	$894,400 ($716,000 - $1,252,000)	$3,880 ($3,100 - $5,430)
StL_16	New Wet Pond	5.1	$499,600 ($400,000 - $700,000)	$5,230 ($4,180 - $7,320)
StL_17	Creek Restoration and Stabilization	20	$550,000 ($275,000 - $1,100,000)	$1,470 ($730 - $2,930)
StL_18	Internal Load Control (Two Whole Lake Alum Treatments)	735	$812,000 ($650,000 - $1,137,000)	$40 ($30 - $50)
StL_21	Creek Restoration and Stabilization	17	$450,000 ($225,000 - $900,000)	$1,410 ($710 - $2,820)
StL_22	Assume upstream lakes meet load and quality goals	29	See table 12.1 for the cost for each lake's BMPs	See table 12.1 for the cost for each lake's BMPs

1. Estimated annual average phosphorus load reduction to the lake, taking pollutant delivery into account.
2. Planning level probably cost; +40% / -20%, dependent on BMP
3. Cost per pound of phosphorus removal per year of operation to the lake, including bot operation, maintenance, and capitol construction costs over a 30 year timeframe.

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RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

Lotus, Silver, Duck, Round, Mitchell, Red Rock Use Attainability Analysis Update; Lake Idlewild and Staring Lake Use Attainability Analysis; and Lower Purgatory Creek Stabilization Study

November, 2016 (Revised March 2017)

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1.0 Background and Study Goals

The approved *Riley-Purgatory-Bluff Creek Watershed District, Water Management Plan*, (CH2M HILL, 2011) (Plan), articulates the Riley-Purgatory-Bluff Creek Watershed District's (RPBCWD) vision of achieving sustainable uses appropriate for each waterbody in the District. Achieving this vision will result in:

- Waters dominated by diverse native fish and plant populations
- Lakes with water clarity of 2 meters or more
- Delisting of half of all impaired (303d) lakes or stream reaches
- An engaged and educated public and scientific community participating in adaptive management activities
- Regulatory recommendations necessary for municipal, county, and state authorities to sustain the achieved conditions

In addition, the Plan also indicates the focus in the Lower Valley of Purgatory Creek is on reducing channel erosion, sediment loads, and promoting channel stability by pursuing the following general themes:

- Invasive species management for both upland and wetland vegetation. Invasive species identified include purple loosestrife, reed canary grass, common buckthorn, and garlic mustard.
- Increase habitat effective area and mitigate the effects of development.
- Protect, preserve, and enhance stream corridor width and composition.
- Reduce the frequency and rate of runoff associated with impervious surface area by implementing stormwater infiltration practices such as bioretention.
- Provide channel stability by implementing channel and floodplain restoration techniques, such as streambank protection, riparian vegetation management, and channel restoration.

In the mid-2000's the RPBCWD elected to suspend completion of the Staring Lake Use Attainability Analysis until the University of Minnesota (UofM) had an opportunity to develop a carp management strategy for the Purgatory Creek basin. The recent success of the cooperative District/UofM lead carp reduction efforts in Staring Lake presented the District with an opportunity to continue the adaptive management of the resources in the Purgatory Creek watershed. In addition, the RPBCWD has implemented the majority of the specific projects identified in the 2011 Plan leading to the need to identify additional water quality improvement/protection projects in the watershed. This study includes a water quality analysis and prescription of protective measures for Purgatory Creek and the eight major waterbodies inside the Purgatory Creek watershed (Lotus Lake, Silver Lake, Duck Lake, Round Lake, Mitchell Lake, Red Rock Lake, Lake Idlewild, and Staring Lake). This analysis is based on historical water quality data, the results of intensive lake and stream water quality monitoring, and computer simulations of land-use impacts on water quality. In addition, best management practices (BMPs) are evaluated to compare their relative effect on lake total phosphorus (TP) concentrations and water clarity (i.e., chlorophyll-a (Chl-a) concentrations and Secchi disc transparencies (Secchi depth)).

1.1 Study Purpose and Goals

The goal of this study is to provide updated information about the water quality and biological integrity of the Lower Valley of Purgatory Creek and the major lakes in the Purgatory Creek watershed. The assessment of the Lower Valley of Purgatory Creek incorporates the extensive efforts previously conducted to establish planning level streambank stabilization strategies. This study also includes trend analyses and comparisons of water quality monitoring with state standards and District goals, watershed and lake water quality modeling calibrated for critical conditions and used to evaluate and recommend restoration measures based on the potential water quality benefits and estimated life-cycle costs, all while aligning with the District's "One Waters" strategy of resource management.

1.2 Purgatory Creek Watershed and Receiving Water Characteristics

The Purgatory Creek watershed mostly lies within the cities of Eden Prairie and Minnetonka. Other smaller portions of the watershed lie within the cities of Deephaven, Shorewood, and Chanhassen. The headwaters of Purgatory Creek originate in Lotus and Silver Lakes as well as the northern branch of Purgatory Creek in the city of Minnetonka. Purgatory Creek then flows through a series of wetlands complexes before entering the Purgatory Creek Recreation Area (aka Purgatory Creek Park Area, Recreation Area) in Eden Prairie, which was constructed in 2003. From the Recreation Area, Purgatory Creek continues into Staring Lake and then through the bluffs of the Minnesota River Valley on its way to its confluence with the Minnesota River. Locations of Purgatory Creek and the eight lakes (Lotus, Silver, Duck, Round, Mitchell, Red Rock, Idlewild, and Staring Lakes) are shown in Figure 1.1.

The Purgatory Creek watershed ranges from marshy with a number of wetlands that have poor drainage north of Highway 7, to a mix of marsh and forested upland areas in the middle of the watershed, to finally the steep valley walls of the Minnesota River valley. In addition to the direct watershed of Purgatory Creek, a chain of lakes known as the Eden Prairie Chain of Lakes discharges into Staring Lake during high flow periods. This chain of lakes includes Round Lake, Mitchell Lake, and Red Rock Lake as well as Lake McCoy (not included in this study). The four lakes were connected to each other and then Staring Lake through a series of pipes installed in 1988 to control lake water levels. From Silver Lake through Staring Lake to the confluence with the Minnesota River the total length of Purgatory Creek is 12 miles with a total watershed area of 19,400 acres (30 square miles).

The history of Purgatory Creek, its watershed and land use can be understood through the examination of aerial photos taken in 1945, 1962, and 1971. The land use of the Purgatory Creek watershed was primarily agricultural until the 1970's. Several portions of Purgatory Creek had been ditched and straightened prior to 1945, with a portion of the creek classified as county ditch. Much of the creek area appears to have been grazed. The lower valley, in particular appeared to have been devoid of undergrowth vegetation. Severe gully formations were evident in the lower valley even in the 1940's.

1.3 Urbanization Influence on Purgatory Creek

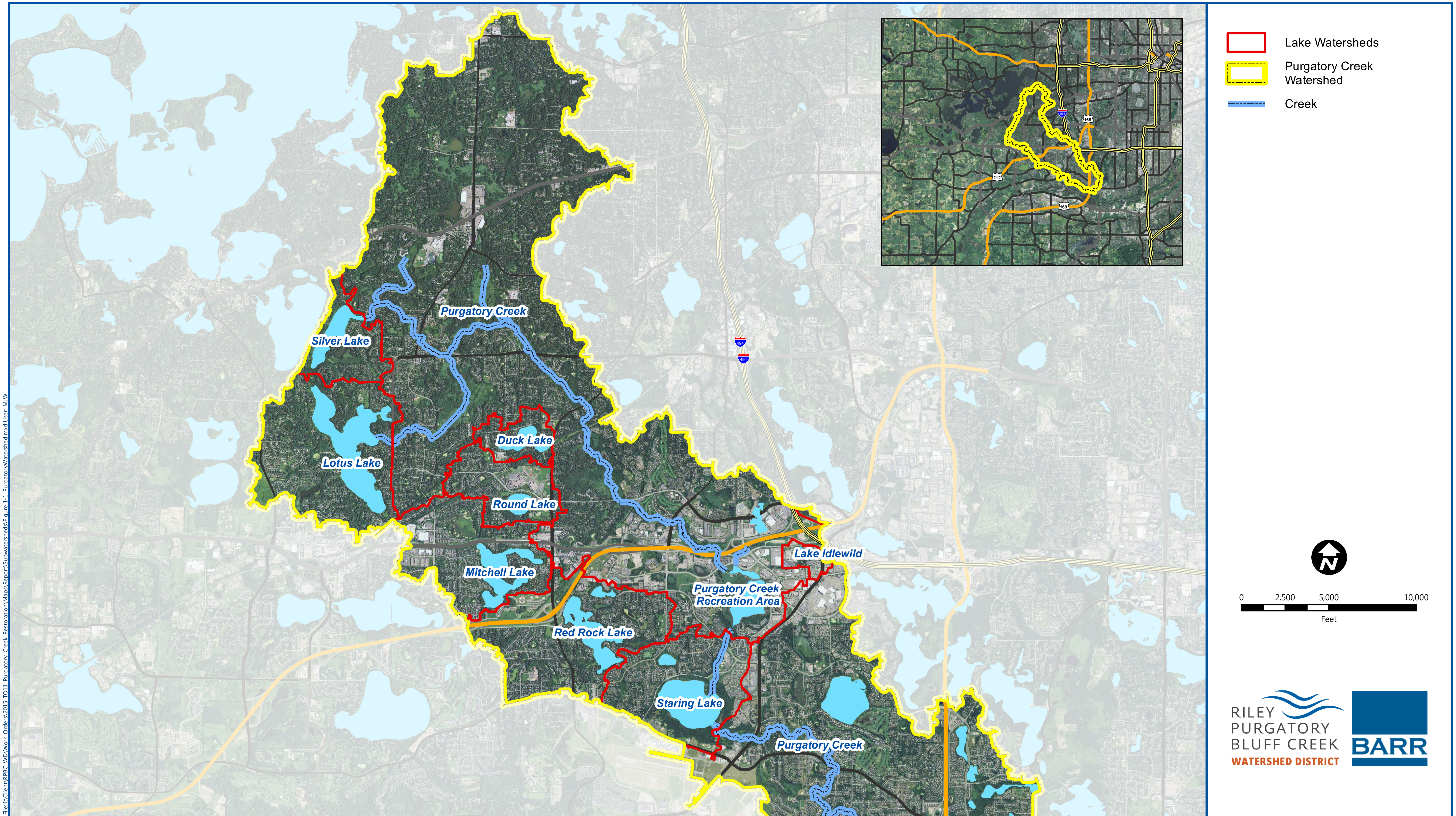
Because of its proximity to the metro area, the Purgatory watershed saw increased urbanization relatively early, and is now almost fully developed. With urbanization, grazing gradually ended and the floodplain has re-vegetated with grass, willow, dogwood, and other shrub vegetation. Many of the severely eroded gullies bordering the lower valley have also re-vegetated, either naturally or artificially with development. Re-vegetation of the floodplain areas appears to have improved the physical condition of Purgatory Creek.

The current dominant land use in the Purgatory Creek watershed is single family residential representing 48% of the total watershed area. The next highest land use classification in the watershed is park, recreational, or preserve which represents 13% of the total watershed area. All land use classifications and areas are given in Table 1.1.

Table 1.1 Land use areas within Purgatory Creek watersheds

Land Use	Area [Acres (percent)]	Land Use	Area [Acres (percent)]
Single Family Detached	9299, (47.9%)	Multifamily	506.6, (2.6%)
Park, Recreational, or Preserve	2604, (13.4%)	Industrial and Utility	467, (2.4%)
Undeveloped	1624, (8.4%)	Golf course	288, (1.5%)
Single Family Attached	1190, (6.1%)	Office	162, (0.8%)
Open Water	1109, (5.7%)	Airport	104, (0.5%)
Institutional	713, (3.7%)	Agricultural/Farmstead	18, (0.1%)
Retail and Other Commercial	683, (3.5%)	Mixed Use	17, (0.1%)
Major Highway	613, (3.2%)		

Data from Metropolitan Council spatial data sets for existing (2010) land use for the Twin Cities Metropolitan Area



RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

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PURGATORY CREEK & LAKES WATERSHEDS

FIGURE 1.1

1.4 Previous Studies

The following is a list of the past studies and reports related to Purgatory Creek as well as the Silver, Lotus, Duck, Round, Mitchell, Red Rock, Staring, and Idlewild lakes. Not included in the list are the numerous reports on water quality and plant surveys conducted on the lakes each year by the City of Eden Prairie and the Riley Purgatory Creek Watershed District:

- Purgatory Creek "One Water" (CH2M HILL, 2011)
- Red Rock Lake use attainability analysis (Barr Engineering, 2006)
- Lotus Lake use attainability analysis (Barr Engineering, 2005).
- Round Lake use attainability analysis (Barr Engineering, 1999).
- Silver Lake use attainability analysis (Barr Engineering, 2003).
- Duck Lake use attainability analysis (Barr Engineering, 2005).
- Mitchell Lake use attainability analysis (Barr Engineering, 2005).
- Purgatory Creek use and attainability analysis (Barr Engineering, 2005).
- Aquatic Plant Community of Lakes Lotus, Lucy, Mitchell, Susan, Riley, and Staring within the Riley Purgatory Creek Watershed (Jaka & Newman, 2014)
- Staring Lake Eurasian watermilfoil early detection and rapid response (Fresh Water Scientific Services, 2015)
- Red Rock Lake plant management plan (Wenck Associates Inc., 2015).
- Mitchell Lake plant management plan (Wenck Associates, Inc., 2014)
- Staring Lake watershed stormwater pond assessment project (Wenck Associates, Inc., 2013).
- Red Rock and Duck Lake watersheds stormwater pond assessment project (Wenck Associates, Inc., March 2014)
- Stormwater pond project 2012 Report (RPBCWD, 2014).
- Paleolimnological historical water quality and ecological change of three lakes (Mitchell, Lotus, and Round) in the Riley Purgatory Creek Watershed District (Ramstack & Edlund, 2011).
- Paleolimnological analysis of Silver Lake, Hennepin County, Minnesota (Ramstack Hobbs & Edlund, 2015)
- Development and implementation of a sustainable strategy to control common carp in the Purgatory Creek chain of Lakes (Sorensen, et al., 2015)
- Creek restoration action strategy (RPBCWD and Barr, 2015).
- Purgatory Creek Watershed: Total Maximum Daily Load implementation plan (Barr, 2013)

A more detail list and summary of previous studies is given in annotated bibliography found in Appendix A.

1.5 Lower Purgatory Creek Water Quality Goals

The District's 3rd Generation Watershed Management Plan has identified stream flows (hydrology), erosion, water quality, and aquatic ecosystem biology/habitat as issues throughout the watershed. The Plan also outlines short and long-term goals aimed to protect and restore the creeks in the District. These goals include the following:

- Long-Term Goal 2. Improve water quality to fully support designated uses for water bodies, and remove water bodies from the Minnesota Pollution Control Agency list of impaired waters;
- Long-Term Goal 3. Preserve vegetation and habitat important to fish, waterfowl, and other wildlife while also minimizing negative impacts of erosion; and
- Long-Term Goal 4. Maintain control of floodwaters and limit the impact of runoff quantity and rate on receiving waterbodies.
- Long-Term Goal 5. Alter stormwater hydrographs (streamflow) through infiltrative strategies that reduce peak discharge rates and overall flow volume.

A discussion of water classes in Minnesota and the standards for those classes is provided below in order to define the regulatory context and environmental endpoint of the assessment of Lower Purgatory Creek. All waters of Minnesota are assigned classes based on their suitability for the following beneficial uses:

1. Domestic consumption
2. Aquatic life and recreation
3. Industrial consumption
4. Agriculture and wildlife
5. Aesthetic enjoyment and navigation
6. Other uses
7. Limited resource value

Purgatory Creek is not listed in the Minn. Rules Ch. 7050.0470 classification therefore it follows the Minn. Rules Ch. 7050.0430 Unlisted Waters as a classification 2B, 3C, 4A, 5, 6 water. The quality of Class 2B surface waters, such as Purgatory Creek, are defined as shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface waters is also protected as a source of drinking water.

1.5.1 Turbidity and Total Suspended Solids

Turbidity in water is caused by suspended sediment, organic material, dissolved salts and stains that scatter light in the water column making the water appear cloudy. Excess turbidity can degrade aesthetic qualities of water bodies, increase the cost of treatment for drinking or food processing uses and can harm aquatic life. Aquatic organisms may have trouble finding food, gill function may be affected and spawning beds may be covered. In addition, greater thermal impacts may result from increased sediment deposition in the stream.

Turbidity is a parameter that has a significant amount of variability associated with the measurement values reported. Unlike many water quality parameters which are a measurement of mass of constituents in a volume of water, turbidity is a measure of the optical properties of a water sample which causes light to be scattered and absorbed (Federal Water Pollution Control Administration, 1968). Differences in the constituents' response to light contribute to the variability in turbidity readings. Adding to this variability, differences between turbidity meter types can result in different turbidity values being measured for the same water samples.

Because of the variability in the turbidity readings the MPCA adopted creek standards related to total suspended solids in 2014 replacing the turbidity standard. According to the total suspended solids (TSS) standard for Class 2B waters, a stream reach is considered impaired if more than 10% of TSS samples collected April through September exceed 65 mg/L, based on the last ten years of monitoring data.

1.5.2 Eutrophication Standard

The 2015 monitoring showed that some of the sample results for TP and chl-a did not meet MPCA's standards for river eutrophication (as approved in 2014). MPCA's TP and chl-a standards for the Central River Nutrient Region are 100 µg/L and 18 µg/L, respectively.

1.6 Creek Dynamics Primer

1.6.1 Flood Frequency and Magnitude

Prior to the introduction of agriculture and grazing practices, Purgatory Creek was likely in dynamic equilibrium with its watershed and was able to convey storm runoff without significant change in its shape, pattern, or profile. Transforming the landscape to one dominated by agriculture likely made fundamental changes to the hydrology by changing the dominant vegetation (both in the watersheds and adjacent to the creek), improving the rate of drainage from fields, and altering the sediment load to the stream. Relatively rapid fundamental changes to the hydrology can disrupt the dynamic equilibrium and result in erosion as the stream gradually moves toward a new balance with the hydrology and sediment supply to the creek in a process that can take years or decades to play out. When the watershed began to urbanize, a similar process likely began again as sediment supply, drainage patterns, and runoff rates and volumes changed again.

The most significant change associated with urbanization, as far as the stream is concerned, is an increase in runoff from the watershed. With urbanization, the rate and volume of runoff generally increases, as shown in Figure 1.2 assuming mitigating measures are implemented.

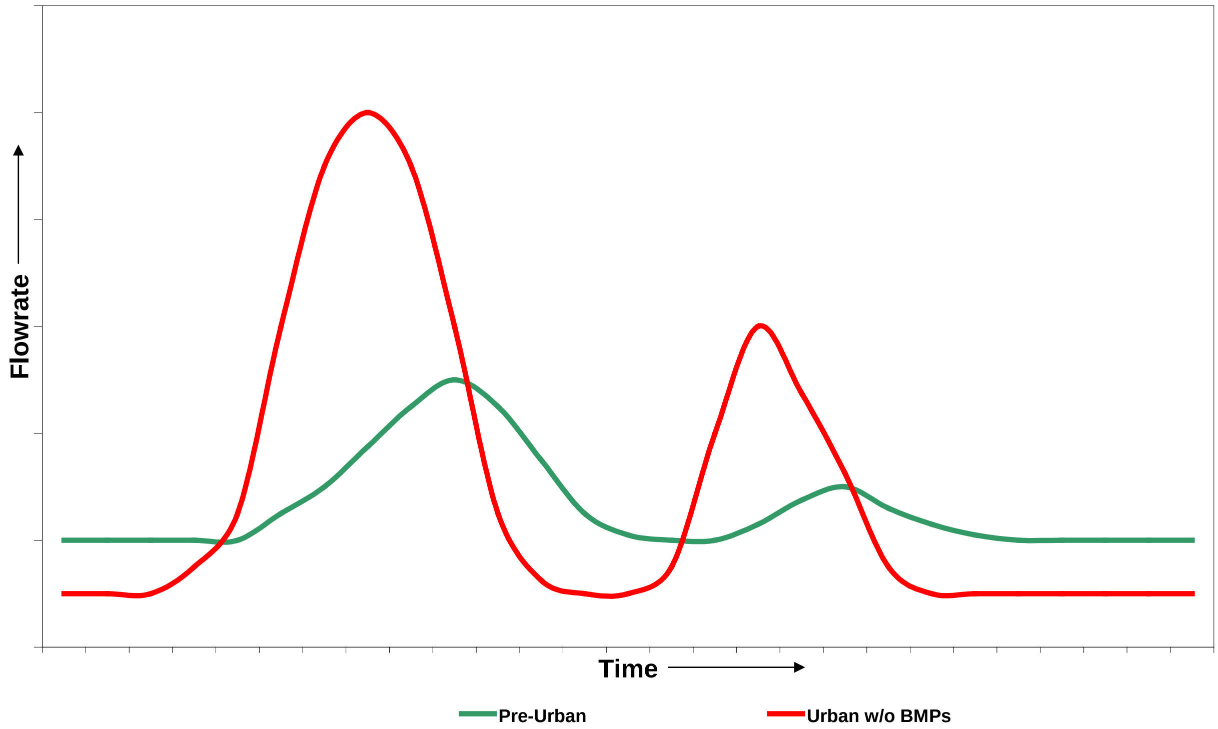


Figure 1.2 Change in Streamflow Due to Urbanization (Center for Watershed Protection, 2003)

The shape, pattern, and profile of the stream channel are intimately related to the bankfull discharge. When the stream is in equilibrium with its environment, the shape, pattern, and profile are such that the stream can convey the bankfull discharge without significant change in those parameters. With urbanization, the frequency of bankfull discharge typically increases depending on the amount of impervious area in the watershed as illustrated in Figure 1.3.

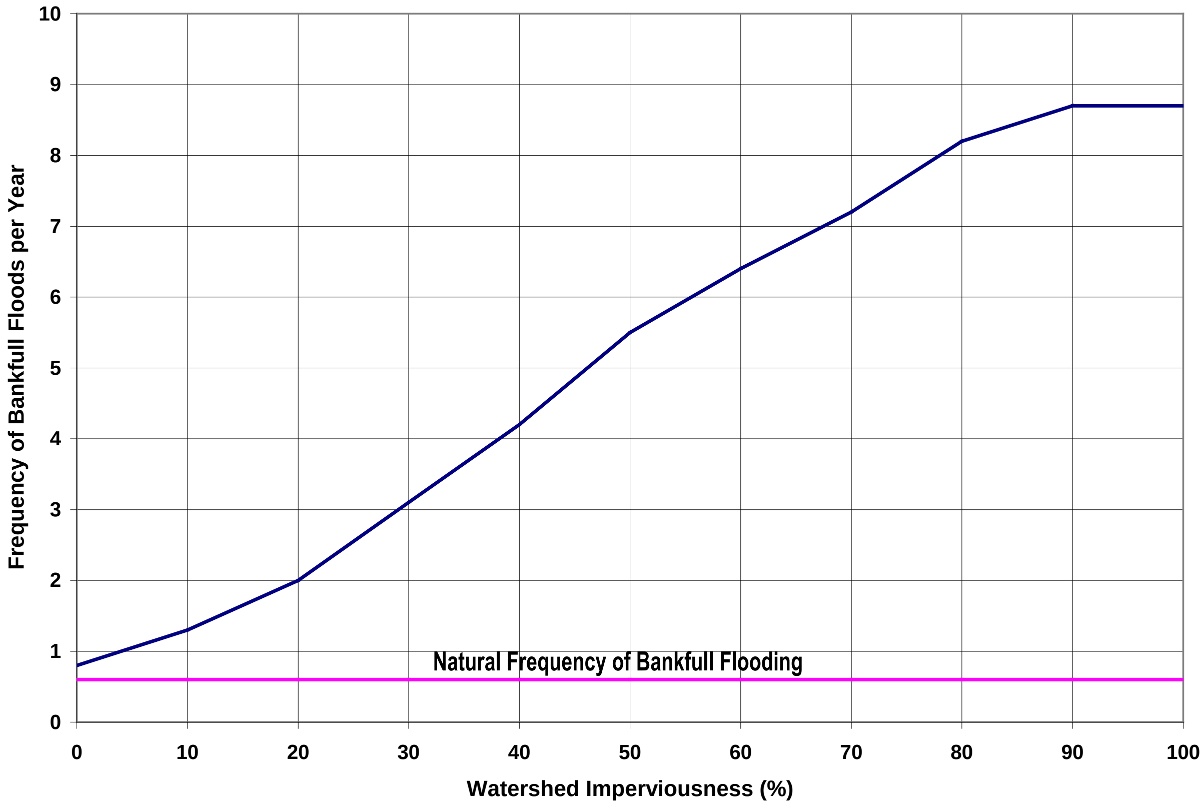


Figure 1.3 Conceptual Frequency of Bankfull Flooding as a Function of Imperviousness (Center for Watershed Protection, 2003)

Because the bankfull flood is the dominant, channel forming flow, and because under natural conditions this flow only occurs on average once every 1 to 2 years, the stream must adjust to what is effectively a larger channel-forming discharge. The channel tends to widen and deepen its cross-section. As it does this, the sinuosity of the stream tends to decrease, with a resulting increase in the slope of the channel.

Detention ponds are often constructed to slow the rate of storm water flow to the stream, and thus attempt to maintain a more natural rate of flow to the stream. By increasing storm water detention volume available it may be possible to approach the pre-urbanized peak runoff rates to the stream. Infiltration practices such as rainwater gardens are even more beneficial, because they reduce not only the rate of runoff but also the volume.

Because it is usually impractical to store enough runoff to eliminate increases in the amount of runoff to the channel, the stream must respond to the flow increases. The natural stream channel tends to widen and deepen to convey the greater frequency and volume of discharge.

1.6.2 Sediment Transport

Sediment transport is an important function of the stream. It forms the shape of the channel, including the pools and riffles which are so important to aquatic life. Sediment transport consists of suspended sediment, which is distributed throughout the water column, and bed load sediment, which moves along the stream bed. Suspended sediment generally consists of finer particles, while bed load sediment consists of larger, heavier particles. With larger flows, bed load sediment particles may become suspended as the power of the stream increases. Bed load sediment occupies from 5 to 50 percent of the total sediment load of a stream; suspended sediment occupies the remaining larger fraction.

The general progression of suspended sediment transport with a single storm typically begins with a low suspended sediment load at low stream flows. As flow increases, the sediment load also increases, until the flow reaches a maximum. The rising sediment load is typically a combination of wash load from the watershed and near channel sources, including mobilization of bed material. Near channel sources of sediment can also include, but are not limited to, scour around fallen trees and bank slumps that have occurred between floods. As the flood recedes, the sediment load is lower than for similar discharges on the rising limb of the hydrograph for a few reasons. Wash load from the watershed is decreased as runoff has either stopped already or easily movable sediment has already been washed into the stream. Removal of slumped bank material and scour around in-stream obstruction decreases, either because the easily transported material has already been moved or because the lower velocities can no longer transport sediment from these sites. Velocities in the channel are also lower on the tail of the hydrograph compared to the same flow on the rising arm of the hydrograph because flows are no longer increasing and tailwater created by the flood help slow velocities; and lower velocities are less capable of eroding the channel and transporting sediment.

1.6.3 Channel Disturbance

Activities such as road crossing of the creek, channel straightening and concentration of flow at culvert crossings also have a negative impact on the stream. These activities alter the stable pattern and profile of the channel. Areas of disturbed natural vegetation along the stream banks and floodplain also results in greater erosion potential.

1.7 Lake Water Quality Goals

The MPCA lake eutrophication criteria establish water quality standards for lakes based on TP, chlorophyll *a*, and Secchi disc transparency (Minnesota Rules, 7050). The standards are based on the geographic location of the waterbody within the state (and the associated ecoregion) and the depth of the waterbody, distinguishing shallow and deep lakes. The standards are based on the growing-season average of the surface data available for any given lake. The growing season is defined as June through September. Surface data is considered to be any water quality data collected in the depth range of 0 to 2 meters from the water surface of the lake. These criteria are used to determine if a lake is impaired by excess nutrients and are the criteria used to list lakes on the MPCA 303(d) list of impaired waters.

All eight lakes studied are located within the North Central Hardwood Forest ecoregion of the state. Four of the lakes (Duck Lake, Mitchell Lake, Red Rock Lake, and Staring Lake) are classified as a shallow lake by the MPCA, two (Round Lake and Lotus Lake) are classified as a deep lake and two (Silver Lake and Lake Idlewild) are not classified by the MPCA. According to the district's 2011 plan, the District goals for Silver Lake are equivalent to the MPCA goals for a shallow Lake (CH2M HILL, 2011). Lake Idlewild is classified as a wetland therefore the wetland non-degradation state goals apply.

As part of the District's 2011 plan (CH2M HILL, 2011), the RPBCWD adopted national and state goals for the water resources within the watershed, including the MPCA lake water quality standards. Additionally, as part of the RPBCWD's vision, an additional long-term goal is to have all lakes achieve water clarity of 2 meters or more. Table 1.2 Water Quality Goals and Standards for Purgatory Creek Lakes summarizes the MPCA and RPBCWD water quality goals and standards as would be applied to Purgatory Creek Lakes.

Table 1.2 Water Quality Goals and Standards for Purgatory Creek Lakes

Agency	Parameter	Silver Lake[1]	Lake Idlewild	Duck Lake	Mitchell Lake	Red Rock Lake	Staring Lake	Lotus Lakes	Round Lake
MPCA	Depth classification	--[2]	--[2]	Shallow				Deep	
	TP	Non degradation		< 60 µg/L				< 40 µg/L	
	Chlorophyll *a*	Non degradation		< 20 µg/L				< 14 µg/L	
	Secchi Depth	Non degradation		> 1.0 m				> 1.4 m	
RPBCWD	TP	< 60 µg/L							
	Chlorophyll *a*	< 20 µg/L							
	Secchi Depth	> 1.0 m							
	Goal for all lakes	SD≥ 2.0 m							

[1] Silver Lake follows the shallow lake standard according to RPBCWD 10 year plan (CH2M HILL, 2011).
[2] Not classified as a shallow or deep lake by MPCA.

1.7.1 Relationship to MPCA's Impaired Waters Program

Four of the lakes (Staring, Lotus, Mitchell, and Red Rock) in the study have been listed as impaired for nutrients/eutrophication by the MPCA since 2002. Red Rock Lake which was listed as being impaired in 2002 was removed from the impairment list in 2016 due to improvement in water quality concentrations in recent years. Mitchell Lake which was listed as being impaired in 2002 is scheduled to be delisted by the MPCA. This delisting will become official in the 2018 impaired water listings. Three lakes (Staring, Red Rock, and Round) are listed as impaired for mercury in fish tissue. Round Lake and Red Rock Lake already have completed TMDLs for the mercury listings. Table 1.3 MPCA Impaired Waters Listings displays the waterbodies on the impaired waters list. Silver Lake has not been listed as impaired by the MPCA.

Table 1.3 MPCA Impaired Waters Listings

Parameter	Lotus Lake	Mitchell Lake	Red Rock Lake		Staring Lake		Round Lake
Description	Lake or Reservoir	Lake or Reservoir	Lake or Reservoir		Lake or Reservoir		Lake or Reservoir
Year Listed	2002	2002	2002		2002	1998	2002
Lake IDs	10-0006-00	27-0070-00	27-0076-00		27-0078-00		27-0071-00
Affected use	Aquatic Recreation	Aquatic Recreation	Aquatic Recreation	Aquatic Consumption	Aquatic Recreation	Aquatic Consumption	Aquatic Consumption
Pollutant of stressor	Nutrient/ eutrophication biological indicators	Nutrient/ eutrophication biological indicators	Nutrient/ eutrophication biological indicators	Mercury in fish tissue	Nutrient/ eutrophication biological indicators	Mercury in fish tissue	Mercury in fish tissue
TMDL target Start date	2014	2014			2014	1998	
TMDL target completion	2019	2019			2019	2025	
TMDL Plan Approved				2008			2008
Year Delisted		2018[1]	2016				

[1] Mitchell Lake is scheduled to be delisted by the MPCA on the 2018 impaired waters list.

1.8 Lake Water Quality Primer and Implications for Management

One focus of this study is the eutrophication in the eight Purgatory Creek lakes. Eutrophication, or lake degradation, is the accumulation of sediments and nutrients in lakes. Typically, the nutrient of concern in fresh-water lake systems is phosphorus, as it often acts as the limiting nutrient that controls algal growth. As a lake naturally becomes more fertile, algae and plant growth increases. The increasing biological production and sediment inflow from the lake's watershed eventually fills the lake's basin. Over a period of centuries, the lake successively becomes a pond, a marsh, and, ultimately, a terrestrial site. This process of eutrophication is natural and results from the normal environmental forces that influence a lake. Cultural eutrophication, however, is an acceleration of the natural process caused by human activities. Nutrient and sediment inputs (i.e., loadings) from wastewater treatment plants, septic tanks, and stormwater runoff can far exceed the natural inputs to the lake. The accelerated rate of water quality degradation caused by these pollutants results in unpleasant consequences. These include profuse and unsightly growths of algae (algal blooms) and/or the proliferation of rooted aquatic plants (macrophytes).

1.8.1 Trophic State

Not all lakes are at the same stage of eutrophication; therefore, criteria have been established to evaluate the nutrient status, or trophic status, of lakes. Trophic status categories include oligotrophic (i.e., low nutrient level), mesotrophic (i.e., moderate nutrient levels), eutrophic (i.e., high nutrient levels), and hypereutrophic (i.e., extremely high nutrient levels). Water quality characteristics of lakes in the various trophic status categories are listed below:

1. **Oligotrophic**: clear, low productivity lakes, with TP concentrations less than or equal to 10 µg/L, chlorophyll *a* concentrations of less than or equal to 2 µg/L, and Secchi disc transparencies greater than or equal to 4.6 meters (15 feet)
2. **Mesotrophic**: intermediate productivity lakes, with TP concentrations between 10 and 25 µg/L, chlorophyll *a* concentrations between 2 and 8 µg/L, and Secchi disc transparencies between 2 and 4.6 meters (6 to 15 feet)
3. **Eutrophic**: high productivity lakes, with 25 to 57 µg/L TP, chlorophyll *a* concentrations between 8 and 26 µg/L, and Secchi disc measurements between 0.85 and 2 meters (2.7 to 6 feet)
4. **Hypereutrophic**: extreme productivity lakes which are highly eutrophic and unstable (i.e., their water quality can fluctuate on daily and seasonal basis, experience periodic anoxia and fish kills, possibly produce toxic substances, etc.) with TP concentrations greater than 57 µg/L, chlorophyll *a* concentrations of greater than 26 µg/L, and Secchi disc transparencies less than 0.85 meters (2.7 feet)

1.8.2 Typical Nutrient Sources

Aquatic organisms influence (and are influenced by) the chemistry of the surrounding environment. For example, phytoplankton extract nutrients from the water and zooplankton feed on phytoplankton. Nutrients are redistributed from the upper waters to the lake bottom as the dead plankton gradually settles to lower depths and decompose. Essential nutrients such as the bioavailable forms of phosphorus and nitrogen in the surface waters typically increase in the spring from snowmelt runoff and from the mixing of accumulated nutrients from the bottom during spring turnover and decrease during summer stratification as nutrients are taken up by algae and eventually transported to the bottom water when algae die and settle out. Any "new" input of nutrients into the surface water may trigger a "bloom" of algae. Such inputs may be from upstream tributaries after rainstorms, from die-offs of aquatic plants, or from pulses of urban stormwater. In the absence of rain or snowmelt, an injection of nutrients may occur simply from high winds that mix a portion of the nutrient-enriched upper waters of the hypolimnion into the epilimnion.

Phosphorus enters a lake from a variety of external sources, such as watershed runoff, direct atmospheric deposition, and discharges from upstream waterbodies. More recently, data collected by RPBCWD and the city of Eden Prairie identified that some of the constructed stormwater ponds and natural wetlands can also experience internal loading from the accumulated sediments and organic materials and can act as sources of phosphorus to the downstream lakes, rather than phosphorus sinks. Because external phosphorus sources can be significant, the phosphorus concentrations in a lake can be reduced by decreasing the external load of phosphorus to the lake.

All lakes, however, also accumulate phosphorus (and other nutrients) in the sediments from the settling of particles and dead organisms and organic matter. In some lakes, this reservoir of phosphorus can be reintroduced in the lake water and become available again for plant uptake. This resuspension or dissolution of nutrients from the sediments to the lake water is known as “internal loading.” As long as the lake’s sediment surface remains sufficiently oxidized (i.e., dissolved oxygen remains present in the water above the sediment), the phosphorus will remain bound to ferric iron in sediment particles. When dissolved oxygen levels become extremely low at the water-sediment interface (as a result of microbial activity using the oxygen), the chemical reduction of ferric iron to its ferrous form causes the release of dissolved phosphorus, which is readily available for algal growth, into the water column. Low-oxygen conditions at the sediments, with resulting phosphorus release, are to be expected in eutrophic lakes where relatively large quantities of organic material (decaying algae and macrophytes) are deposited on the lake bottom.

In addition to the dissolved oxygen levels along the sediment interface, the pH of the water column can also play a vital role in affecting the phosphorus release rated under oxic conditions. Photosynthesis by macrophytes and algae during the day tend to raise the pH in the water column, which can enhance the phosphorus release rate from the oxic sediment. Enhancement of the phosphorus release at elevated pH (pH great than 7.5) is thought to occur through replacement of the phosphate ion (PO_4^{-3}) with the excess hydroxyl ion (OH^-) on the oxidized iron compound (James, et al., 2001). How this internal phosphorus load from the sediments impacts the observed water quality in the lake is highly dependent on the thermal stratification and mixing dynamics within the lake.

Another potential source of internal phosphorus loading is the die-off and subsequent decay of curlyleaf pondweed, an exotic (i.e., non-native) lake plant prevalent in many Minnesota lakes. Curlyleaf pondweed grows over the winter and tenaciously during early spring, crowding out native species. It releases a small reproductive pod (turion) that resembles a small pinecone during late June. After curlyleaf pondweed dies out, often in late-June and early-July, it may sink to the lake bottom and decay, releasing phosphorus and causing oxygen depletion and exacerbating internal sediment release of phosphorus. This potential increase in phosphorus concentration during early July can result in algal blooms during the peak of the recreational season.

Benthivorous (bottom feeding) fish activity is another common source of internal loading in some lakes. Benthivorous fish, such as carp and bullhead, can have a direct influence on the phosphorus concentration in a lake (LaMarra, 1975), as these fish typically feed on decaying plant and animal matter and other organic particulates found at the sediment surface and convert these nutrients into a soluble form that is then available for algal uptake. They also cause resuspension of sediments that reduce water clarity as well as high phosphorus concentrations (Cooke, et al., 1993). Additionally, benthivorous fish can destroy the aquatic rooted vegetation, which can have a significant impact on the overall lake water quality (Sorensen, University of Minnesota, phone conversation, 6/19/2013).

1.8.3 Lake Dynamics

Thermal stratification, or the changes in the temperature profile within a lake system, profoundly influences a lake's chemistry and biology. In lakes of the upper Midwest, the water near a lake's bottom will usually be at 39°F just before the lake's ice cover melts in the spring as water has the highest density at this temperature. Water density decreases as temperatures increases or decreases from 39 degrees. As the weather warms, the ice melts. As the surface water heats its density increases causing the surface water to sink and mix with the waters below. Spring turnover occurs when the temperature (and density) of the surface water equals that of the bottom water and continues until the water temperature of the entire lake reaches approximately 39°F. The surface waters continue to absorb heat, causing the water temperatures to rise above 39°F, resulting in the density of the water to decrease and become lighter than the cooler water below. For a while, winds may still mix shallower lakes from bottom to top, but eventually the upper water of deeper lakes become too warm and too buoyant to completely mix with the denser deeper water. The relatively large differences in density at higher temperatures are very effective at preventing mixing.

As summer progresses, the temperature (and density) differences between upper and lower water layers become more distinct. Deep lakes generally become physically stratified by temperature into three identifiable layers, known as the epilimnion, metalimnion, and hypolimnion. The epilimnion is the upper, warm layer, and is typically well mixed. Below the epilimnion is the metalimnion or thermocline region, a layer of water in which the temperature declines rapidly with depth. The hypolimnion is the bottom layer of colder water, isolated from the epilimnion by the metalimnion. The density change at the metalimnion acts as a physical barrier that prevents advective mixing of the upper and lower layers for several months during the summer. The depth of mixing depends in part on the exposure of the lake to wind (its fetch), but is most closely related to the lake's size. Smaller to moderately-sized lakes (50 to 1000 acres) reasonably may be expected to stratify and be well mixed to a depth of 10–23 feet in north temperate climates. When this occurs, generally in mid-summer, oxygen from the air cannot reach the bottom lake water and, if the lake sediments have sufficient organic matter, biological activity can deplete the remaining oxygen in the hypolimnion. The epilimnion can remain well oxygenated, while the water above the sediments in the hypolimnion becomes completely devoid of dissolved oxygen (anoxic).

As the weather cools during autumn, the epilimnion cools too, reducing the density difference between it and the hypolimnion. As time passes, winds mix the lake to greater depths, and the thermocline gradually deepens. When surface and bottom waters approach the same temperature and density, autumn winds can mix the entire lake; the lake is said to turn over again in fall. As the atmosphere cools, the surface water continues to cool until it freezes. A less distinct density stratification than that seen in summer develops under the ice during winter. This pattern (spring turnover — summer stratification — fall turnover — winter stratification) is typical for temperate lakes. Deeper lakes with this pattern of two mixing periods are referred to as dimictic, while shallower lakes with several mixing periods that can occur throughout the summer with sufficient wind energy are referred to as polymictic.

Thermal stratification can significantly influence the amount of internal phosphorus loading from the sediments that can occur in the lake, and in some lakes, can significantly influence the water quality in the epilimnion (surface layer). Biological activity peaks during the spring and summer when photosynthetic activity is driven by high solar radiation. Furthermore, during the summer most lakes in temperate climates are stratified. The combination of thermal stratification and biological activity causes characteristic patterns in water chemistry. During summer stratification, the conditions in each layer diverge. The dissolved oxygen (DO) concentration in the epilimnion remains high throughout the summer because of photosynthesis and diffusion from the atmosphere. However, oxygen conditions in the hypolimnion vary with trophic status. In eutrophic (more productive) lakes, hypolimnetic DO declines during the summer because it is cut-off from all sources of oxygen, while organisms continue to respire and consume oxygen. The bottom layer of the lake and even the entire hypolimnion may eventually become anoxic, or totally devoid of oxygen.

As microorganisms continue to decompose material in the lower water column and in the sediments, they consume oxygen, and DO is depleted. No oxygen input from the air occurs with ice cover, and, if snow covers the ice, it becomes too dark for photosynthesis. This condition can cause high fish mortality during the winter, known as "winter kill." Low DO in the water overlying the sediments can exacerbate water quality deterioration; because when the DO level drops below 1 mg O_2/L chemical processes at the sediment-water interface frequently cause release of phosphorus from the sediments into the water. When a lake mixes in the spring, this new phosphorus and ammonium that has built up in the bottom water fuels increased algal growth.

2.0 Project Approach

The Plan includes the flow diagram shown in Figure 2.1 to outline the District's overall approach to protection and restoration of the water resources in the District.

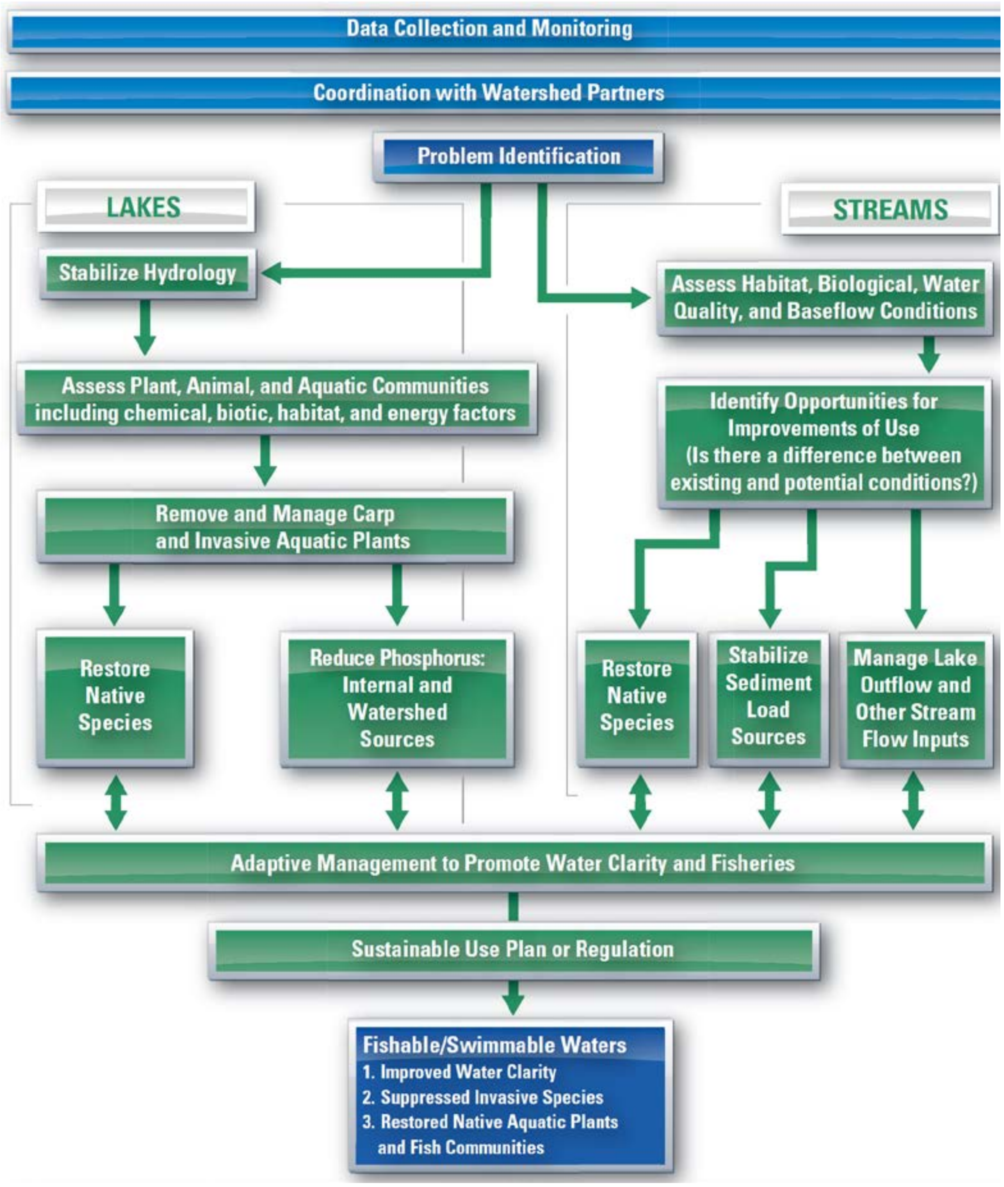


Figure 2.1 RPBCWD Overall Approach to Resources Protection and Restoration

2.1 Creek Assessment Approach

The assessment of the Lower Valley of Purgatory Creek incorporates the extensive efforts previously conducted as part of the RPBCWD Water Management Plan, (CH2M HILL, 2011), CRAS report (Barr and RPBCWD, 2015), creek inventories by District staff (RPBCWD 2014), city of Eden Prairie Purgatory Creek - 2006 to 2013 Erosion Changes (Wenck 2014), and 2005 Purgatory Creek Use Attainability Analysis (Barr

2005) to establish planning level streambank stabilization strategies. The assessment relied on existing information and did not involve the collection of any new field data. In addition, the focus was on Purgatory Creek downstream of Staring Lake and reserved the assessment of the creek and wetlands upstream of Valley View Road for future efforts.

The geomorphic assessment generally followed guidelines and techniques included in the Rosgen classification system (Rosgen, 1996). Rosgen classification uses multiple measurements and ratios to classify a given stream into one of eight different stream types (Figure 2.2). Streams that fall into each stream type typically share many characteristics. One or more measurements that are inconsistent with typical or expected values can help indicate if a stream is stable or unstable.

As can be seen in Figure 2.2, the Rosgen classification system is dependent on the entrenchment ratio, the width to depth ratio, sinuosity, slope, and bed material. The entrenchment ratio and width-to-depth ratio both use dimensions from the bankfull level for each channel. Bankfull is generally defined as the depth at which flow in the channel just begins to spill into the adjacent floodplain. The flow that results in a bankfull depth is typically between the 1- and 2-year recurring flows, although the exact frequency is dependent on each stream and watershed characteristics. The 1.5-year recurring flow is often used to estimate bankfull flows. The key components of the Rosgen classification system are briefly summarized below:

- *Entrenchment ratio* is the ratio between the bankfull width and the floodplain width. The flood prone width is defined as the width of the floodplain at twice the bankfull depth. This ratio helps described how confined the stream is within its floodplain. A large value indicates a wide floodplain, and a small value indicates a small floodplain.
- The *width-to-depth ratio* is the ratio between the bankfull width and bankfull depth. It provides information about the channel shape.
- *Sinuosity* is the stream length divided by the valley length and provides information about how much the stream meanders through the landscape.
- *Slope* is the average channel slope through the study area.
- *Bed material* characterizes the dominant material and size of material on the channel bottom.

All channel types can be stable in the right site characteristics. In the Twin Cities and central Minnesota, the most common stable channels are Type C and Type E channels. Type C channels are often found in forested areas whereas E channels are often found with grassy riparian areas.

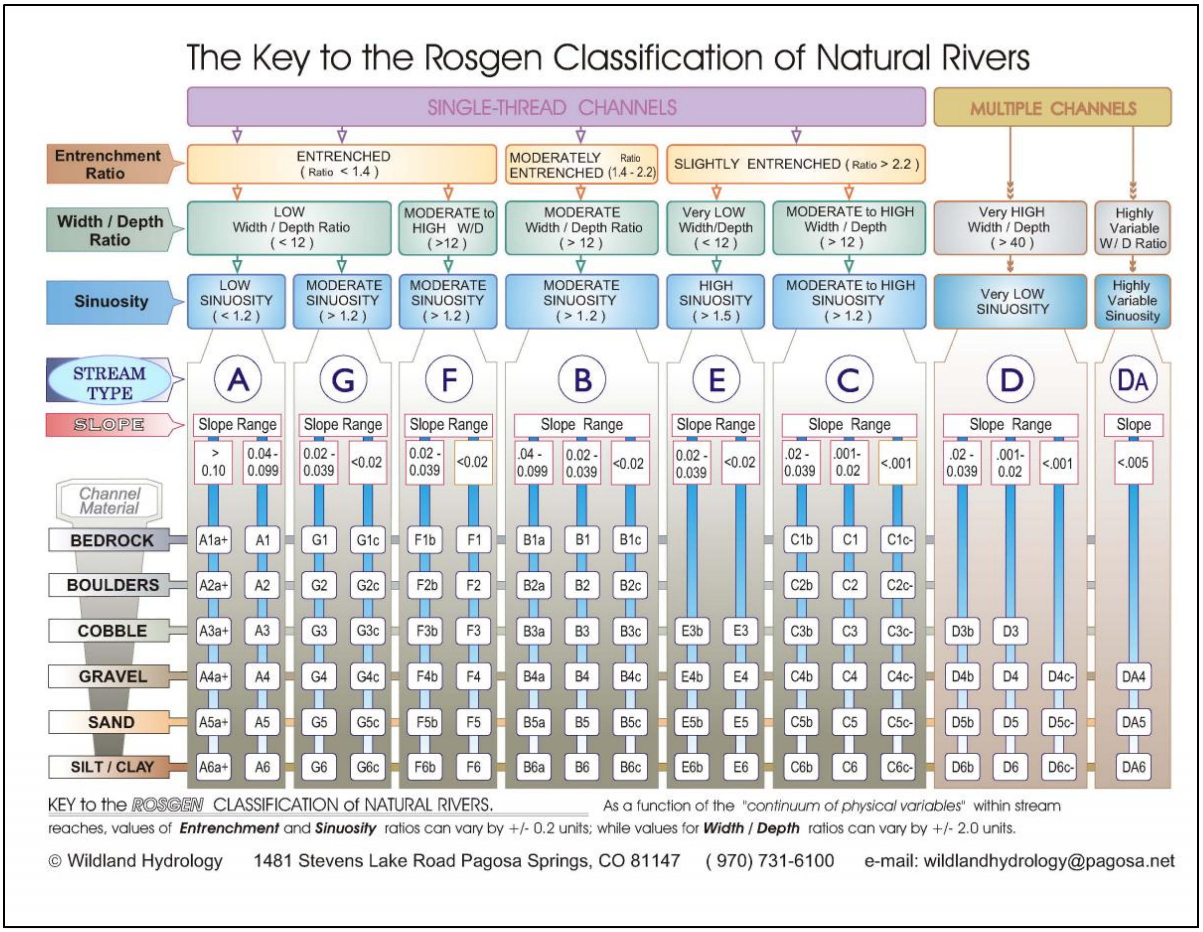


Figure 2.2 Rosgen Classification System Key (Rosgen, 1996)

2.1.1 Evaluation Criteria

Specific stabilization measures should be selected and designed based on expected velocities and shear stresses within the channel for all sites and reaches. Published threshold values for stabilization measures can aid in the selection of stabilization criteria. Examples of published threshold criteria are presented in Table 2.1.

Table 2.1 Published threshold values for selected stabilization techniques

Stabilization Technique	Allowable Velocity (fps)	Allowable Shear Stress (lbs/ft^2)
Sandy loam soil[a]	1.75-2.25	0.045-0.05
Stiff clay[a]	3-4	0.26
Vegetated soil with short native grasses[a]	3-4	0.7-0.95
Vegetated turf reinforcement mat[a]	8-21	8
Vegetated Reinforced Soil Slopes (VRSS) – immediately after installation[b]	3-5	5-9
Vegetated Reinforced Soil Slopes (VRSS) – after 1-2 years of growth[b]	8	14
Riprap (12-in D_{50})[a,c]	10-13	5.1
Riprap (24-in D_{50})[a,d]	14-18	10.1
Rootwads[e]	N/A	N/A

a – from Reference (Fischenich, 2001)

b – Sotir and Fischenich (2003)

c – for use in constructed riffles and grade control

d – for use in rock vanes

e – design and installation guidelines in Reference (Sylte, 2000)

2.1.2 Typical Streambank Stabilization Measures

Techniques for stream stabilization generally fall into two categories: bioengineering (also known as soft armoring) and hard armoring. Bioengineering techniques employ biological and ecological concepts to control erosion, using vegetation or a combination of vegetation and construction materials, including logs and boulders. Techniques that do not use vegetative material but are intended to achieve stabilization of natural flow patterns and create in-stream habitat, such as boulder or log vanes, are generally included under the umbrella of bioengineering. Hard armoring techniques include the use of engineered materials such as stone (riprap or boulders), gabions, and concrete to stabilize slopes and prevent erosion. Technical stakeholders, including the USACE and MDNR, have expressed a preference for bioengineering over hard armoring for stream stabilization where possible. The RPBCWD Rules (Rule F) include specific language requiring that a preference be made for natural materials and bioengineering over hard armor.

The following is a brief discussion of potential stabilization measures for the Lower Valley of Purgatory Creek. For additional information on the proposed measures, please refer to the schematics presented in Appendix F.

2.1.2.1 Bioengineering and Hard Armoring Stream Stabilization Techniques

Bioengineering techniques maintain more of a stream's natural function and provide better habitat and a more natural appearance than hard armoring. If vegetation is well-established this approach can also be self-maintaining. Due to biodegradation of construction materials and variable vegetation establishment success, it is typically assumed that bioengineering installations have a shorter life span and may need more frequent (if less expensive) maintenance, particularly as the vegetation is becoming established. Compared to hard armoring, the success of bioengineering techniques is more dependent on the skill of the designer and installer—sometimes making bioengineering construction more expensive. Hard armoring and bioengineering techniques present different challenges, costs, and benefits for stream stabilization design.

Bioengineering techniques

- Active floodplain/vegetated bench—modifications made to the stream cross section to increase floodplain connectivity and decrease erosive stress during flood flows; can involve construction of a soil bench, lowering an existing bench, and/or raising the channel bed
- Boulder or log vane—boulders or large logs buried in the stream bed and extending partially ("vanes") or entirely across the stream ("cross vanes") to achieve one or more of the following goals: re-direct flows away from banks, encourage sediment deposition in selected areas, control stream bed elevations, and create scour pool habitat features Vanes are largely submerged and inconspicuous.
- Constructed riffle—gravel or cobble material installed in the stream bed to create natural flow patterns/varied habitat features and, frequently, to control stream bed elevations.
- Vegetated buffer—native vegetation established along a stream bank or overbank area to stabilize bare soils and increase resistance to fluvial erosion
- Vegetated reinforced slope stabilization (VRSS)—soil lifts created with long-lasting, biodegradable fabric and vegetated to stabilize steep slopes and encourage establishment of root systems for further stabilization
- Root wads or toe wood—consist of logs with the root ball attached anchored into the bank, so that only the root ball is exposed. Typically placed about half below and half above the normal water line, they are well suited to deeper locations such as outside bends. The trunk portion is placed in the bank by either placing it in a trench or by pushing the trunk into the bank. The root wad absorbs energy and diverts flows away from the bank, create undercut/overhanging bank habitat features, re-direct flows away from banks, and provide a bench for establishment of riparian vegetation. Rootwads are generally cost effective and provide excellent fish habitat.
- Scarp Toe Stabilization – vertical cedar pilings placed one foot on center along the toe of the actively eroding scarp and extending approximately 2 feet above the channel bed. Salvaged trees are installed longitudinally on the landward side of the cedar pilings. The combined structure would reduce further erosion of the scarp toe and provide a bench for scarp material to deposit, eventually reducing the slope of the scarp and allowing for the scarp revegetation.
- Scarp Stabilization – intended to be constructed in conjunction with Scarp Toe Stabilization, this technique involves grading of the scarp to a stable slope (3:1 or 2:1), installation of erosion control blanket, and establishment of erosion resistant vegetation.

Hard armoring methods are viewed as standard and time-tested and typically have a longer life span due to the permanence of the materials used. Hard armoring is usually effective in preventing erosion where it is installed; however, placement must consider downstream impacts, understanding that the armoring may push the erosive stresses downstream. Hard armoring typically requires little maintenance; however, if the armoring fails, maintenance or replacement can be expensive, particularly if the armoring materials need to be removed from the site.

Hard armoring techniques

- Riprap-lined channel—riprap throughout an entire channel cross section to control stream bed elevations and prevent erosion
- Stone toe protection— Stone toe protection employs stones to armor the toe of the bank. It is often used on sites that are too shaded to support good ground vegetation cover, and where vanes or root wads are not necessary. Stones are selected to be large enough so that they would not be moved by flood flows, but small enough to be consistent with the size of other stones found in and near the stream and thus appear natural.
- Riprap slope stabilization—riprap along a steep slope to protect against erosion and prevent undercutting and slumping

2.1.2.2 Vegetation Management

Vegetation management involves the selection of an optimal species mix to contribute to a healthy and stable stream. Typically an optimal species mix will provide good root structure to help stabilize streambanks and provide good habitat for riparian birds and animals. Obtaining this mix often requires planting new species, removing unwanted or exotic species, and/or thinning existing vegetation to provide enough sunlight to allow new ground vegetation to become established. Vegetation management should be considered for the entire Lower Valley, where mature trees block most of the sunlight from reaching the forest floor during the summer months. Invasive species of vegetation and less desirable tree species could be removed, leaving the more valuable trees and vegetation in place. Supplemental planting of ground vegetation is also desirable.

2.1.2.3 High Bank Stabilization Measures

High bank stabilization methods are employed on the taller eroded banks to prevent future slumping and bank failure. Bank stabilization will reduce sediment loading to the stream and will reduce the loss of adjacent property. Stabilizing the high, eroded banks require a combination of methods, depending on the specific site conditions. In particular, some of the erosion sites are exacerbated by groundwater seepage, which when combined with steep banks, sparse vegetation, and fluvial erosion leads to bank failure. Two basic methods of upper bank stabilization typically used are – bank grading and revegetation, and vegetated reinforced soil slope technique. With either method, stabilization of the lower bank is usually required and is a priority if resources are limited.

Grading and revegetation of the eroded bank is the most common method for stabilization. With this method, the upper bank is graded at a 2:1 (2 foot horizontal to 1 foot vertical) or flatter slope to allow for replanting. The slope is typically seeded with a cover crop and covered with erosion control fabric. Plant plugs and shrubs such as willows or dogwood can then be installed through the erosion control fabric. The stabilized slope and vegetation work together to prevent erosion from stream flows, wind, and raindrop impact.

Vegetated reinforced soil slope (VRSS) is another method for upper bank stabilization. It is typically used on steep slopes where grading the bank to a more stable slope is not an option due to site restrictions. VRSS typically involves protecting layers of soils with a blanket or geotextile material (e.g. erosion control blanket) and vegetating the slope by either planting selected species (often willow or dogwood species) between the soil layers or by seeding the soil with desired species before it is covered by the protective material. In either case, if given enough light and moisture, the vegetation grows quickly and provides significant root structure to strengthen the bank. This method tends to be labor intensive.

2.1.2.4 Stream Vortex Tubes

Some stream stabilization techniques are neither hard armoring nor bioengineering. Stream Vortex Tubes can be used in situations where excess sediment is the main cause of channel instability. The Stream Vortex Tube removes sediment from a stream channel and stores it in an off-channel basin. An open-top pipe is placed in the stream so that flow over the top of the opening is forced into a vortices thereby removing sediment from the water. This sediment is conveyed along the pipe into a pond. The sediment could be used as a commercial product for road base, surfacing, and material processing.

2.2 Lake Assessment Approach

The project approach utilized in this study includes four main steps. Step one involved the analysis of all available water quality data and past studies in the Purgatory Creek watershed with the focus on Secchi depth, chlorophyll-a, and TP. Step two of the analysis was the modeling of watershed TP loads reaching each lake and the development of an in-lake daily time step TP concentration model (step 3). With calibrated in-lake and watershed models, Best Management Practices (BMPs) were devised to reduce or protect water quality level in each of the eight lakes. Each devised BMP was modeled to determine TP load reductions. Finally costs were calculated for each BMP examined. These four steps are part of an adaptive management approach to providing provide water quality improvements to the lakes in Purgatory Creek. Figure 2.3 highlights the adaptive management approach to achieve this goal. This project is focused on the first four steps of that approach.

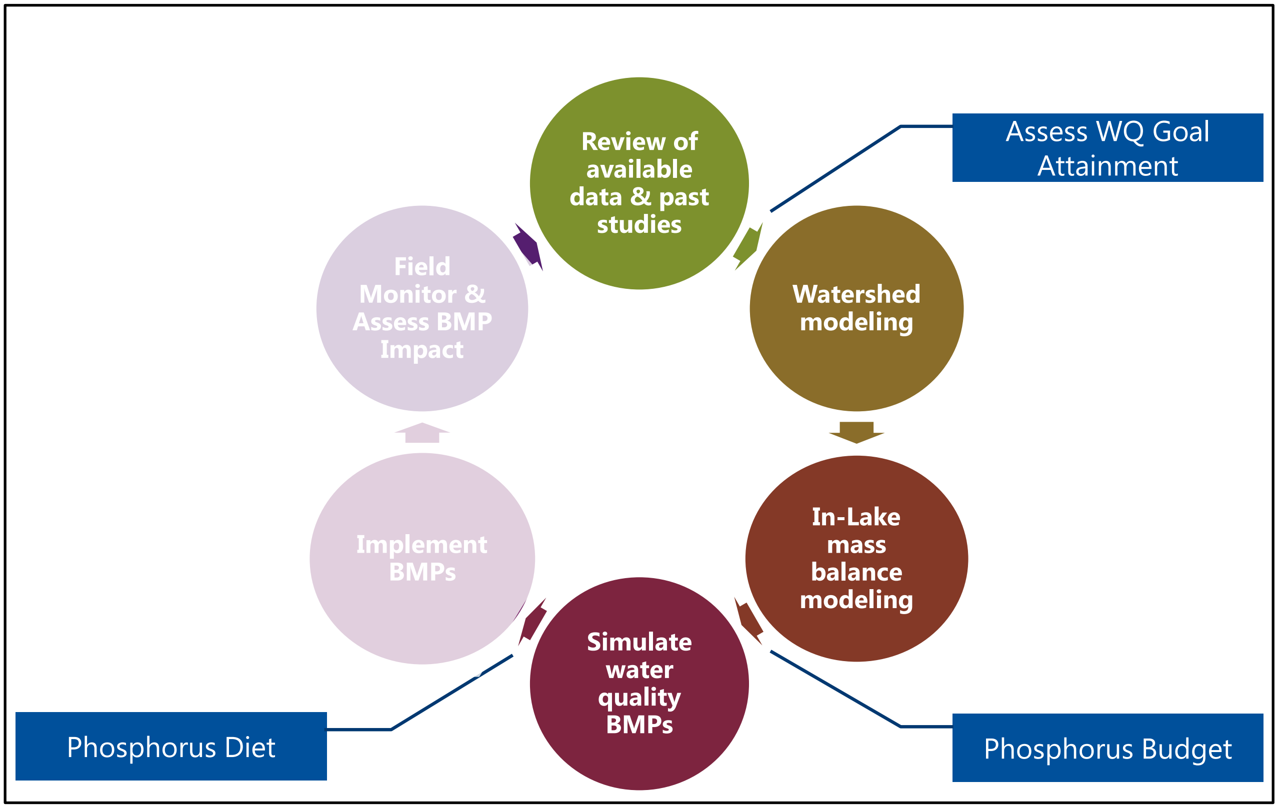


Figure 2.3 Project adaptive management approach

2.2.1 Water Quality Analysis

Water quality data was compiled for each of the waterbodies from various sources including the RPBCWD Environmental Quality Information System (EQuIS) database, the MPCA environmental data access web site, the Metropolitan Council environmental database, electronic data obtained from CH2MHill, electronic data obtained from city of Eden Prairie, and data that was not available electronically but highlighted in various water quality reports. A summary of available water quality data, categorized by water quality parameters and the year collected, for each lake and for Purgatory Creek are displayed in Appendix C. Appendix C shows all of the water quality parameters collected for each lake during a particular year including grab samples, profiles, plant surveys, macrophyte analysis, plankton surveys, sediment diatom analysis, sediment phosphorus fractionations, and other analyses conducted on the waterbody. Using the data from available sources, the water quality parameters were compiled for TP, chl-a, and Secchi depth and summarized based on the growing season (June-September) for all years with available data. A Thiel-Sen slope was calculated on the annual average growing season values and the significance of the trend was tested using the Mann-Kendall non parametric test. Trends and significance of the trends were calculated for the entire data record as well as for years 1999-2015. The 1999-2015 time period was chosen to determine whether lake water quality was improving or degrading over a more recent time frame. The 17-year window allows for a large enough period to determine trend significance in most of the data sets. The year 1999 also represents the year that detailed water quality analyses were conducted on a number of the lakes for the Use Attainability Analyses (UAAs), giving a good base point to start the trend analyses. A discussion of the trends by lake is given in Sections 4 through 11.

2.2.2 Lake and Watershed Water Quality Modeling

Watershed runoff modeling was conducted using the P8 Urban Catchment Model (Program for Predicting Polluting Particle Passage thru Pits, Puddles, and Ponds). P8 is a model used for predicting the generation and transport of stormwater runoff and pollutants in urban watersheds. The model tracks the movement of particulate matter (fine sand, dust, soil particles, etc.) as it is carried along by stormwater runoff traveling over land and pavement. Particle deposition in ponds/infiltration practices are tracked in order to estimate the amount of pollutants that eventually reach a waterbody.

P8 was used for this study as it can be run with updated climate data to develop phosphorus (total and dissolved) and total suspended solids (TSS) loadings to a receiving waterbody. P8 has already been used extensively in the RPBCWD as well as other urban TMDL studies throughout Minnesota and maintains widespread acceptance by all levels of government and practitioners. Existing BMPs were modeled and available water quality monitoring data was used to calibrate the watershed modeling where possible. The results of the watershed modeling were used as an input into the in-lake water quality modeling as well as to identify high priority areas for BMP implementation.

For the majority of Minnesota lakes, phosphorus is the limiting nutrient for algae, and an increase in total phosphorus (TP) results in an increase in chlorophyll *a* concentrations and a decrease in water clarity. Eutrophic lakes can be restored by reducing TP concentrations. An in-lake mass balance model for TP was developed for each lake in order to quantify TP source loads to the lake. To-date, much of the past receiving waterbody water quality modeling efforts in the Purgatory Creek watershed has been accomplished with BATHTUB or another simplified mass balance model using a spreadsheet. The empirical equations in BATHTUB and other spreadsheet models simplify the lake TP mass balance by assuming that the lake system is in a steady state over the averaging period that has been used (typically a year). For this study the in-lake modeling was accomplished through the development of a daily time step TP mass balance spreadsheet model. This differs from BATHTUB and other empirical spreadsheet equations in that it determines the water and TP mass balance calculations on a daily basis throughout the critical monitoring period for each lake. This enables the in-lake water quality modeling to be calibrated to the important watershed and internal load dynamics that vary in response to stormwater runoff and seasonal fluctuations. This approach for in-lake water quality modeling has been used in several other TMDL studies and has gained acceptance from MPCA and EPA. The calibrated watershed and in-lake water quality modeling was used in combination for each lake's critical condition to determine the relative level of importance that must be placed on reducing external and internal TP loadings to meet the state standards and District goals.

A detailed description of the watershed and in-lake TP modeling methodology used for all eight analyzed lakes is provided in Appendix D. Modeling results are presented for individual lake in the lake sections of the report (Sections 4.0-11.0).

2.2.3 BMP Selection / Typical Stormwater Management Strategies

The results of the watershed and in-lake modeling were used to determine and prioritize locations for implementation of additional best management practices (BMPs) and/or stormwater management strategies to improve lake and stream water quality. For the purposes of considering future BMP implementation, it was expected that each city has been maintaining, and will continue to maintain, existing BMPs consistent with the requirements of the MPCA Municipal Separate Storm Sewer Systems (MS4) Stormwater Permit. This section discusses improvement options and general BMPs to remove TP and/or reduce sediment and litter entering the receiving waters. Three types of BMPs were considered during the preparation of this report: structural, in-lake, and nonstructural.

1. Structural BMPs remove a fraction of the pollutants and sediment loads contained in stormwater runoff prior to discharge into receiving waters.

2. In-Lake BMPs reduce TP already present in a lake, and/or prevent the release of TP from anoxic lake sediments.

3. Nonstructural BMPs (source control) eliminate pollutants at the source and prevent pollutants from entering stormwater flows.

2.2.3.1 Structural Watershed Practices

Structural BMPs temporarily store and treat urban stormwater runoff to reduce flooding, remove pollutants, and provide other amenities (Schueler, 1987). Water quality BMPs are specifically designed for pollutant removal, and their typical effectiveness is summarized in Table 2.0.2. Structural BMPs control TSS and TP loadings by slowing stormwater and allowing particles to settle or be filtered in areas before reaching receiving waters. More recently, these structural BMPs have been modified and enhanced with materials such as iron filings or spent lime to improve removal of not only the pollutants associated with particulates but to also begin addressing the soluble fraction of pollutants such as phosphorus that cannot be filtered or settled out of the runoff.

Examples of structural BMPs installed to improve water quality include:

- Wet detention ponds
- Bioretention (rainwater gardens)
- Infiltration basins or trenches
- Sand filters
- Iron-enhanced sand filters
- Vegetative buffer strips
- Oil and grit separators
- Alum or ferric chloride treatment plants
- Spent lime treatment

The general effectiveness of each of the BMPs is summarized in Table 2.0.2. When choosing a structural BMP, the ultimate objective must be well understood. The BMP should accomplish the following (Schueler, 1987):

- Reproduce, as nearly as possible, the stream flow before development
- Remove at least a moderate amount of most urban pollutants
- Require reasonable maintenance
- Have a neutral impact on the natural and human environments
- Be reasonably cost effective compared with other BMPs

General description of several of the BMPs are provided below Appendix B.1.

Table 2.2 General Phosphorus Removal Effectiveness of Stormwater BMPs (source: adapted from the Minnesota Stormwater Manual, MPCA 2005)

BMP group	BMP design variation	Average TP removal rate (%)[b]	Maximum TP removal rate (%)[c]	Average soluble P removal rate (%)[d,f,g,i]
Bioretention[f]	Underdrain	50	65	0
	Infiltration	100	100	100
Filtration	Sand filter	50	55	0
	Dry swale	0	55	0
	Wet swale	65	75	70
Infiltration[f]	Infiltration trench	100	100	100
	Infiltration basin	100	100	100
Stormwater ponds	Wet pond	50	65	0
	Multiple pond	60	75	0
Stormwater wetlands	Shallow wetland	40	55	0
	Pond/wetland	55	75	0
Iron-Enhanced Sand Filtration[i]	Basin	N/A	N/A	40-90
Spent Lime Treatment[j]	Basin	N/A	N/A	80

[a] Removal rates show in table are a composite of five sources: 1) Caraco (Center for Watershed Protection, 2001), 2) Maryland Department of the Environment (2000), 3) Winer (Center for Watershed Protection, 2000), 4) P8 modeling (William Walker)

[b] Average removal (MDNR, 2011) efficiency expected under MPCA Sizing Rules 1 and 3

[c] Upper limit on phosphorus removal with increased sizing and design features, based on national review

[d] Average rate of soluble phosphorus removal in the literature

[e] See section on calculating credits for each BMP in this Manual.

[f] Note that the performance numbers apply only to that portion of total flow actually being treated; it does not include any runoff that bypasses the BMP

[g] Note that soluble P can transfer from surface water to groundwater, but this column refers only to surface water

[h] Note that 100% is assumed for all infiltration, but only for that portion of the flow fully treated in the infiltration facility; by-passed runoff or runoff diverted via underdrain does not receive this level of treatment.

[i] Range based on City of Bellvue, WA, 1999; Erickson et. al., 2006; Erickson et. al., 2009

[j] Based on 2012 monitoring data from experimental spent lime treatment system installed in Ramsey-Washington Metro Watershed District

2.2.3.2 In-Lake Management Activities

In-lake management activities are intended to target the "internal" sources of phosphorus in the lake, which can include the prevention of the release of phosphorus from the lake sediments. In-lake management practices intended to reduce phosphorus include:

- Removal of benthivorous (bottom-feeding) fish, including carp
- Application of alum (aluminum sulfate) or similar precipitant to reduce sediment phosphorus release

- Application of herbicides to control non-native macrophyte species such as curlyleaf pondweed
- Mechanical harvesting of lake macrophytes
- Hypolimnetic withdrawal
- Hypolimnetic aeration
- Iron salt applications

Several in-lake BMPs are discussed in Appendix B.2.

2.2.3.3 Non-Structural Practices

Nonstructural practices are generally thought of as "good housekeeping" activities or actions that are intended to reduce pollutants at the source. While RPBCWD, Cities and other governmental agencies routinely perform many of the non-structural BMPs, every resident and business can play a vital role in the restoration and protection of the water resources through self-implementation of small scale non-structural measures. This can include keeping leaves, grass clippings, and fertilizers off impervious surfaces; educating neighbors; cleaning catch basins; installing individual rainwater gardens; establishing riparian buffers; and reducing impervious cover on lots (i.e., promote infiltration). These non-structural measures are important even if the property is not immediately adjacent to a water resource because the runoff will ultimately reach a valued resource. Collectively, the individual actions of watershed residents and businesses can have a profound impact on reducing the potential adverse impacts of pollutants on downstream resources. Examples of non-structural BMPs include:

- Public education and outreach
- City ordinances
- Street sweeping
- Deterrence of waterfowl

A detailed description of various non-structural practices are described in Appendix B.3.

2.3 Cost Methodology

Planning-level costs were developed for each BMP that was identified for this study. For each BMP, the physical characteristics and the storm water routing were defined so that construction quantities could be estimated. Construction quantities included mobilization, erosion protection (construction entrance, silt fence, erosion control blanket, etc.), tree removal or clearing and grubbing, excavation and disposal, filtration material if necessary, lengths of pipe, inlets and outlets, site restoration, and others. Additionally, the planning-level cost estimates included engineering and design (15%), construction management (15%), legal (5%), and permitting (5%), as was assumed for the UAA for Rice Marsh Lake and Lake Riley (Barr Engineering, November, 2015). Industry resources for cost estimating provided guidance on cost uncertainty that ranged from -20%/40% for most BMPs, and was -50%/+100% for others (American Society for Testing and Materials, 2006) and (Association for the Advancement of Cost Estimating, 2005). The cost estimates do not include wetland mitigation or land acquisition (where applicable). The cost estimates for each BMP, including the quantities and unit costs, are included in Appendix E. These costs were combined with respective TP load reduction estimates to estimate the efficiency of each BMP in terms of dollars per pound of TP removed. It should be noted that each BMP option will require further feasibility analysis and consideration of land acquisition and water quality goal attainment prior to its inclusion in the RPBCWD Capital Improvements Plan.

2.4 Time for Lake to Respond to Reduced Nutrient Loading

Each lake is unique in its water quality respond to reduced nutrient loading. There are numerous factors that influence the time it takes for a lake to respond to reductions in nutrient loads. Some of these factors include hydrology, vegetation growth, transport rate and path, hydraulic residence time, nutrient sources, flow dynamics, ecosystem/biologic dynamics, nutrient cycling, and type of best management practice. Structural, non-structural and in-lake best management practices will each affect the lake response in different ways in that some BMPs represent a "quick-fix" (e.g., point source reduction and alum) while other are long-term management options (e.g., P-fertilizer elimination and watershed BMPs).

Jeppesen et al. (2005) indicates that it will take a minimum of three residence times for the benefits of watershed loading reduction to be realized by the receiving waterbody. Jeppesen et al. (2005) examined 35 long-term lake improvement case studies covering shallow and deep lakes, most of which were northern temperate lakes. Their review noted a "delay in the reduction of in-lake total phosphorus (TP) concentrations because at least three retention times are needed to wash out 95% of the excess P pool in the water column of fully mixed lakes, unless P is permanently lost to the sediment, (Sas, 1989), and because internal loading continuously replenishes the P pool in the water column (Søndergaard, Jensen & Jeppesen, 2003; Nurnberg & LaZerte, 2004)." They concluded reduced external phosphorus loading leads to lower in-lake TP concentration, lower chlorophyll a (chl a) concentration and improved water clarity. The study also found that most lakes, shallow and deep, reached a new equilibrium phosphorus level after 10–15 years, which was only slightly influenced by the hydraulic retention time, and internal loading delayed the improvement response to external load reductions (Jeppesen et al. 2005). This suggests that to be effective at restoring and protecting the waterbodies both short-term and long-term management strategies should be considered and results of management efforts will take time to materialize. Long-term management techniques to control sediments and nutrients can occur simultaneously with the appropriate in-lake restoration techniques. To successfully protect and restore the health of a lake the program will likely need to manage both external and internal nutrient sources (Department of ecology, State of Washington, http://www.ecy.wa.gov/programs/wq/plants/algae/lakes/LakeRestoration.html).

Figure 2.4 shows two potential approaches to addressing phosphorus loading to a lake.

1. Continue to address/reduce external sources of phosphorus with the expectation that internal sources of phosphorus will slowly be flushed out of the system and water quality will come to a new equilibrium with lower phosphorus. As discussed above, this method may take many decades and is less likely to result in long-term success for lakes with low flushing rates.
2. Because internal loading has the potential to continually replenish the phosphorus in the water column the benefits of external load reduction will take time to materialize. In addition, as the

phosphorus concentration in the lakes water decrease a larger concentration gradient has the potential to exacerbate the release of phosphorus from lake sediment. Conducting an in-lake alum treatment to greatly reduce sediment phosphorus release and recycling while continuing to address external sources of phosphorus load improves the potential to achieve the water quality goals and standards over both the short-term and long-term. It also has the potential to be more cost-effective than only implementing watershed BMPs. Caution should be used if internal load control measures are pursued too soon in the management plan, or without addressing the impacts of carp in shallow lakes, because uncontrolled or unmitigated external sources could overwhelm the internal measure and reduce the effective live of the treatment, such as was experienced on Lake Susan in the lake 1990's. In general, it is recommended that external phosphorus load reductions of 30 to 50 percent (from untreated levels) should be attained before considering internal load controls.

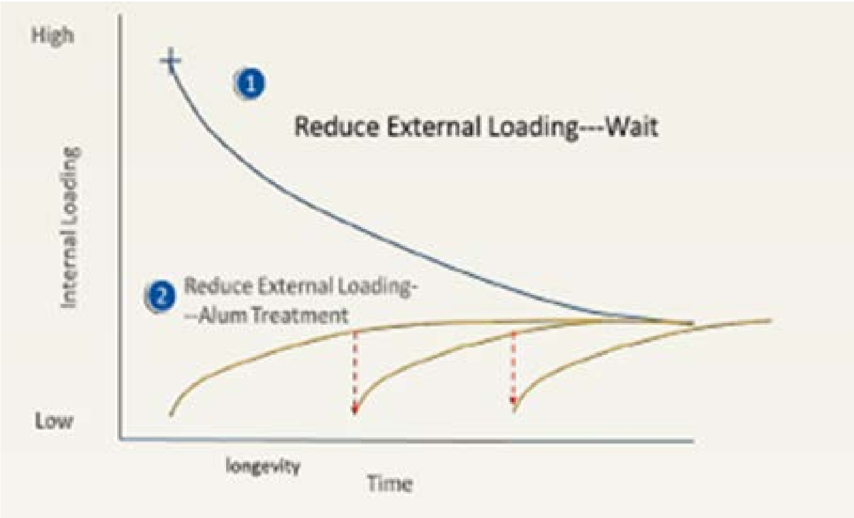


Figure 2.4 **Potential approaches for addressing lake phosphorus loadings**

3.0 Purgatory Creek

The Purgatory Creek watershed mostly lies within the cities of Eden Prairie and Minnetonka. Other smaller portions of the watershed lie within the cities of Deephaven, Shorewood, and Chanhassen. The headwaters of Purgatory Creek originate in Lotus and Silver Lakes as well as the northern branch of Purgatory Creek in the city of Minnetonka. Purgatory Creek then flows through a series of wetlands complexes before entering Staring Lake. The creek then flows through the bluffs of the Minnesota River Valley on its way to its confluence with the Minnesota River. From Silver Lake through Staring Lake to the confluence with the Minnesota River the total length of Purgatory Creek is 12 miles with a total watershed area of 19,400 acres (30 square miles).

This study focused the assessment on the Lower Valley of Purgatory Creek (Lower Valley) to assess the health of the Lower Valley relative to the District's and MPCA water quality goals and identify potential remedial measure to protect and restore the resource. The discussion in the following sections focus on the Lower Valley.

3.1 Watershed Characteristics

The Lower Valley watershed includes the reach between the outlet of Staring Lake and the culvert crossing of Riverview Road. The drainage area of the Lower Valley is 4,620 acres. While the dominate land use in the Lower Valley is single family residential a significant impervious area in the watershed is Eden Prairie Center. As flows leave Staring Lake the creek meanders through relatively steep, glacial outwash deposits of sand and gravel in its course to the Minnesota River floodplain.

3.1.1 Watershed Slopes

The District's hydrologic and hydraulic model of the Lower Valley indicates that the overall slope of the study watershed is relatively steep, with more than 30 percent of the catchment area having a slope of more than 10 percent and an average slope over the entire Lower Valley watershed of 9.4 percent. This is an indication that, independent of other factors (such as runoff intensity, soil erodibility, land use, etc.), the potential for soil erosion in the watershed uplands is relatively high. The slope of the watershed uplands increases from the watershed divide to the stream channel, which implies that in addition to the relatively high potential for soil erosion, the conditions are favorable for most of this sediment from areas near the creek will likely reach the main channel rather than depositing before reaching the stream.

3.2 Channel Geometry

The channel geometry of most streams is influenced by several factors. Channel slope, streambed material, stream bank material, and riparian vegetation are factors that are directly connected to the stream and have significant influence over channel geometry. Similarly, several hydrologic factors have significant influence as well since they will control how much water enters the stream. These factors include the amount of rainfall, the intensity of rainfall, watershed slopes, storage within the watershed, infiltration capacity within the watershed, impervious area, and land use. All of these factors can change over time or change along the length of the stream, so the stream is constantly trying to achieve equilibrium with these changing influences.

Natural processes of change, such as changing weather patterns or changing vegetation communities, typically happen at a gradual rate, so the stream and the channel geometry has ample time to slowly adjust to these influential factors. Even with these slow processes, it is possible for a stream to undergo significant changes and have large erosion problems. This can be caused either by large catastrophic events or by the stream channel and/or valley reaching a point where a major adjustment is necessary.

Man-made processes of change, such as increased development, altering of storage areas, and altering drainage patterns, tend to happen too quickly for the stream to gradually adjust. Even though greater measures are being taken to protect streams through the use of detention ponds and other best management practices within the watershed, the streams still require a certain amount of adjustment to once again achieve equilibrium with their watersheds.

Purgatory Creek, as it flows through the Lower Valley, has varying channel geometries that reflect the influence of some of the factors listed above. Between Staring Lake and Homeward Hills Road, the channel meanders through several wetland complexes. The basic channel geometry changes in typical ways as the stream moves between the wetland complex and a riffle and pools system. Downstream of Pioneer Trail, the channel geometry changes dramatically as the stream enters a reach that is experiencing some severe erosion problems as the creek makes it way to the Minnesota River.

3.2.1 Lower Valley Rosgen Indicators

Several cross sections in the Lower Valley were surveyed in 1995 and again in 2003. Table 3.01 shows the range of key components of the Rosgen classification system estimated from past field surveys. Based on the data in Table 3.01, the creek reach downstream of Pioneer Trail would be considered a Rosgen class C-5 stream while upstream of Homeward Hills Road the creek is considered a Rosgen class E-5. Combining these classification with Rosgen's sensitivity of streams information summarized in Table 3.2 suggests that both reaches are highly sensitive to disturbance and vulnerable to streambank erosion.

Table 3.1 Summary of Rosgen classification values for Lower Valley (CH2M HILL, 2011)

Rosgen Variable	Between Homeward Hills Road and Riverview Road		Between Staring Lake and Homeward Hills Road	
	1996	2003	1996	2003
Entrenchment Ratio[1]	4	3	16	17
	Slight	Slight	Slight	Slight
Width/Depth[2]	11	14	8	9
	Low	Moderate	Low	Low
Sinuosity[3]	2.7	1.7	2.5	3.1
	Very high	High	Very high	Very High
Slope[4]	0.003	0.003	0.0005	0.0009
	Low	Low	Low	Low
Bed Material	Sand	Sand	Sand	Sand
Rosgen Classification	C-5	C-5	E-5	E-5

[1] Entrenchment Ratio = Floodprone Width/Bankfull Channel Width
[2] Width/Depth = Bankfull Channel Width/Average Bankfull Channel Depth
[3] Sinuosity = Channel Length/Valley Length
[4] Slope = Change in Water Surface Elevation/Channel Length

Table 3.2 Sensitivity of Stream Types (Rosgen, 1996)

Stream Type[1]	Sensitivity to Disturbance[2]	Recovery Potential[3]	Sediment Supply[4]	Streambank Erosion Potential	Vegetation Controlling Influence[5]
C-5 (sand)	very high	fair	very high	very high	very high
E-5 (sand)	very high	good	moderate	high	very high

[1] Stream types condensed to those evident along the Purgatory Creek Lower Valley.
[2] Includes increases in streamflow magnitude and timing and/or sediment increases.
[3] Assumes natural recovery once cause of instability is corrected.
[4] Includes suspended and bedload sediment from channel sources and from adjacent to stream.
[5] Vegetation that influences width/depth ratio stability.

3.3 Stream Profile

As with any stream, the slope of Purgatory Creek varies along its length. Analyzing the changes in channel slope can help identify either current or potential problem areas. The greater the channel slope is, the greater potential there is for erosion because the slope plays a critical role in the flow velocities and the stresses imposed on the stream bed. Given that the streambed in Purgatory Creek ranges from cohesive clay to gravel and some cobble, a slope less than or equal to 0.5 percent would likely result in a stable creek system. For slopes greater than approximately 0.5 percent, the stream would need larger bed material in order to remain stable for the long term. These reaches, with slopes between approximately 0.5 and 0.75 percent, can be stable and many of them on Purgatory Creek are stable. However, periodic monitoring of these reaches is recommended to detect early signs of erosion problems. Slopes between 0.75 percent and 1 percent are an additional indicator of potential erosion. If erosion is not already present along these reaches, they should be monitored on an annual basis. Slopes greater than approximately 1 percent are a strong indicator of potential erosion problems. These slopes can generate stream velocities that easily erode streambed or streambank materials. The profile of Purgatory Creek transitions from a gentle 0.1 percent just downstream of Staring Lake to slopes approaching 0.6 percent at some locations downstream of Pioneer trail.

3.4 Erosion Types

There are four main types of erosion along Purgatory Creek. They can be categorized as Groundwater Erosion, Stream Bank Erosion, Incision, and Bluff Erosion. These are described in more detail in the following discussion.

3.4.1 Groundwater Induced Erosion

Groundwater erosion is caused by springs and groundwater seepage. Along Purgatory Creek, this type of erosion occurs most commonly where a bluff meets the floodplain (usually at the toe of the bluff slope). It is characterized by very moist soils or visible springs at the toe of the bluff and results in two subcategories of erosion. The first and most common type of erosion attributed to groundwater flow is a result of the groundwater seepage being a catalyst for additional erosion. The high moisture content in the toe of the bluff significantly reduces cohesion between the soil particles and makes the toe of the bluff highly susceptible to erosion by the creek. During high flows, creek flow easily erodes the soils at the toe of the bluff that are already saturated from the groundwater flow. As the toe of the bluff erodes, the bluff above the toe also recedes. This process also happens in bluffs that do not have groundwater seepage along the toe, but the rate of erosion is often greatly increased by the presence of seepage.

The second form of erosion attributed to groundwater flow results from the groundwater flow itself. The saturated soil has a positive pore water pressure that can cause soil in the area of the spring to be displaced. This causes a slow failure of the bank as small quantities of soil are carried away by the seeping groundwater. This type of erosion generally occurs slowly, but can occur more quickly if groundwater flows are high and soil cohesion is low.

3.4.2 Stream Bank Erosion

Stream bank erosion is caused by water flowing in the stream channel. The shear stress caused by the flow entrains soil particles into the flow, causing the stream bank to erode away. This is, by far, the most common type of erosion that occurs in streams. Virtually all streams have some amount of this type of erosion occurring as streams naturally change their flow path over time. However, the rate of stream bank erosion can increase when the stream is out of equilibrium with its watershed. Increased flow from a watershed will increase the rate of erosion.

A severe bank erosion site in the Lower Valley as observed in 2014.

Stream bank erosion is occurring along all reaches on Lower Purgatory Creek. In most cases, it appears to be a part of the natural process of stream evolution as the creek adapts to urbanization. However, it can lead to high-bank failure where the stream abuts the steep valley walls, and it can exacerbate other forms of erosion.

3.4.3 Channel Incision

Channel incision, or down-cutting, occurs when there is an imbalance between the sediment supply and the sediment carrying capacity of the stream. Erosion occurs when the sediment carrying capacity of a stream exceeds the sediment supply. In streams with cohesive banks, such as Purgatory Creek, the erosion will occur primarily as streambed incision because that is where the erosive forces are the strongest. While sediment that is eroded from bank erosion often redeposits locally (such as on the opposite bank), sediment is often transported a large distance in an incised system. This indicates that the stream is out of balance with the watershed hydrology. As the channel deepens, the banks gradually fail and stream becomes wider. Although the stream will eventually return to equilibrium, the process can take many years and significant amounts of erosion can occur during the process.

While there is no significant evidence that channel incision is occurring along the Lower Valley based on the information provided by the city of Eden Prairie (Wenck 2014), monitoring should continue to identify if erosions areas or downcutting form which can lead to significant channel incision.

3.4.4 Bluff Erosion

Bluff erosion occurs on the valley walls of the stream corridor. For the purposes of this analysis, bluff erosion is distinguished as erosion that is above the creek itself and is, therefore, not entirely due to the flow in the creek. It is a naturally occurring phenomenon that can have several different causes, including groundwater seepage, concentrated runoff on the bluff, effects from falling trees, or massive slope failure due to an imbalance of geotechnical forces.

There are some areas of isolated bluff erosion within the Lower Valley, the most notably occurrence was in 2014 at Burr Ridge. Other areas of bluff erosion within the Lower Valley are more typically a side effect of either groundwater or fluvial bank erosion.

3.5 Current Water Quality Conditions

According to the total suspended solids (TSS) standard for Class 2B waters, a stream reach is considered impaired if more than 10% of TSS samples collected April through September exceed 65 mg/L, based on the last ten years of monitoring data. Figure 3.1 shows the magnitude and frequency with which the TSS sample results have exceeded 65 mg/L for the Purgatory Creek sampling stations, downstream of Staring Lake.

Figure 3.1 shows that the Purgatory Creek TSS sample results only exceeded a concentration of 51 mg/L ten percent of the time. Since just 4% of the Purgatory Creek TSS samples exceeded the 65 mg/L, the standard is being achieved and Purgatory Creek will be considered for water quality protection in this study and will not be subject to TMDL development by the MPCA. While the available TSS data for Purgatory Creek meets the standard, the results are limited in that most of the historic sampling has occurred upstream of significant near-channel sources of erosion and mass wasting, including landslides.

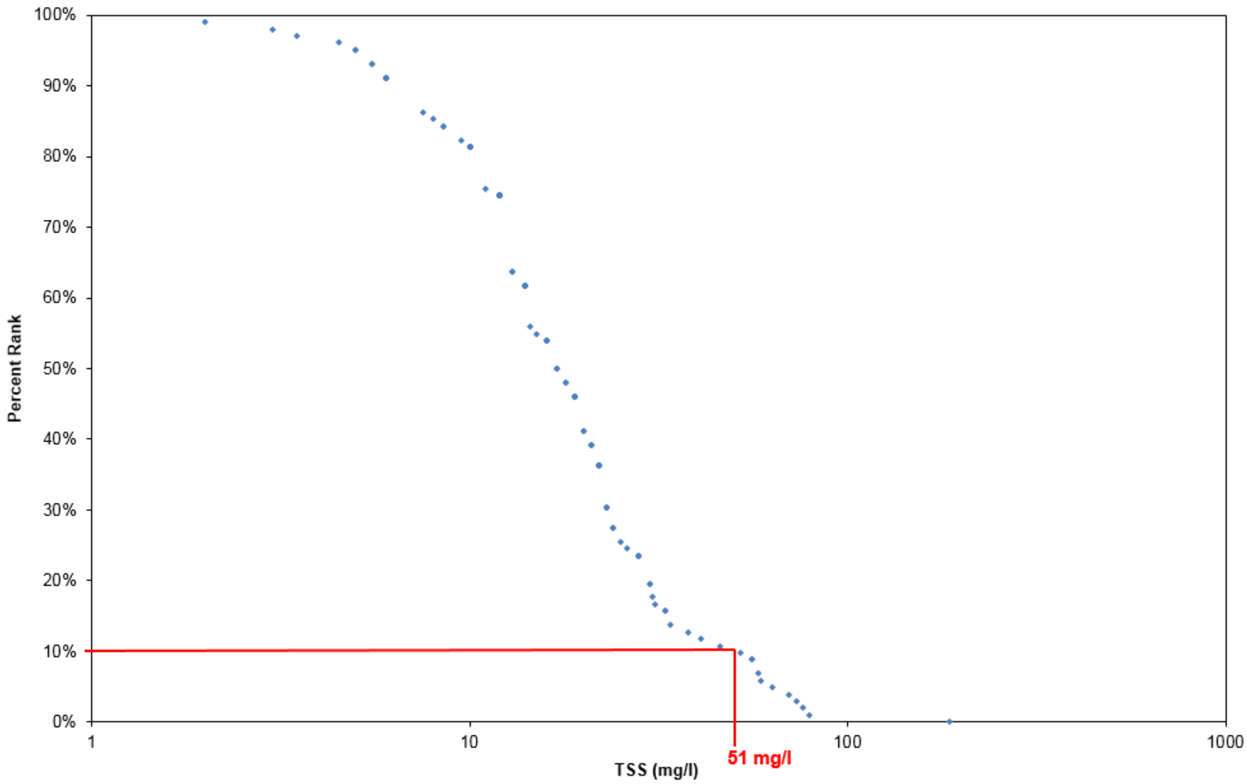


Figure 3.1 Purgatory Creek TSS concentration cumulative frequency curve, 2006-2015

In addition to TSS, RPBCWD (2015) has sampled eight sites along Purgatory Creek for other water quality constituents. The 2015 monitoring showed that some of the sample results for TP and chl-a did not meet

MPCA's standards for river eutrophication (as approved in 2014), although MPCA had not applied these standards to Purgatory Creek as of the 2016 impaired waters listing cycle.

3.6 Summary of Stream Ecosystem Data

MPCA will adding the segment of Purgatory Creek between Staring Lake and the Minnesota River to its draft impaired waters listings in 2018 for a low Index of Biological Integrity (IBI) score for macro-invertebrates, which is a measure of the biological health of the system, as well as an E. coli impairment.

3.7 Current and Past Management Actions

RPBCWD (2014) detailed a site assessment of the overall impact of an erosion/landslide event that occurred on May 11, 2014 at Burr Ridge Road in Eden Prairie. The bluff failure was caused by a rain event that overwhelmed a broken storm sewer and a house ultimately had to be removed. Significant sediment deposition occurred at the erosion site and along the Purgatory Creek bank downstream and immediately upstream from the site. Jennings et al. (2016) also documented the same landslide event in a historical inventory for the Twin City Metropolitan Area. The material exposed is primarily dry sand and gravel, which lack cohesion and typically seek an angle of repose of approximately 30 to 45 degrees depending on the average grain size and mixture. If stormwater is focused and creates a ravine in dry sediment, newly formed steep slopes quickly fail to the angle of repose. Similar failures, along the high terraces of the Minnesota River in Eden Prairie, have occurred both recently and historically (Jennings et al., 2016). A conservative approach may be to include slopes of approximately 20% or greater in a general susceptibility map. For site-specific rules, slopes associated with particular geologic units should be reviewed. The Lower Minnesota River Watershed District encourages additional setbacks of 30' from the tops of slopes (Jennings et al., 2016).

3.8 Sediment Source Assessment

The CRAS report (Barr and RPBCWD, 2015) identified relative sources of erosion and prioritized areas for improvements along Purgatory Creek. The erosion and channel stability results of the CRAS assessments were combined with previous efforts to quantify steep slopes (greater than 18%) and concentrated flow conveyances within high risk erosion areas in the lower valley portion of Purgatory Creek (shown in Figures 3.2 through 3.5). Each reach of the lower valley of Purgatory Creek is classified based on the erosion and channel stability scoring criteria (1=very stable, 3=moderately stable, 5=moderately unstable, and 7=unstable). It was estimated that incremental changes between each erosion category translates to increases in erosion rates that are two- to five- times higher.

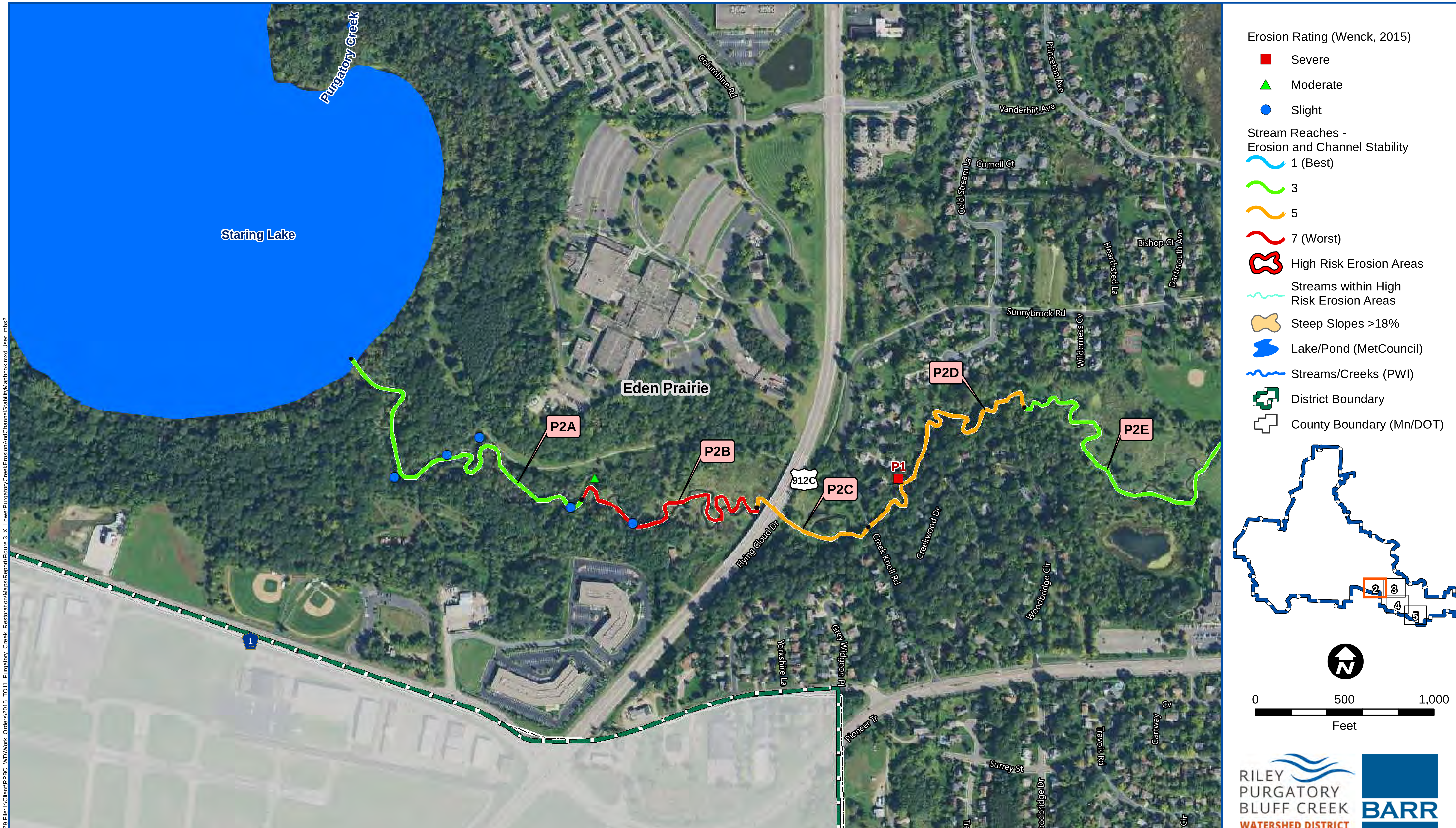
Figures 3.2 through 3.5 show that there are five individual reaches that were assessed as being unstable with severe erosion, meaning they possess bare banks with gullies and severe vegetative overhang and/or fallen trees. All but one of these reaches is located within the high risk erosion areas where elevated levels of overland flow and/or concentrated stormwater discharge would also be expected to contribute to ravine and gully erosion.

The District's hydrologic and hydraulic model for this reach helped inform the understanding of velocities and shear stresses that can be expected to be present in this reach during extreme events. Table 3.3 summarizes the modeled flow rate, velocities, and shear stress values in the Lower Valley. The simulated velocities in this reach range between less than one foot per second (fps) to almost 3.8 fps for the 2-year return period flow while the shear stress for the same event ranges between 0.2 to 2.8 pounds per square foot. As one would expect the velocities and the modeled shear stress both increase during larger storm event. Based on the modeling results it appears that about 60 percent of reach downstream of Staring Lake will experience velocities that are greater than the recommended velocity threshold for the native materials present in the bed and bank of the creek. In addition, greater than 95 percent of the reach will experience shear stress levels greater than the native soils can withstand during the 2 year event. Therefore, substantial erosion over time could be expected. It should be noted that these values represent the average values for the channel. Peak values in the middle of the channel and on bend in the creek are typically greater and values at the edge of the channel are typically smaller. Also, site specific assessment are needed to better define soil types, cross sections and other factors which influence erosion, such as groundwater seepage.

Table 3.3 Range of Modeled Velocities and Shear Stresses along the Lower Valley

Event	Flowrate (cfs)	Velocity (fps)	Shear Stress (lbs/ft^2)
2-year	83-296	0.8-3.8	0.2-2.8
100-year	258-782	1.3-4.9	0.3-4.4

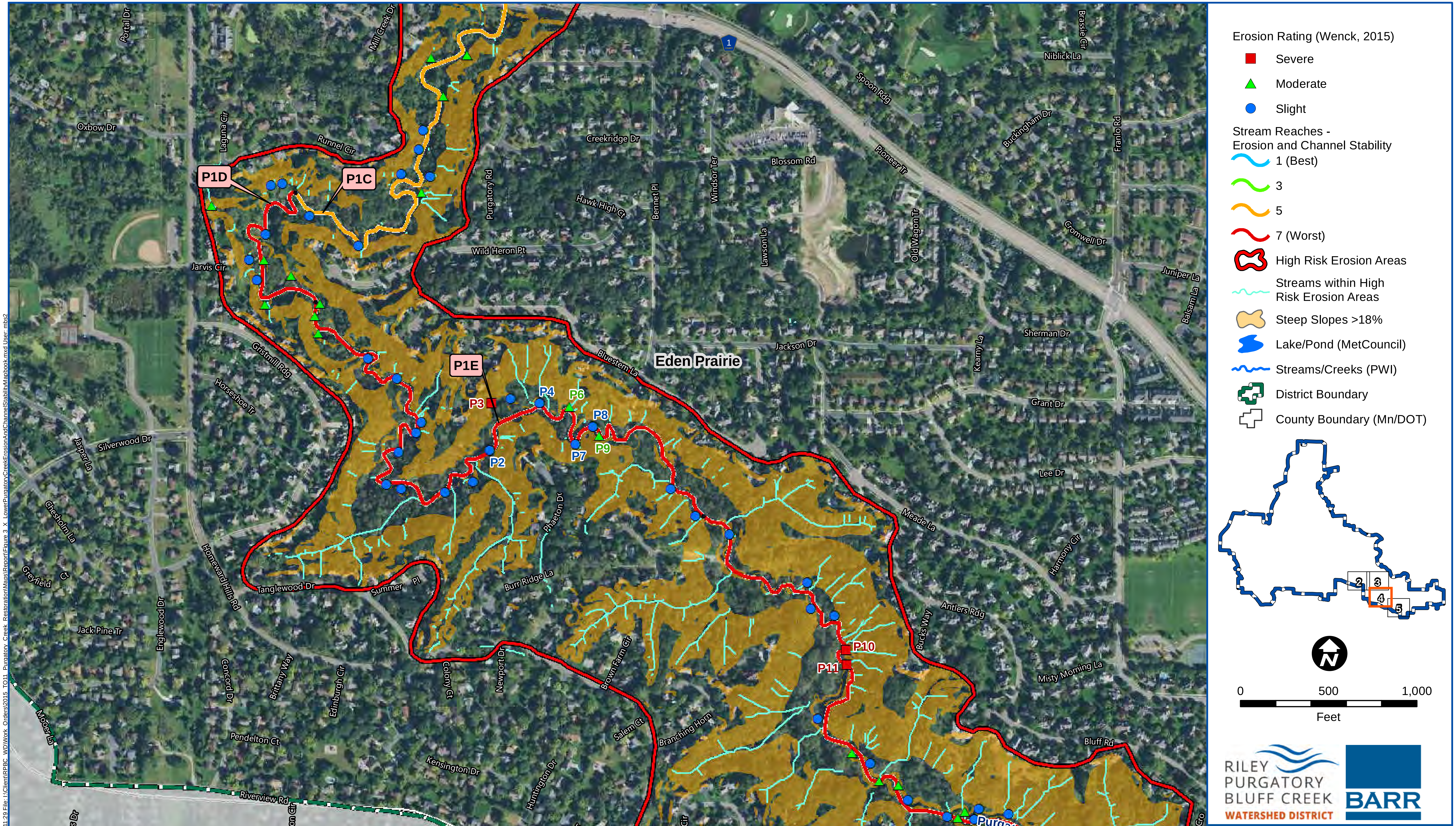
The city of Eden Prairie has also assessed the Lower Valley in 2006 and again in 2013. Eden Prairie's Local Surface Water Management Plan (Wenck 2016) provides information identifying over 80 moderately unstable to unstable erosion sites along the Lower Valley in 2006. In 2013, the most severe areas visited to assess any change in conditions. The City's 2013 erosion assessment suggests there are 17 distinct locations where erosion was exacerbated between 2006 and 2013. The information also suggests that many of the other locations had minimal change from the 2006 investigations and some had started to revegetate. The 17 sites that experienced continued erosion were estimated to have lateral bank loss rates of between 0.01 and 0.5 feet per year leading to about 56 tons of sediment annually. Eden Prairie also provided information for the reach downstream of Riverview Road which suggests the area had annual lateral bank loss rates of 0.3 to 5 feet per year between 2011 and 2013 based on bank pin measurements. This results in an estimates sediment load over the same time period of 1.8 to 51 tons per year (Wenck, 2014). It should be noted that since the last survey occurred in 2013, it is expected that the creek and amounts of erosion were significantly altered following high flow and mass erosion events that occurred in 2014. In addition, while the proposed measures address stabilization of the creek, they do not include stormwater treatment options to better control the high flow rates and discharge velocities that occur in the main channel and side channels of the lower valley.



LOWER PURGATORY CREEK EROSION AND CHANNEL STABILITY

FIGURE 3.2


Erosion Rating (Wenck, 2015)
Severe
Moderate
Slight
Stream Reaches - Erosion and Channel Stability
1 (Best)
3
5
7 (Worst)
High Risk Erosion Areas
Streams within High Risk Erosion Areas
Steep Slopes >18%
Lake/Pond (MetCouncil)
Streams/Creeks (PWI)
District Boundary
County Boundary (Mn/DOT)
0
500
1,000
Feet
P1A
P1B
P2E
Eden Prairie
Lake Neil
Purgatory Creek
Imagery Source: USDA NAIP, 2015
RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT
BARR
LOWER PURGATORY CREEK EROSION AND CHANNEL STABILITY
FIGURE 3.3



LOWER PURGATORY CREEK EROSION AND CHANNEL STABILITY

FIGURE 3.4

Erosion Rating (Wenck, 2015)

- Severe
- Moderate
- Slight

Stream Reaches - Erosion and Channel Stability

- 1 (Best)
- 3
- 5
- 7 (Worst)
- High Risk Erosion Areas
- Streams within High Risk Erosion Areas
- Steep Slopes >18%
- Lake/Pond (MetCouncil)
- Streams/Creeks (PWI)
- District Boundary
- County Boundary (Mn/DOT)

2 3 4 5

0 500 1,000
Feet

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

BARR

LOWER PURGATORY CREEK EROSION AND CHANNEL STABILITY

FIGURE 3.5

3.9 Recommendations for Water Quality Improvement Options

To improve the overall quality of Purgatory Creek, improvements should be implemented on a watershed basis to reduce the frequency, rate, and volume of runoff to Purgatory Creek, and on a localized basis to restore the physical stability of the stream channel.

Activities associated with reducing the frequency, rate and volume of runoff generally include storm water detention ponds or basins to reduce discharge rates and volumes from the urbanized area. Introduction of rainwater gardens can be used to infiltrate runoff, thereby reducing the volume and rate of runoff to the creek. Implementing these activities can reduce the frequency of bankfull flooding, and help maintain the stability of the stream. The District should continue to promote the cost share program and coordination with stakeholder to implement a watershed-wide volume reduction strategy which will reduce the pollutants to Purgatory Creek and the lakes in the watershed, reduce erosion in streams related to high stream flows and velocities, and help Cities meet MPCA NPDES nondegradation requirements.

Activities associated with improving the channel stability include channel and floodplain restoration techniques, such as improving stream bank protection, management of riparian vegetation, and restoring a stable channel shape, slope, and sinuosity. Vegetation can also be reestablished at areas that lack sufficient vegetation to prevent erosion. Selective tree removal may be necessary in order to provide more sunlight to areas that have a lack of ground vegetation. When removing invasive plants and reintroducing native species, a number of related and follow-up measures must be addressed, either by the District or in collaboration with municipalities and other agencies. These include

- Ongoing maintenance of restored areas (even after invasive species have been eradicated, the threat for new infestations remains)
- Controlling deer, which can decimate a newly planted area and degrade existing diverse areas
- Controlling erosion, which is often related to unmanaged foot paths on steep slopes. Establishing properly sloped, sustainable trails and cutting off certain routes may be necessary.

Improving the physical characteristics of Purgatory Creek will improve: (1) the ability of the stream to continue to naturally meander without excessive bank erosion, (2) the ecological characteristics and aesthetics of the stream, and (3) the ability of the stream to convey flood flows efficiently without degradation. Improving streambank and riparian vegetation throughout the stream system will improve the resistance of the stream to erosion.

Water quality improvement options for Purgatory Creek will need to prioritize and complete stormwater control and streambank stabilization projects at sites that are contributing inordinate sediment loads to the study lakes and stream reaches, including subreaches that are at high-risk of bank instability and excessive bedload. Depending on the ephemeral or perennial flow conditions, sources of erosion are highly variable and it is difficult to quantify the water quality benefits that can result from stabilization projects. Figures 3.2 through 3.5 combine the necessary information to identify and prioritize likely sources of near-channel erosion as well as side-catchment areas that may also represent significant sources of ravine and gully erosion, depending on the extent of disturbance or existing vegetation that can mitigate changes to stormwater discharge.

Implementation of the recommended BMPs through an adaptive management approach would significantly reduce the TP and sediment loads to the receiving waters and allow time to evaluate the effectiveness of the measures implemented to ensure cost-effective use of resources while striving to improve the overall water quality. The CRAS report (Barr and RPBCWD, 2015) identified relative sources of erosion and prioritized areas for improvements along the Lower Valley. While over 80 moderately unstable to unstable erosion site were identified in Eden Prairie's Local Water Management Plan (Wenck Associates, 2016), 17 sites were considered for stabilization by the City and were grouped into two groups. Based on the severity of erosion at these 17 site and the proposed stabilization measures in the City's Local Surface Water Management Plan, the budgetary opinion of probable cost to stabilize the streambanks at these locations along the Lower Valley is estimated to be $450,000 with a range of $225,000 to $900,000. Prior to implementation of streambank stabilization measures along the reach, more detailed study should be completed to verify and/or develop specific BMPs for implementation. The study should also assess the potential benefits of implementing additional watershed detention and volume reduction efforts to help mitigate the impacts of urbanization on the creek.

Table 3.4 - Summary of the Lower Valley BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - Sediment Load Reduction at BMP (tons/yr)[2]	Planning Level Cost Estimate & Range[3]	Estimated Annual O&M Cost ($/yr)[4]	Cost per Pound P Removed at BMP ($/lb)[5]	Cost per Ton Sediment Removed at BMP ($/ton)[6]
PC_1	Creek Restoration and Stabilization *- Restoration and stabilization of 10 locations (725 feet) downstream of Pioneer Trail (Group 1)*	3.8	19.6	$265,000 ($133,000 - $531,000)	$5,300 ($2,700 - $10,600)	$3,720 ($1,860 - $7,440)	$720 ($360 - $1,440)
PC_2	Creek Restoration and Stabilization *- Restoration and stabilization of 6 locations (380 feet) downstream of Pioneer Trail (Group 2)*	7.2	36.6	$185,000 ($93,000 - $370,000)	$3,700 ($1,900 - $7,400)	$1,370 ($690 - $2,740)	$270 ($130 - $540)

Notes:

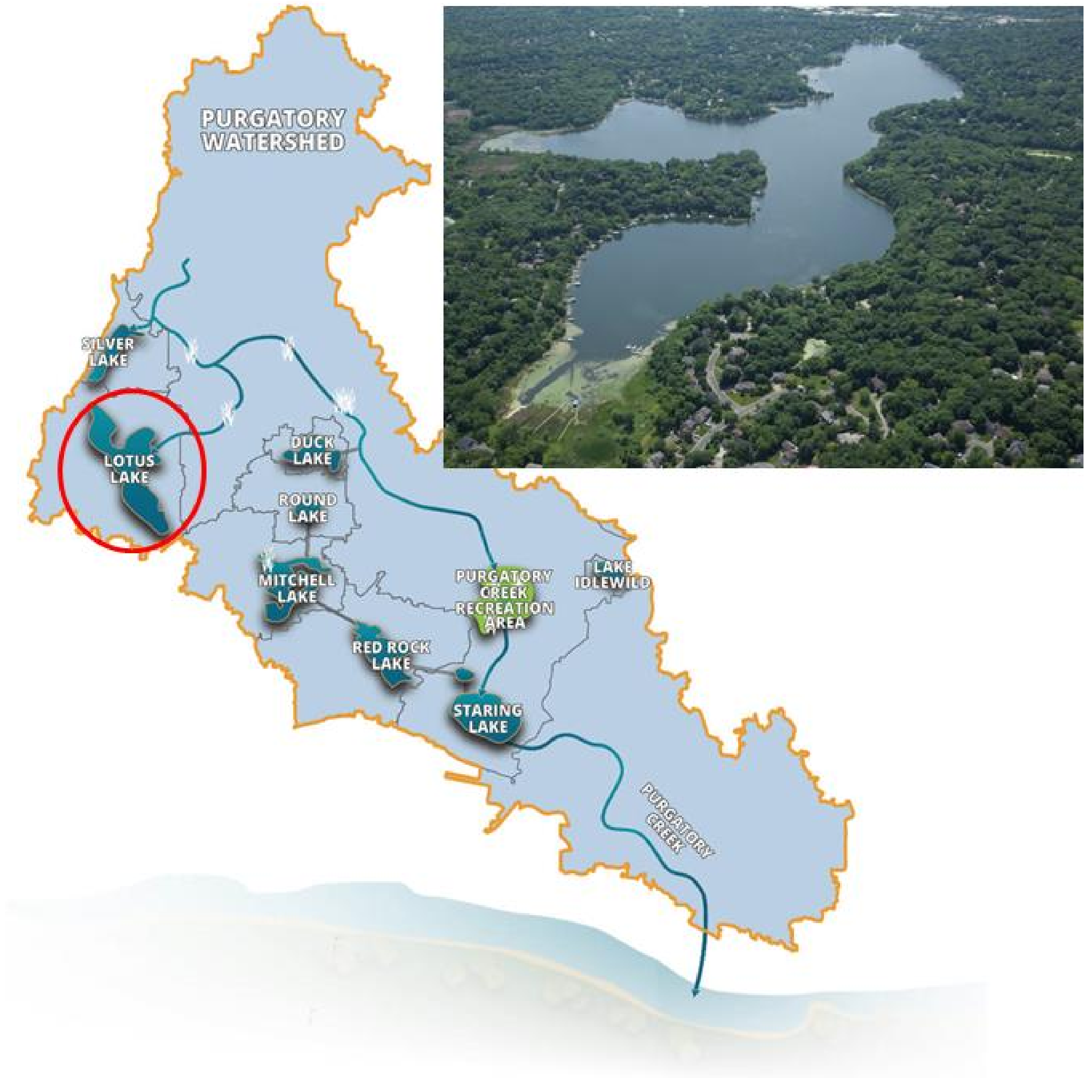
1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average sediment load reduction at the outlet of the BMP or downstream end of the creek reach
3. Planning level probable cost detailed in Appendix E; range is generally +100%/-50% for creek restoration and stabilization
4. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
5. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
6. Cost per ton of sediment removed per year of operation at the outlet of the BMP, including both construction and O&M.

3.10 Recommendations for Future Monitoring and Study

Follow-up monitoring should also be completed to both evaluate progress toward the water quality targets provided in the TMDL Report and to inform and guide implementation activities. The aquatic life impairment will remain listed until water quality standards and the macro-invertebrate IBI threshold score are met. Stream monitoring for turbidity and flow is expected to continue at the Purgatory Creek WOMP site. This monitoring will occur during open water season and at a set frequency and timing (15 minutes). In addition to turbidity and flow, samples measuring TSS, total suspended volatile solids and Chl-a will continue to be analyzed at the monitoring stations to better target implementation efforts and conduct on-going assessment. As previously discussed, the monitoring results from the Purgatory Creek segment between Staring Lake and the Minnesota River are somewhat limited by the fact that most of the historic sampling has occurred upstream of significant near-channel sources of erosion and mass wasting. For that reason it is recommended that RPBCWD establish a monitoring station to measure continuous turbidity and collect TSS samples near the mouth of the creek, likely at the Riverview Road crossing. This would enable direct comparison of the continuous turbidity measurements with the data that is currently being collected at the Pioneer Trail WOMP station and allow RPBCWD to evaluate water quality improvements associated with the implementation of projects in the lower valley area.

In addition to the water quality monitoring, RPBCWD staff have also been installing bank pins in eroding streambanks that will be monitored for relative amounts of erosion throughout the system. It is recommended that this information be combined with information regarding channel and flow characteristics and mapped to evaluate patterns and develop additional improvement options, as well as refinements to the sediment loading rates.

4.0 Lotus Lake



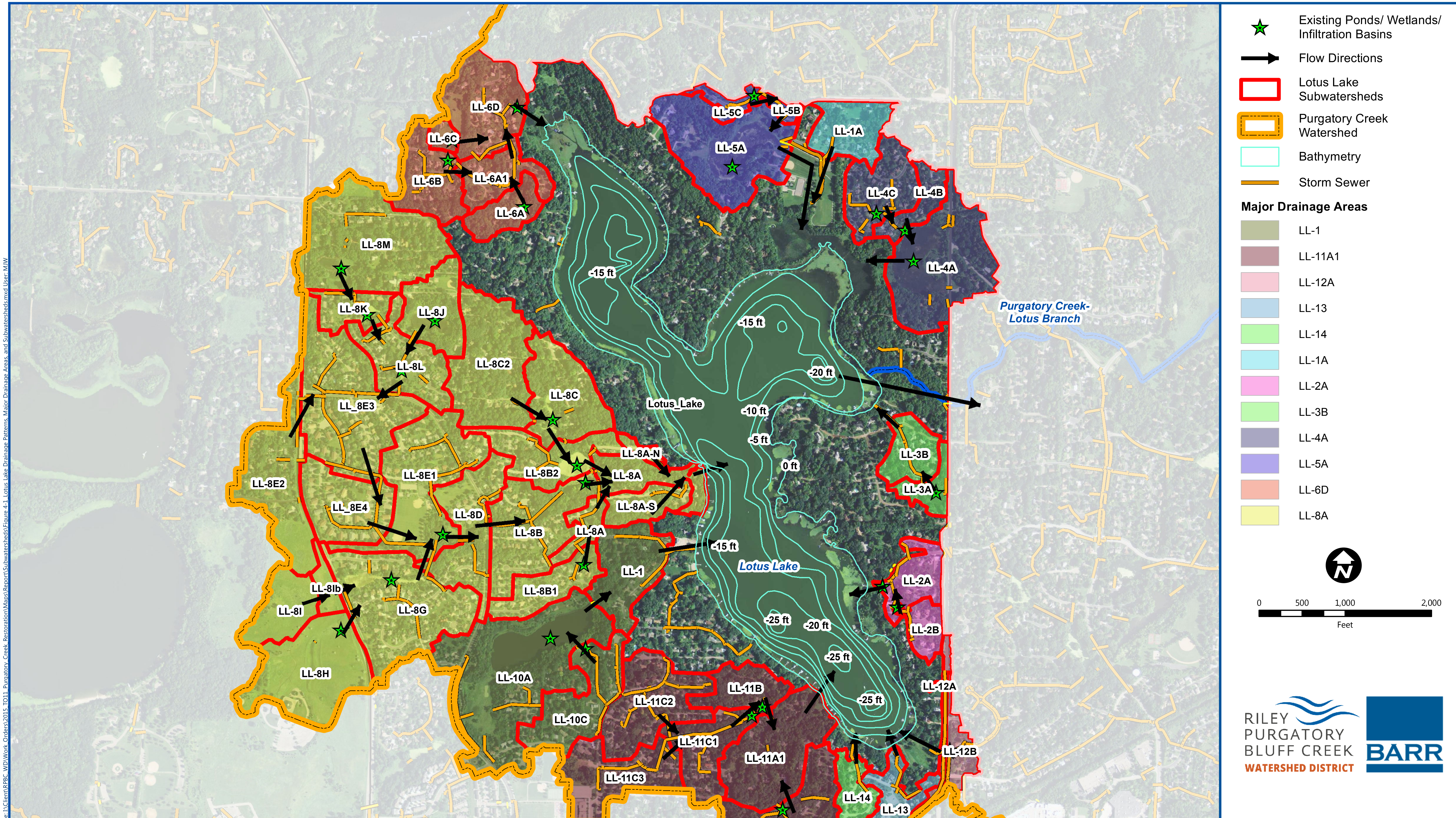
4.1 Watershed Characteristics

Lotus Lake is a headwater lake to Purgatory Creek. Lotus Lake lies mostly within the boundaries of the City of Chanhassen. A small portion of the watershed along the east side lies within the city of Eden Prairie. Lotus Lake has an overall watershed of 1397 acres, including the lake surface area of the approximately 248 acres (Figure 4.1).

4.1.1 Drainage Patterns

The stormwater conveyance system in the Lotus Lake watershed is comprised of storm sewer networks, constructed stormwater detention ponds, and natural wetlands within the watersheds tributary to the lake (Figure 4.1). Most of the constructed stormwater ponds within the Lotus Lake watershed are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows.

The Lotus Lake watershed was divided into subwatersheds based on updated topographical data (MDNR, 2011), storm sewer data, BMP locations, and other information from the cities of Chanhassen and Eden Prairie. The subwatersheds were grouped into 11 major drainage areas within the Lotus Lake watershed (Figure 4.1). Each major drainage area is named after the terminating watershed in each conveyance network. In addition to the major drainage areas is the lakes direct watershed. The direct watershed includes areas along the shoreline of the lake that contribute flow directly to the lake through surface flow as well as small stormsewered sections that do not receive treatment before discharging into the lake.



LOTUS LAKE SUBWATERSHEDS AND STORMSEWER ALIGNMENTS

FIGURE 4.1

4.1.2 Land Use

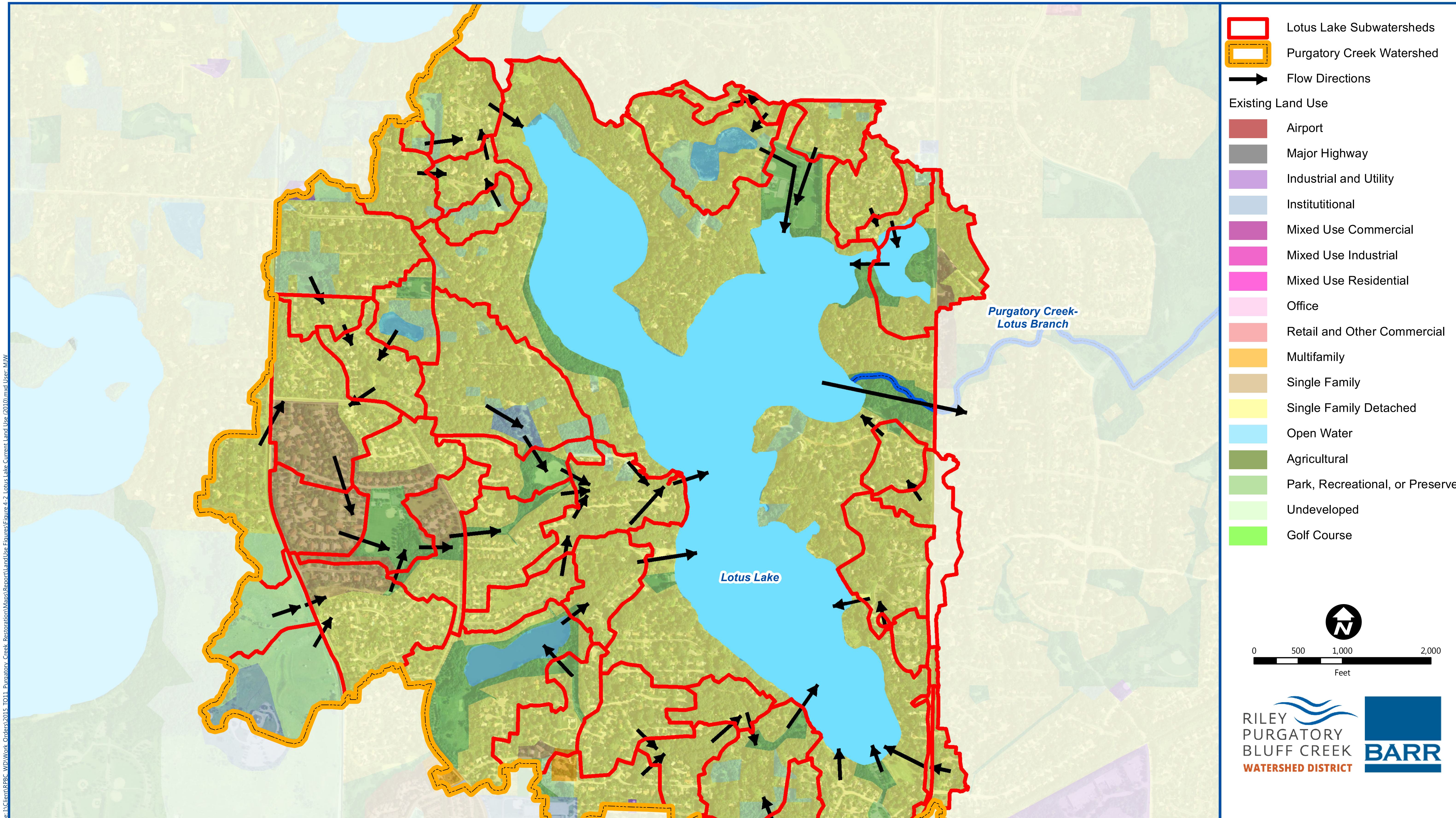
Land use within a lake's watershed can impact the hydrology and water quality of a lake. Varying land uses contribute different quantities of sediments and TP to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

Existing land-use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council. The land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix D.

The majority of the Lotus Lake watershed is covered by single family residential land use (65%). Figure 4.2 shows the existing land uses present in the Lotus Lake watershed.

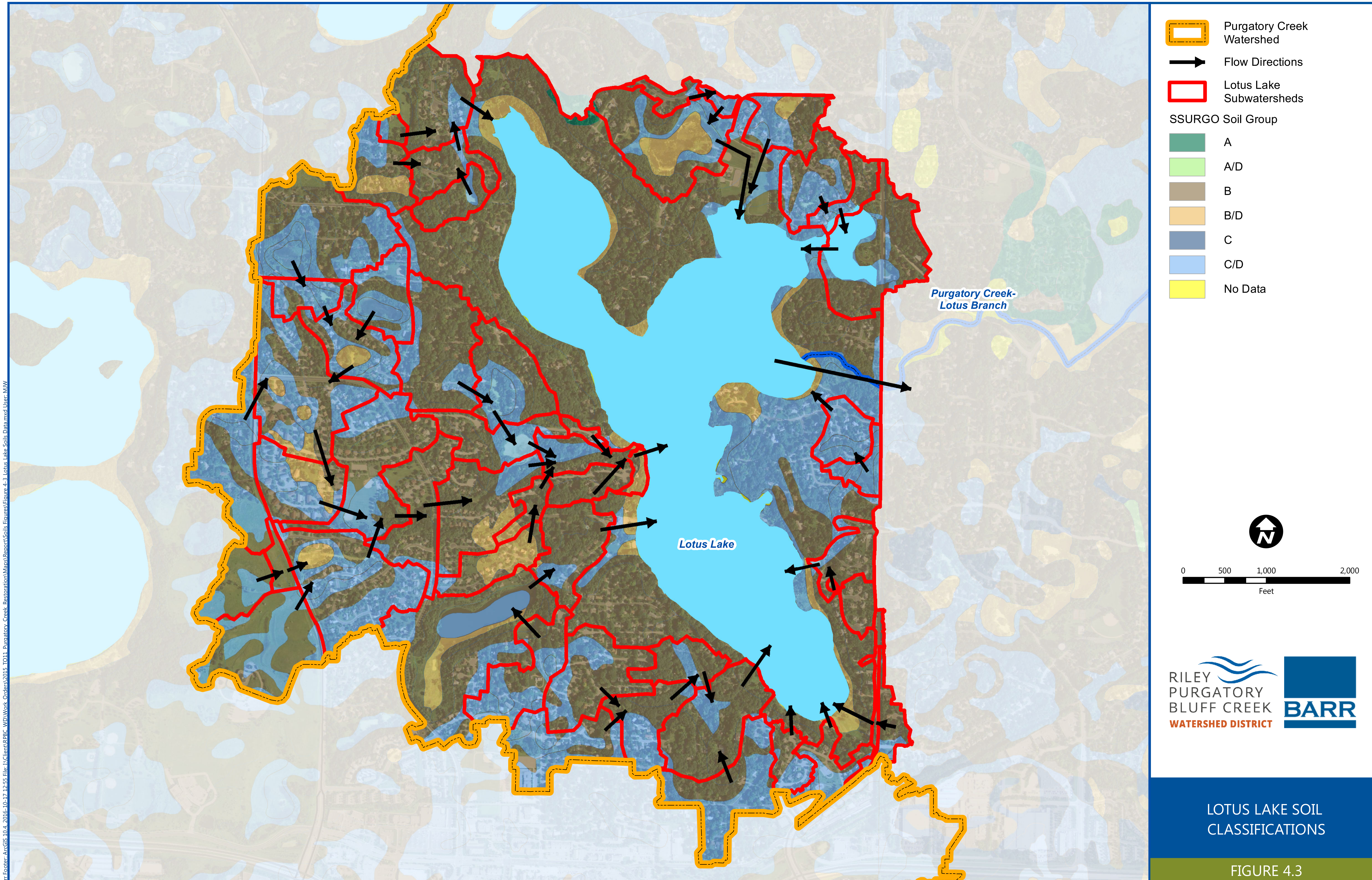
4.1.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database map for Carver and Hennepin counties, the underlying soils in the Lotus Lake watershed are predominantly classified as hydrologic soil group (HSG) B with moderate infiltration rates (Figure 4.3). The remaining areas in the watershed are coved by HSG C/D or B/D soils with low infiltration rates. High infiltration rate HSG A soils are not present in the watershed besides a small section north of the lake.



LOTUS LAND USE CLASSIFICATIONS

FIGURE 4.2



LOTUS LAKE SOIL CLASSIFICATIONS

FIGURE 4.3

4.2 Lake Characteristics

Table 4.1 provides a summary of the physical characteristics for Lotus Lake. Lotus Lake has an open-water surface area of approximately 248 acres. The lake is deep, with a maximum depth of approximately 31 feet and mean depth of approximately 16 feet. The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 897 feet mean sea level (MSL) (1992) to a low measurement of 893.2 feet MSL (1976). Since 2010 water levels in Lotus Lake have averaged at a measurement of 895.49 feet MSL. The outlet of Lotus Lake is a manmade structure that conveys water to Purgatory Creek. The outlet is at elevation of 895.4 feet. At the average water elevation of 895.49 feet, the total water volume in Lotus Lake is 2,500 acre-ft.

Table 4.1 Lotus Lake Physical Characteristics

Lake Characteristic	Lotus Lake
Lake MDNR ID	10-0006-00
MPCA Lake Classification	Deep
Water Level Control Elevation (feet MSL)	895.4
Average Water Elevation (feet MSL)	895.49
Surface Area (acres)	248
Mean Depth (feet)	16
Maximum Depth (feet)	31
Littoral Area (acres)	177
Volume (at normal water elevation) (acre-feet)	2,500
Thermal Stratification Pattern	Dimictic
Estimated Residence Time (years) – 2013-2015 climatic Conditions	2.7
Watershed Area Tributary to Upstream Lake	0
Total Watershed Area	1,397[1]
Subwatershed Area (acres)	1,397[1]
Trophic Status Based on 2015 Growing Season Average Water Quality Data	Hypereutrophic

1 – Watershed area includes surface area of lake.

Given the depth of Lotus Lake and the review of temperature and dissolved oxygen profiles suggest that Lotus Lake is a dimictic lake. This means that the lake mixes twice a year in the fall and spring as surface water temperature reach the temperature of maximum density (~39° F). During the summer months, temperature stratification is strong enough to prevent a wind mixing event from fully mixing the lake water column.

4.3 Water Quality Conditions

Historical water quality data, in terms of growing-season (June – September) average TP concentrations, chlorophyll *a* concentrations, and Secchi disc transparency for Lotus Lake are presented in Figure 4.4. Also shown in these figures is the MPCA water quality standards for each parameter. The growing season average concentrations consistently failed to meet the MPCA water quality standards throughout the record. The most recent growing-season average TP concentration in year 2015 was calculated as 65 µg/L, slightly less than the 73 µg/L concentration recorded on 2014. TP concentrations reached a recent minimum in 2010 of 30 µg/L, but have been elevated in recent years since 2012.

Chl-a concentrations follow a similar patters to the TP values. Historically Chl-a concentrations in Lotus Lake have exceeded the MPCA water quality standard for a deep lake. The 2015 growing season average concentration of 64 µg/L was the highest recorded average concentration on record.

Historical Secchi depths in Lotus Lake have mostly not met the MPCA water quality standard of 1.4 meters. Since 2009 five out of the seven growing season average values have met the water quality standard with each of the last three values (2013-2015) meeting the goal. The best average Secchi depth value of 1.8 meters was recorded in 2011. The most recent 2015 average depth was 1.5 meters.

Trends in the water quality data were determined by calculating a Thiel-Sen slope on the annual average growing season values and the significance of the trend was tested using the Mann-Kendall non parametric test at the 95% confidence internal. No significant trends are present over the recent time period of 1999-2014 or through the entire record since 1972 in any of the three parameters (Table 4.2). A slope of slight improvement in water clarity (Secchi Depth) was calculated, however it was not statistically significant.

Table 4.2 Lotus Lake water quality parameter Thiel-Sen trends for year 1999-2015

Parameter	1999-2015	Entire Record
TP (µg/L/yr)	0	0
Chl-a (µg/L/yr)	0	-0.1
Secchi Depth (m/yr)	0.03	0.01

Notes:
* Designates significant trends at the 95% confidence level using Mann-Kendall significance test

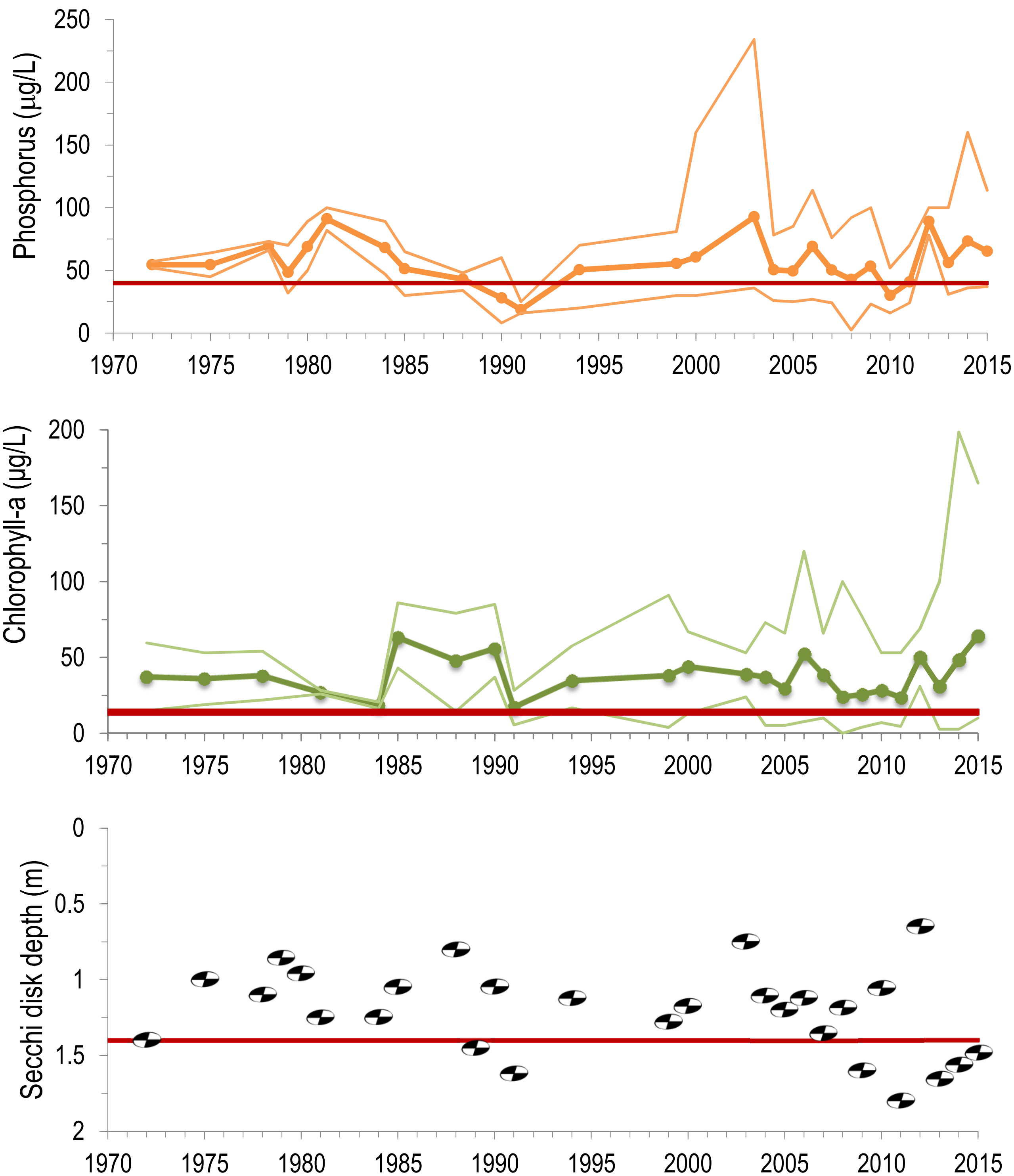


Figure 4.4
Lotus LakeWater Quality Growing Season (June - September) Average, Min and Max Values

4.3.1 Paleolimnology

In 2011 the district contracted with St. Croix Watershed Research Station to use paleolimnological techniques to reconstruct the trophic and sedimentation history of Lotus Lake (Ramstack & Edlund, 2011). A sediment core was collected and lead-210 activity was analyzed to develop a dating model and determine the sediment accumulation rate over the past 150 to 200 years.

The Lotus Lake reconstruction shows TP concentration in the most recent analyzed year (2010) consistent with concentrations observed in the pre-European settlement time periods (1860-1900). An increase in concentration was observed in the 1950's-1980's followed by a decreasing trend in the 1990's and 2000's back to pre-settlement concentrations (Figure 4.5).

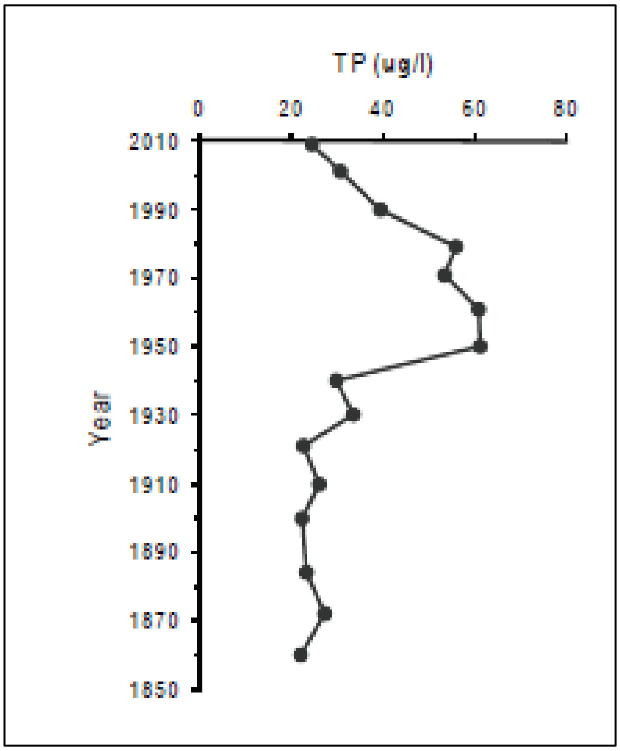


Figure 4.5 Lotus Lake diatom-inferred TP reconstruction (Ramstack & Edlund, 2011).

4.3.2 Water Quality Relationships

As previously discussed, phosphorus often acts as the limiting nutrient for algal growth (as measured by chlorophyll *a*), which in turn, affects lake water clarity (Secchi depth). This section describes how incremental phosphorus load reductions would be expected to impact perceptible changes in lake water quality. The compiled data for the water quality variables from Lotus Lake were analyzed to develop relationships between the water quality parameters: TP, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season averages. In addition to developing the water quality relationships based on the observed data, the regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) were also plotted against the lake data.

The relationships between the various water quality parameters for the actual Lotus Lake data did indicate some correlation between the water quality parameters (Figure 4.6). The MPCA regression equations resulted in similar fit for the chlorophyll *a*, Secchi disc transparency data, and TP. For this reason the MPCA statewide regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Lotus Lake based on TP concentration.

Figure 4.6 shows the individual water quality data points for Lotus Lake, along with plots of the MPCA statewide regression equations.

The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla (µg/L) = 1.31 Log10 TP (µg/L) – 0.95
- Log10 Secchi (meters) = -0.59 Log10 Chla (µg/L) + 0.89
- Log10 Secchi (meters)= -0.81 Log10 TP (µg/L) + 1.51

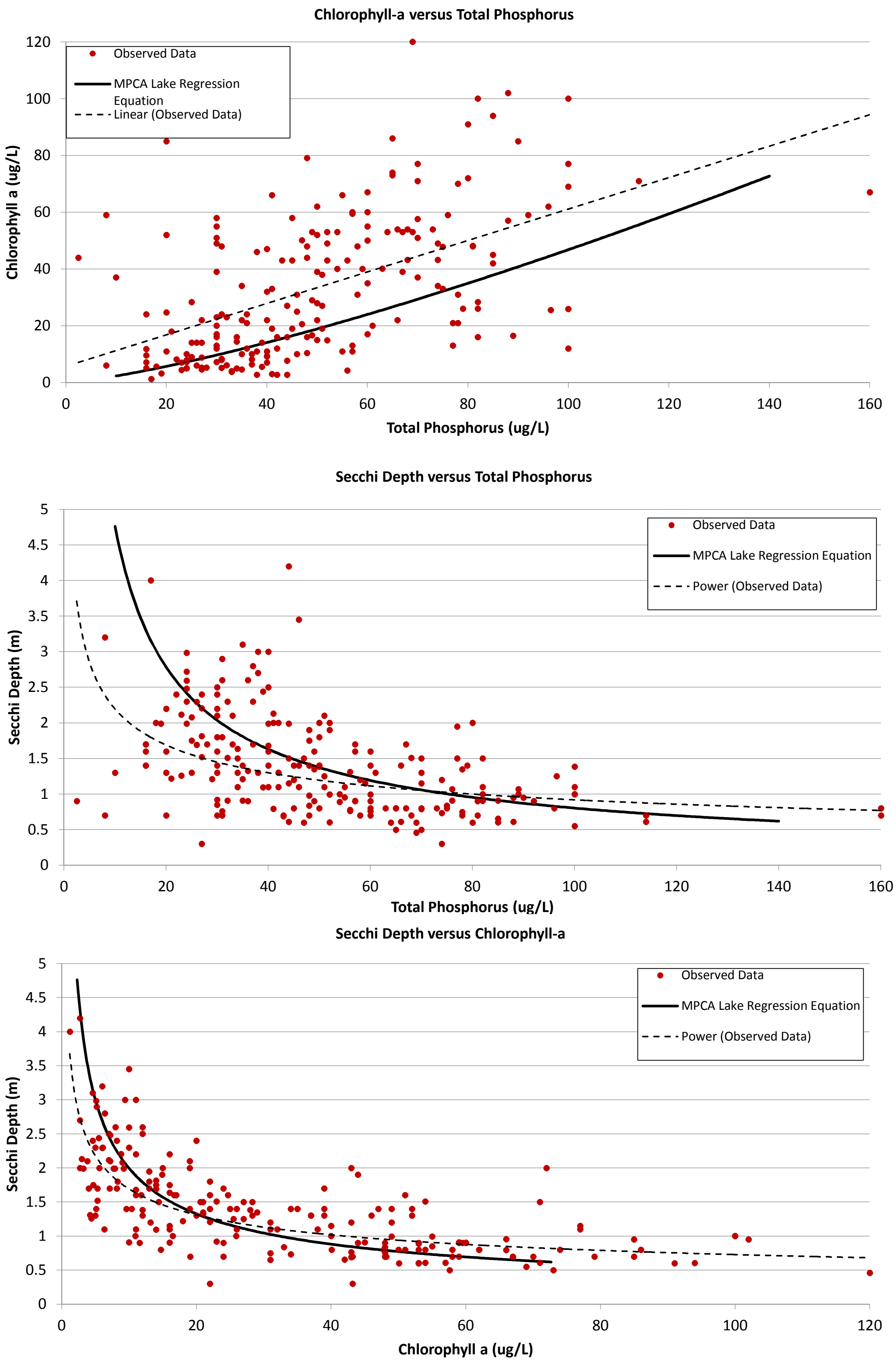


Figure 4.6
Lotus Lake Individual Samples
Water Quality Parameter
Regression Relationships

4.4 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

4.4.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species in Lotus Lake form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess TP loads.

RPBCWD has collected phytoplankton data in Lotus Lake for years: 1999, 2008, and 2009. Additionally, phycocyanin (cyanobacteria (blue-green algae) pigment) readings have been collected in years 2009 and 2013. A 2008 analysis (CH2M HILL, 2009) of zooplankton and phytoplankton in Lotus Lake showed phytoplankton was dominated (66 percent) by dinoflagellate while 32 percent were cyanobacteria.

While green algae are edible to zooplankton and serve as a valuable food source, cyanobacteria are considered a nuisance type of algae because they:

- Are generally inedible to fish, waterfowl, and most zooplankters
- Float at the lake surface in expansive algal blooms
- May be toxic to animals when occurring in large blooms
- Can disrupt lake recreation because they are most likely to be present during the summer months

4.4.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

The most recent analysis of zooplankton occurred in September of 2008. The zooplankton population was dominated by small bodied organisms that were unable to control algal growth. Copepodes represented 29% of the zooplankton density with Rotifers representing 40% and cladocerans representing 30%. Only 1% of the zooplankton density was represented by large bodied cladocerans. An analysis conducted in 1999 (Barr Engineering, 2005) found a similar result during the late summer/fall months. However, large populations of large bodied cladocerans were observed from April-June resulting in estimated grazing rates of the surface water column (0-6 ft) ranging from 7 to 20 percent. Declining grazing rates observed during June corresponded with declining numbers of large bodied cladocera and increasing volume of blue-green algae.

4.4.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

Plant surveys have been conducted on Lotus Lake in years 1999, 2013, and 2014. The 1999 plant survey was part of the Lotus Lake UAA (Barr Engineering, 2005). The most recent survey conducted on Lotus Lake was a set of point intercept surveys during the summer of 2013 and 2014 by the University of Minnesota (Jaka & Newman, 2014). It was found that Lotus Lake has a diverse macrophyte community with 18 different species present with moderate species richness at each sample site. Most plant species were observed in low frequencies and low densities with coontail (Ceratophyllum demersum, a native species) as the dominate species found in both frequency of occurrence and dry plant mass. Coontail was found at approximately 35 percent of the sites during both 2013 and 2014 with plant masses of 250 and 100 g dry/m^2 during the 2013 and 2014 sampling dates respectively. Eurasian watermilfoil (Myriophyllum spicatum, an exotic species) and Curlyleaf pondweed (Potamogeton crispus, an exotic species) were both found in Lotus Lake during both years, however at levels that are not of concern (Jaka and Newman, 2014). Plant management is not suggested at this time for Lotus Lake, but occasional monitoring is recommended (Jaka and Newman, 2014).

4.4.4 Fishery

The MDNR has developed a classification system for Minnesota lakes relative to the chemical and physical properties of each lake class and the fishery that is supported by each lake (Schupp, 1992). This ecological classification is a function of lake area, percentage of the lake surface area that is littoral, maximum depth, degree of shoreline development, Secchi disc transparency, and total alkalinity. According to it ecological classification, Lotus Lake is a class 24 lake. Class 24 lakes typically have a good permanent fishery (Schupp, 1992). According to its classification, Lotus Lake's primary fish species are northern pike, bluegill, and carp. Northern pike is a predator fish (eats bluegills). Bluegills are planktivores (eat zooplankton). Carp is considered a benthic or bottom feeding fish.

Based on a lake fish survey conducted in 1999 by the DNR the lake's fisheries consist of panfish, gamefish, roughfish, and other fish species. The 1999 MDNR fish survey showed that the following species were present in Lotus Lake.

- **Panfish:** Black crappie, bluegill, hybrid sunfish, green sunfish, and pumpkinseed sunfish.
- **Gamefish:** largemouth bass, northern pike, yellow perch, and walleye
- **Rough fish:** black bullhead, yellow bullhead, and common carp
- **Other fish:** golden shiner, spottail shiner, fathead minnow, jonney darter, and white sucker.

Overall results of the survey indicated an excellent fishery in Lotus Lake. Increased numbers of gamefish were observed when compared with the previous survey in 1994. Fish numbers, sizes, and growth rates were good when compared to class 24 lakes.

The RPBCWD funded the University of Minnesota to conduct multi-year research on the movement of common carp through the Purgatory Creek chain of lakes and document the key factors that influence carp recruitment (Sorensen, et al., 2015). Boat electrofishing surveys conducted in 2011 as part of this study found moderately abundant levels of carp (6 carp/hectare) in Lotus Lake. Further surveys using mark capture analyses conducted in 2012 and 2013 found the population of carp in Lotus Lake to be ~1,700 carp with a biomass of 60 kg/hectare. The carp populations in Lotus Lake were being adequately managed by natural predation within the lake system and carp are prevented from leaving the lake due to a fish barrier at the outlet. Carp biomass reductions through netting were conducted in 2012 and 2013 resulting in a reduction of the carp biomass to 51.7 kg/hectare. Subsequent surveys found a lack of young carp in the system further reinforcing the initial conclusions that native fish are adequately controlling the carp population in Lotus Lake (Sorensen, et al., 2015).

On July 6th, 2015 the MnDNR conducted a score the shore analysis on the shoreline of Lotus Lake. This analysis is a quick classification of shoreline fish habitat in the lake. The analysis gave the shorelines habitat of Lotus Lake a score of 74 out of 100 which corresponds to an overall fair lakeshore condition. Developed shoreline had an average score of 71 while undeveloped sites had an average score of 93.

The DNR also conducted a fish IBI (FIBI) study along with the score the shore analysis. The fish analysis found 12 different species of fish in the near shore sampling. The species included zero intolerant species and 2 tolerant species (common carp and green sunfish).The FIBI gave a score of 29 which is below the impairment threshold of 45. This low score was based on a low diversity of vegetation dwelling species, a low proportion of intolerant species of fish in the near shore, and a low biomass of top carnivores compared to lakes used to develop the FIBI scoring system.

4.5 TP Source Assessment

The watershed and in-lake water quality models were developed to assess both the external and internal TP loads in Lotus Lake for the 2015 water year (October 2014 – September 2015). A detailed discussion of the modeling methods used is presented in Section 2.2.2 and Appendix D. Possible lake external loads of TP include atmospheric depositions, stormwater runoff from the lake watershed, erosion from ravines/channels contributing to the lake, surficial groundwater interactions with the lake waters, internal loads from upstream ponds and wetlands, and load from any upstream lakes that might flow into the waterbody.

External loads that applied to Lotus Lake are atmospheric deposition, watershed loads, and erosion. Based on the 2015 water balance it appeared that there was no net surficial groundwater inflow meaning the inflow of groundwater likely equals the outflow, and Lotus Lake being a headwaters lake to Purgatory Creek is not downstream from another major waterbody/Lake. Internal TP loads can come from sediment phosphorus release, curly leaf pondweed, or benthivorous fish activity.

Figure 4.7 summarizes the 2015 annual water year TP budgets for Lotus Lake, including the relative contributions of the internal and external TP loads. This budget explains the sources of TP to the lake and help identify implementation strategies. Each of the sources are discussed further in the following section(s).

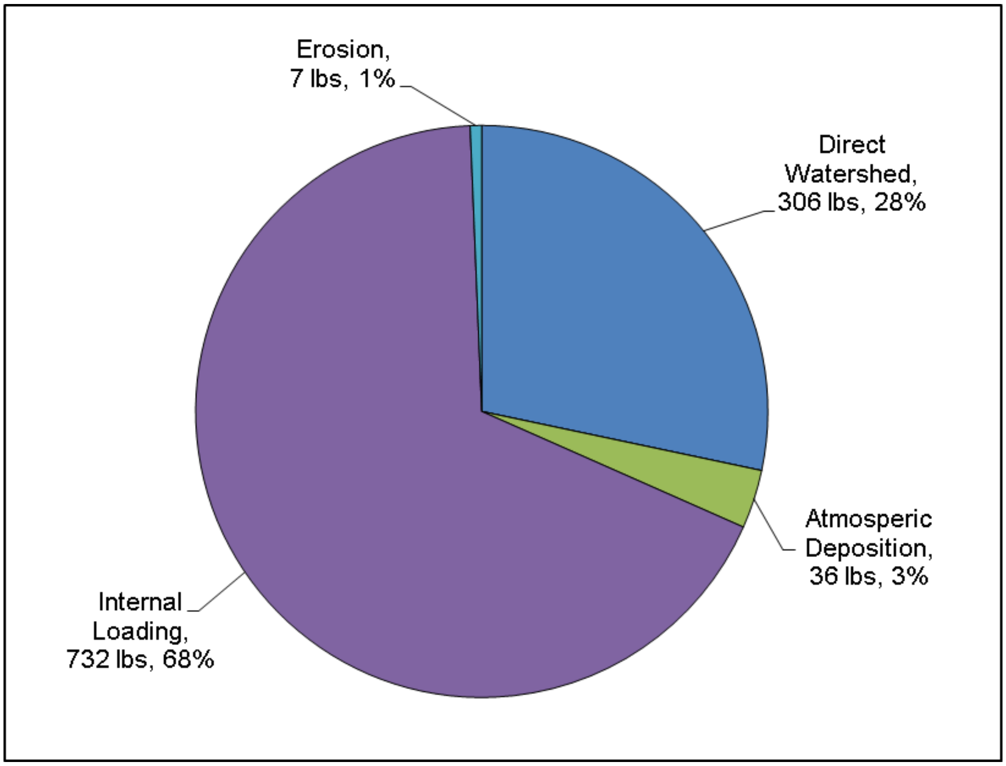


Figure 4.7 Lotus Lake TP load sources for 2015 water year

4.5.1 External Loads

4.5.1.1 Atmospheric Deposition

Atmospheric deposition of TP onto the lake water surface was calculated by using the estimated statewide TP atmospheric deposition rate of 0.17 kg/ha/year (Barr, 2004). For Lotus Lake, this loading rate was applied to the combined open water area. The daily rate was applied to the surface area of the lake based on the modeled lake water elevation from the lake water balance model. The resulting atmospheric deposition TP load for the 2015 water year was 36 pounds which amounted to 3% of the TP load to Lotus Lake (Figure 4.7).

4.5.1.2 Watershed Loads

The P8 watershed model estimated surface runoff from Lotus Lake's subwatersheds (not passing through upstream lakes) based on observed climatic data (precipitation and temperature). The total untreated watershed load from the watersheds in Lotus Lake for the 2015 water year was modeled to be 472 pounds. The watershed load travels through existing stormwater ponds, wetlands, infiltration practices, and other BMPs located throughout the watershed providing treatment resulting in a load of 306 pounds reaching the lake. This represents a 35% removal being provided by existing treatment practices in the watershed. The 306 pound TP load reaching the lake from the watershed load represented 28% of the total TP load to Lotus Lake (Figure 4.7).

To help evaluate areas that might benefit from additional treatment watershed loads to the lake were calculated for each of Lotus Lake's individual subwatersheds. The load to the lake is defined as the amount of TP load from that watershed reaching the lake without being removed by an existing BMP within the subwatershed or downstream from the subwatershed. The P8 results were used to calculate the total annual average untreated watershed TP loads from each subwatershed. Next the watershed load to the lake was calculated. This was accomplished by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each subwatershed that reached the lake without being removed by an existing BMP. The watershed load to the lake for each subwatershed is shown in Figure 4.8.

4.5.1.3 Erosion Loads

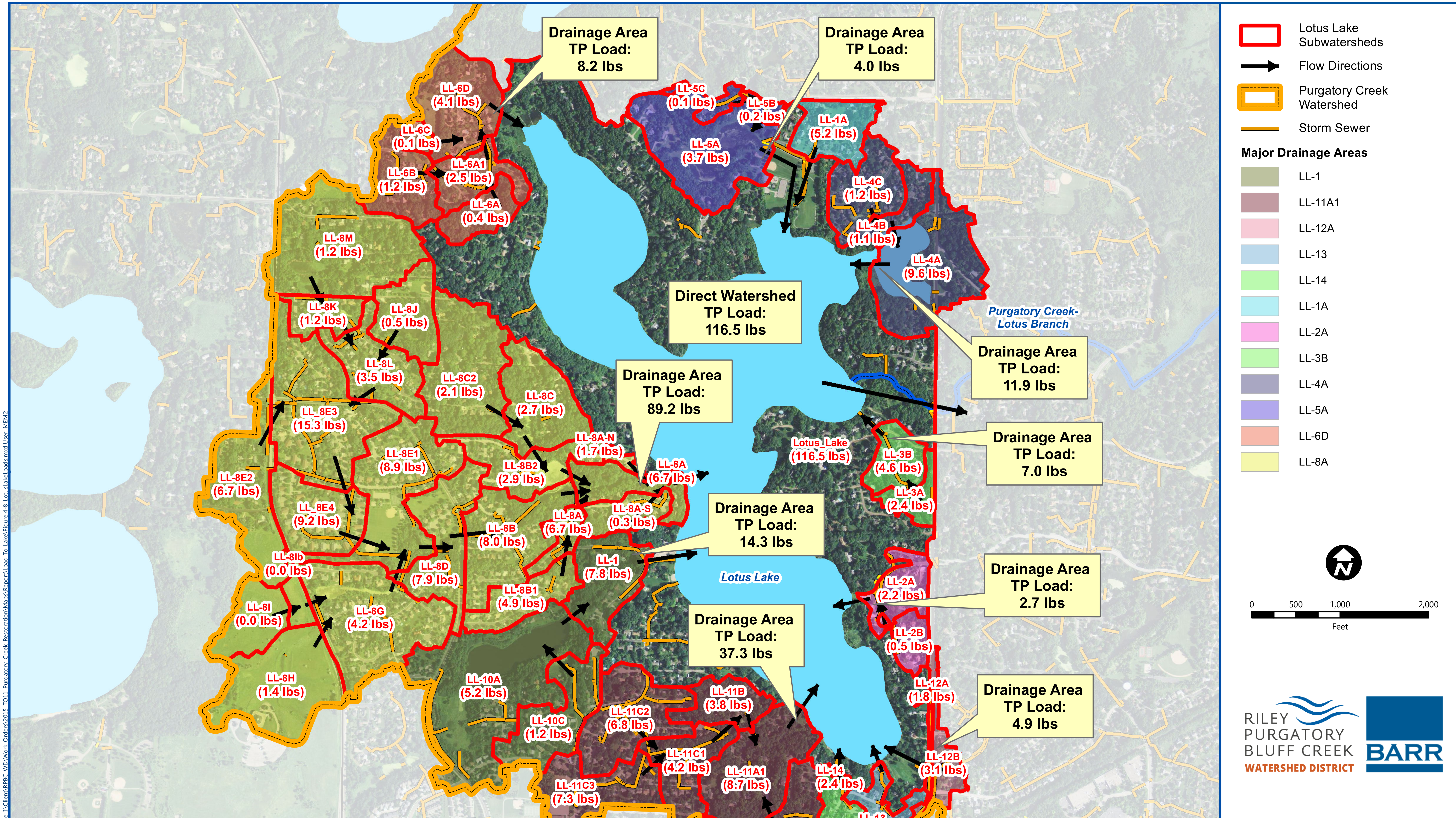
TP loads from bank erosion were calculated for tributaries to Lotus Lake based on estimates resulting from the RPBCWD Creek Restoration Action Strategy (CRAS) report (Barr Engineering, 2015) and associated documentation for the surveys of the stream reaches within the respective watersheds. Since the CRAS methodology quantifies a range in the amount of material that is at-risk of eroding during a 20-year period, the bank erosion estimates were based on the average of the highest and lowest annual sediment and TP loading rate estimates which were further reduced to account for a 20 percent delivery ratio to the lake. From this calculation an erosion load of 7 pounds of TP was estimated. This load represents 1% of the TP load to Lotus Lake (Figure 4.7).

4.5.2 Internal Loads

The Internal load in Lotus Lake represents 68% (732 pounds) of the TP load in the 2015 water year. Internal loading sources appear to be from three primary sources: Curly leaf pondweed, benthivorous fish activity, and sediment phosphorus release.

Curlyleaf Pondweed

Because of the relatively low occurrence of curlyleaf pondweed in Lotus Lake during the most recent U of M macrophyte survey completed in 2014, the TP loading from curlyleaf pondweed was not explicitly modeled for this study. The internal loading calibration parameter was used to simulate this release along with other sources of internal loading. In 2013 and 2014 curlyleaf pondweed was found to be in Lotus Lake but at levels that are not of concern (Jaka & Newman, 2014). Due to the low levels it is likely that curlyleaf pondweed is a minor source of TP to Lotus Lake.



LOTUS LAKE SUBWATERSHED TP LOADS TO THE LAKE

FIGURE 4.8

Benthivorous Fish Activity

Although carp have historically been present in Lotus Lake, the current carp densities estimated suggest that carp activity does not have a significant impact on the observed water quality in the lakes. Carp populations appear to be naturally controlled in Lotus Lake through predation of young carp by predator fish in the Lake. Through four years of surveys (2011-2014) carp biomass has been determined to be well below the water impairment threshold of 100 kg/hectare determined by the University of Minnesota (Sorensen, et al., 2015). The most recent survey conducted in 2014 found biomass levels equal to 51.7 kg/hectare. Because of the relatively low biomass of carp and other benthivorous fish, the TP load from benthivorous fish activity was not separated out from the other internal loads.

Sediment Release

Internal loading through sediment release occurs during anoxic conditions. A review of dissolved oxygen profiles in Lotus Lake showed anoxic conditions reaching a depth of 13 feet from the lakes water surface during the middle summer months. Persistent stratification in Lotus Lakes occurs throughout the summer with mixing events only happening in the late fall and early spring. The stratification and subsequent anoxic conditions in the hypolimnion allow for the release of phosphorus throughout the growing season months. Elevated TP concentrations have been recorded in the lake hypolimnion corresponding to anoxic conditions. TP concentrations in the hypolimnion have reached as high as 1000 µg/L since 2013 with concentrations typically seen between 400 and 600 µg/L during the summer months. As the lake mixes due to turnover in the fall from temperature changes this phosphorus load is distributed throughout the water column, impacting surface water concentrations.

4.5.3 TP Load Reductions

The in-lake model was used to determine the TP load reductions needed to meet the water quality goal for Lotus Lake. Table 4.3 shows the measured and modeled growing season average (June – September) concentration, the TP load to the lake under existing conditions, the water quality goal, the TP loading capacity for meeting the water quality standard and the required percent reduction needed to meet the water quality goal. Under existing conditions, Lotus Lake is not meeting the TP concentration goal for a deep lake of 40 µg/L. Modeled and measured growing season TP average concentrations in the lake surfaces waters for the 2015 water year was 64 µg/L and 65 µg/L respectively. Lotus Lake was modeled as a stratified lake with modeled concentrations for the hypolimnion and epilimnion. The annual TP load to the whole lake under existing conditions was 1,081 pounds for the 2015 water year. To meet the water quality goal the annual TP load to Lotus Lake would need to be reduced to approximately 682 pounds, resulting in an overall 37% TP load reduction.

Table 4.3 Lotus Lake estimated load reductions required to meet TP water quality goal for 2015 water year

Measured growing season average TP concentration (µg/L)	Modeled growing season average TP concentration (µg/L)	Estimate 2015 TP loading rate (lbs/yr)	TP concentration goal (µg/L)	Estimated Loading Capacity to meet WQ goal (lbs/yr)	Percent reduction needed to achieve goal (%)
65	64	1,081	40	682	37%

Figure 4.9 shows how lake concentrations react to lake load reductions. The calibrated in-lake TP model was used to determine in-lake water quality based on the amount of TP load to the lake. TP concentrations were estimated using the in-lake model. Chl-a and Secchi depth concentrations were determined based on the water quality relationships discussed in Section 4.3.2. The figure shows how incremental load reductions would impact the water quality in Lotus Lake.

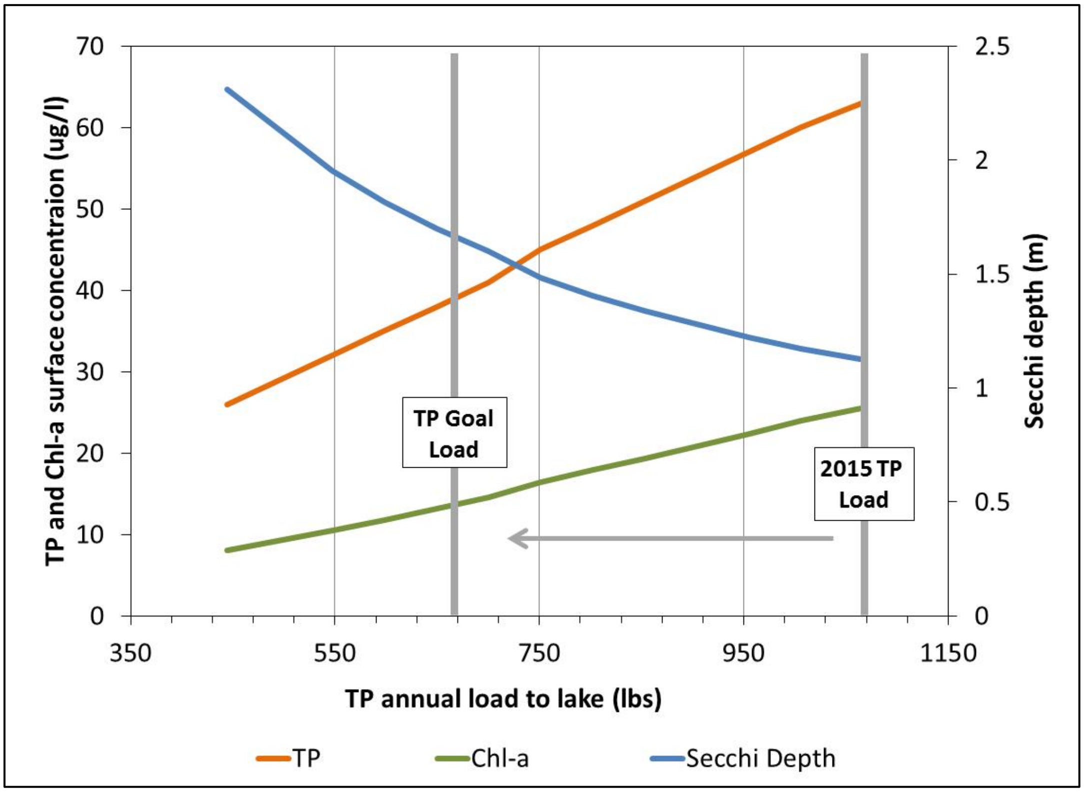


Figure 4.9 Lotus Lake TP load relationship with lake water quality (TP, Chl-a and clarity)

4.6 Summary of Diagnostic Findings

Table 4.4 provides a summary of the key water-quality findings for Lotus Lake.

Table 4.4 Diagnostic Findings for Lotus Lake

Topic	Lotus Lake
Water Quality Standards and Goals	- Does not meet MPCA Deep Lake Standards - Does not meet RPBCWD goals or long term vision
Baseline Water Quality	- Water quality concentrations are elevated above reconstructed concentrations from predevelopment time periods
Water Quality Trends	- No significant trends since 1999
Watershed Runoff	- Represents 28% of annual TP load - Watershed load appears to be reduced by 35% by existing BMPs, ponds and wetlands located throughout the watershed.
Macrophyte Status	- Diverse macrophyte community dominated by native coontail - Curlyleaf pondweed is present in low numbers - Eurasian water milfoil is present in low numbers
Fishery Status	- Carp populations currently below water quality degradation threshold
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer
Internal Loading from sediments	- Thermally stratifies during summer months with anoxic conditions of the hypolimnion reaching up to 13 ft depth from surface waters - Internal loading (sediment, curlyleaf, and carp) estimated to be 68% of annual TP load
Methylmercury in Fish Tissues	- No studies have been conducted, not currently listed as impaired - No consumption advisories

Additional discussion of the diagnostic findings in relation to the sources of TP and water quality of the lake based on the data analyses, watershed and in-lake modeling, and review of recent studies and information is summarized below. These conclusions influenced the implementation strategies evaluated for the management of Lotus Lake water quality (see Section 4.8).

- Lotus Lake is currently listed on the MPCA 303(d) impaired waters list for excess nutrients with TP concentrations exceeding the 40 µg/L MPCA deep water standard. A TMDL analysis is currently being developed with the MPCA. A complete historic review of water quality conditions in Lotus Lake show TP concentration consistently above the standard for TP, Chl-a and Secchi depth. A trend analysis showed no significant trends in water quality over the entire period of record as well as over the most recent time period since 1999.

- Roughly 67 percent of the watershed runoff receives treatment prior to entering Lotus Lake due to the number of stormwater ponds and other waterbodies within the watershed. As stormwater runoff passes through the many constructed stormwater ponds and natural wetlands in the watershed, removal of TP associated with particulates in the runoff occurs due to particle settling.

As a result, the watershed modeling suggests the TP in the watershed runoff reaching the lake is in a soluble form or associated with very small particles that are difficult to settle. Therefore, treatment practices that can remove dissolved TP such as infiltration and enhanced filtration practices should be examined in addition to practices in currently untreated areas.

- The watershed phosphorous load to Lotus Lake represented 28 percent of the total annual TP budget to the lake during the 2015 water year, internal loading represented another 68 percent of the total annual TP budget (see Figure 4.7)

- Water quality data collected along the depth profile of Lotus Lake indicates that the interface along the bottom sediments can become anoxic during the summer and elevated TP levels have been observed near the lake bottom, supporting that internal loading is a source of TP in Lotus Lake.

- Figure 4.8 shows the estimated 2015 water year TP loading from the major drainage basins in the Lotus Lake watershed. The watershed modeling suggests that the direct watershed to Lotus Lake provides 38 percent of the watershed load to Lotus Lake. Providing treatment to areas draining directly into Lotus Lake should be examined. Another 29 percent of the watershed load to Lotus Lake passes through the LL-8A major drainage area. This drainage area appears to provide a good opportunity for the implementation of additional watershed BMPs or modifications to existing BMPs.

- Based on the 2013 and 2014 macrophyte data collected by the University of Minnesota (Jaka & Newman, 2014), Lotus Lake has a diverse macrophyte community dominated by native coontail. Eurasian watermilfoil and curlyleaf pondweed were found in the lake surveys but at low levels that are not of concern.

- According to the U of M the carp population in Lotus Lake is currently at low levels and appears to be managed through natural predation from blue gill feeding on carp eggs (Sorensen, et al., 2015). Harvesting campaigned in 2012 and 2013 reduced the biomass of carp in the lake from 60 kg/hectare to 51 kg/hectare (Sorensen, et al., 2015).

4.7 Current and Past Management Actions

The following includes a summary of BMPs either implemented or analyzed in the Lotus Lake watershed:

- Suggested BMP and mitigation measures for Lotus Lake as part of the "One Water" Water Management Plan (CH2M HILL, 2011) included:
    - Curlyleaf pondweed mitigation through herbicide and mechanical treatment,
    - Eurasian water milfoil treatment through mechanical or herbicide treatment,
    - carp mitigation through collaboration with the University of Minnesota,

  - control internal loading of phosphorus and mercury methylation through oxygenation, aeration, sediment oxygenation, alum treatment, or a combination of methods,
  - control purple loosestrife with beetles,
  - control cyanobacteria through destratification.
- Moderate carp populations were found in Lotus Lake in 2011 with carp removal conducted in 2012. High presence of blue gills in Lotus Lake is likely suppressing the reproduction of carp in the lake. Carp population was comprised primarily of old individuals (Sorensen, et al., 2015).
- In 2012 a pilot program was implemented to create low impact development projects in the Carver Beach neighborhood (RPBCWD, 2012).
- Shoreline restoration project was implemented along Lotus Lake in 2012 (RPBCWD, 2012).
- Ponds LL-P10.7, LL-P10.4, LL-P6.3, analyzed in the Lotus Lake watershed over years 2012 and 2013, were determined to have TP concentration above 0.250 mg/l and could benefit from remediation measures (RPBCWD, 2014).
- Continued carp monitoring to maintain low carp populations (Sorensen, et al., 2015). Continued plant monitoring to maintain low densities of invasive macrophytes (Jaka & Newman, 2014).

4.8 Evaluation of Water Quality Improvement Options

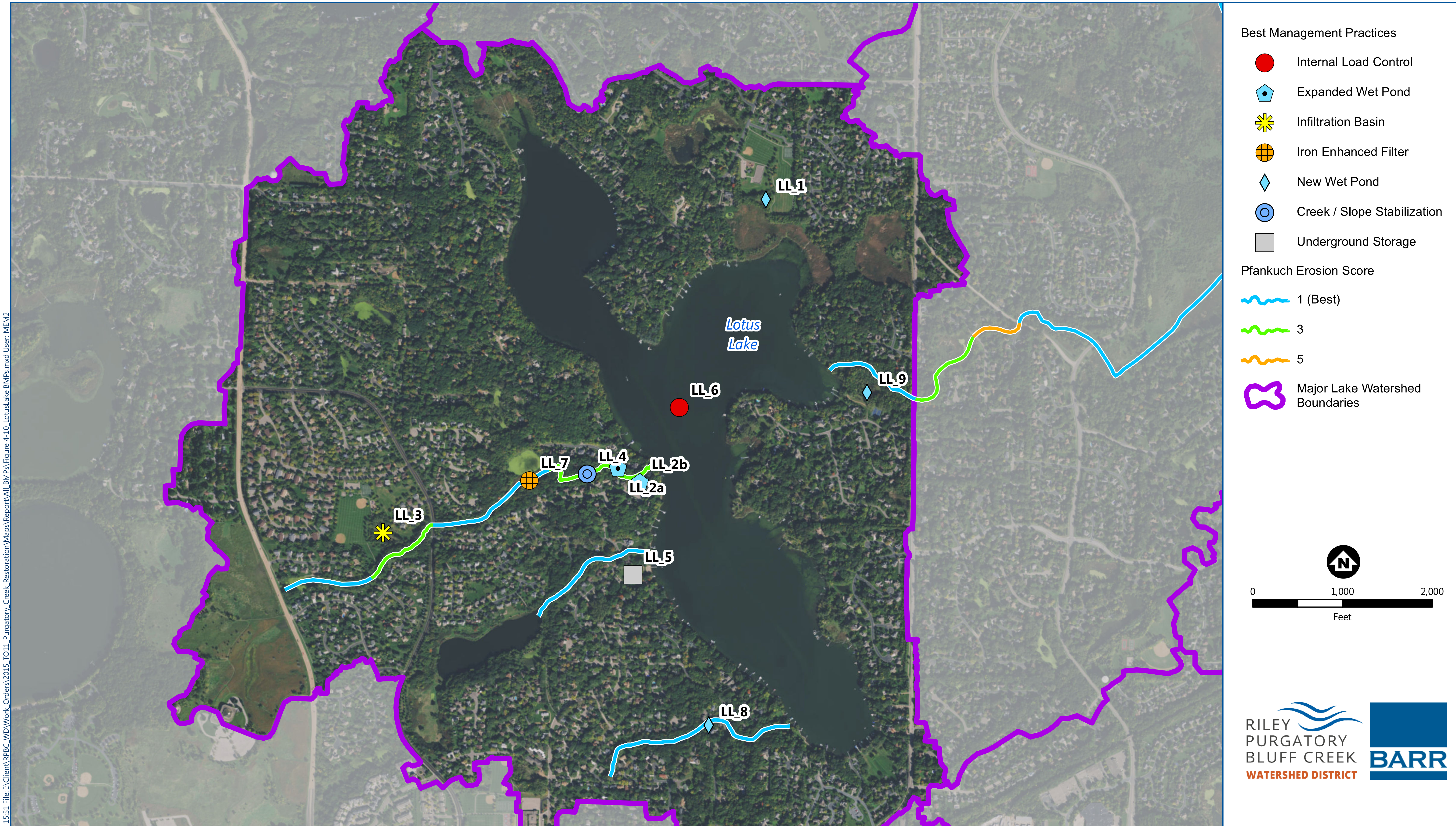
All of the BMPs identified for Lotus Lake are listed and described in detail in the following subsections. Table 4.5 provides a list of the potential BMPs and Figure 4.10 shows the identified potential BMP locations in the Lotus Lake watershed.

Table 4.5 - Summary of Lotus Lake BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
LL_1	New Wet Pond *- A 0.6 acre, 3-foot deep wet pond designed to treat 4.0 acres of impervious area*	6.4	6.4	2%	$186,300 ($149,000 - $261,000)	$3,700 ($3,000 - $5,200)	$1,550 ($1,240 - $2,170)	$1,550 ($1,240 - $2,170)
LL_2	Expanded Wet Ponds *- Two ponds totalling 0.25 acres, 2.5-feet deep, designed to treat 1.9 acres of impervious area*	0.4	0.4	0%	$88,600 ($71,000 - $124,000)	$1,800 ($1,400 - $2,500)	$11,880 ($9,510 - $16,640)	$11,880 ($9,510 - $16,640)
LL_3	Infiltration Basin *- A 1.6 acre, 1.7-foot deep infiltration basin designed to treat 20.9 acres of impervious area*	58.8	48.5	12%	$389,700 ($312,000 - $546,000)	$7,800 ($6,200 - $10,900)	$350 ($280 - $500)	$430 ($340 - $600)
LL_4	Creek Restoration and Stabilization *- Restoration and stabilization of the 1,550-foot reach between Carver Beach Road and Lotus Lake.*	2.6	2.6	1%	$388,000 ($194,000 - $776,000)	$7,800 ($3,900 - $15,500)	$7,970 ($3,990 - $15,950)	$7,970 ($3,990 - $15,950)
LL_5	Underground Storage and Reuse *- A 0.4 acre, 3-foot deep buried concrete structure designed to store 2.8 inches off of 5.2 acres of impervious area for reuse later*	18.7	18.7	5%	$1,737,400 ($1,390,000 - $2,432,000)	$34,700 ($27,800 - $48,600)	$4,950 ($3,960 - $6,930)	$4,950 ($3,960 - $6,930)
LL_6	Internal Load Control *- Two treatments of a whole lake alum treatment*	586	586	147%	$1,258,000 ($1,006,000 - $1,762,000)	$0	$70 ($60 - $100)	$70 ($60 - $100)
LL_7	Iron Enhanced Sand Filter *- A 0.8 acre, 1.6-foot deep iron enhanced sand filter designed to treat 8.9 acres of impervious area.*	58.7	58.7	15%	$585,700 ($469,000 - $820,000)	$11,700 ($9,400 - $16,400)	$530 ($430 - $740)	$530 ($430 - $740)
LL_8	New Wet Pond *- A 0.45 acre, 3-foot deep wet pond designed to treat 12.1 acres of impervious area*	8.7	6.7	2%	$142,400 ($114,000 - $199,000)	$2,800 ($2,300 - $4,000)	$870 ($690 - $1,210)	$1,130 ($900 - $1,580)
LL_9	New Wet Pond *- A 0.9 acre, 4-foot deep wet pond designed to treat 4.2 acres of impervious area*	10	10	3%	$556,200 ($445,000 - $779,000)	$11,100 ($8,900 - $15,600)	$2,960 ($2,370 - $4,150)	$2,960 ($2,370 - $4,150)
LL_3&7	Infiltration Basin and Iron Enhanced Sand Filter *- Combination of BMPs LL_3 and LL_7 as described above.*	73.1	73.5	18%	$975,400 ($780,000 - $1,366,000)	$19,500 ($15,600 - $27,300)	$710 ($570 - $1,000)	$710 ($570 - $990)

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. Overall load reduction goal for Lotus Lake is 399 pounds of phosphorus per year; 97 lbs/yr from the watershed, and 302 lbs/yr internally.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.



ALL IDENTIFIED BMPs, LOTUS LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 4.10

4.8.1 New wet pond in subwatershed Lotus_Lake, LL_1

BMP LL_1 would be a new wet pond receiving runoff from roughly 4.0 acres of untreated impervious area in subwatershed Lotus_Lake just south of a baseball field and park on the east side of Pleasantview Road . This pond is proposed to be approximately 0.6 acres at the surface and about 3 feet deep on average. Computer simulations suggest the pond would remove approximately 6.4 pounds of TP per year based on 30-year modeling results. Because the BMP is near Lotus Lake, the TP reduction to the lake is also anticipated to be about 6.4 pounds of TP per year. The cost-benefit of this BMP for Lotus Lake is estimated to be about $1,550 per pound of TP, assuming the BMP functions for 30 years.

4.8.2 Expanded wet ponds in subwatershed LL-8A, LL_2

BMP LL_2 is the combination of expanding two existing wet ponds in subwatershed LL-8A currently treating 1.9 acres of impervious area. These ponds are at the ends of Big Woods Boulevard and Bighorn Drive. These ponds together are proposed to be approximately 0.25 acres at the surface with an average depth of about 2.5 feet. The smaller size relative to the area treated is driven by the space constraints. The expanded ponds are estimated to remove an additional 0.4 pounds of TP per year. Based on the proximity of the ponds in the watershed relative to Lotus Lake, the TP reduction to the lake is also estimated to be 0.4 pounds of TP per year. The cost-benefit of this BMP for Lotus Lake is estimated to be about $11,880 per pound of TP, assuming the BMP functions for 30 years.

4.8.3 New infiltration basin in subwatershed LL-8E1, LL_3

BMP LL_3 would replace the existing dry detention basin in subwatershed LL-8E1, located near the park just west of Kerber Boulevard and south of Pontiac Lane, with a new infiltration basin to treat runoff from 20.9 acres of untreated impervious area. According to the NRCS Soil Survey Geographic (SSURGO) database map for Carver County the soils in this area are "B" soils, with a good capacity to infiltrate water. This infiltration basin is proposed to be approximately 1.6 acres at the surface and about 1.7 feet deep. The infiltration basin would have three inlets of various sizes, and one 60-inch overflow outlet. The infiltration basin could potentially remove an additional 58.8 pounds of TP. Based on the distance of the BMP in the watershed relative to Lotus Lake, the actual TP reduction to the lake is estimated to be 48.5 pounds of TP per year. The cost-benefit of this BMP for Lotus Lake is estimated to be about $430 per pound of TP, assuming the BMP functions for 30 years. Because of the efficiency of the BMP and the relatively low cost-benefit, BMP LL_3 is recommended for further consideration.

If BMP LL_3 is combined with proposed BMP LL_7, the total TP reduction to the lake is 73.5 lbs. The combined cost-benefit for both LL_3 and LL_7 is $740 per pound of TP, assuming the BMPs function for 30 years. Because of the efficiency of these BMPs and the relatively low cost-benefit, constructing both BMP LL_3 and BMP LL_7 is recommended for further consideration.

4.8.4 Creek restoration and stabilization in subwatershed LL-8D, LL_4

BMP LL_4 is the restoration and stabilization of a 1,550-foot reach of a ravine/creek, between Carver Beach Road and Lotus Lake, in subwatershed LL-8A. This reach of the ravine/creek was identified in the ravine walks completed by RPBCWD staff as a reach with an estimated severe erosion rate. The purpose of this BMP is to reduce the soil erosion quantities which will also reduce the TP load from this watershed. The restoration and stabilization of this ravine/creek reach is estimated to reduce TP loading from the creek by about 2.6 pounds per year. The simulated load of TP to the lake is also estimated to be reduced by 2.6 pounds of TP per year since this reach flows directly into the lake. The cost-benefit of this BMP for Lotus Lake is estimated to be about $7,970 per pound of TP, assuming the creek remains stable for 30 years. Because of the relatively low load reduction and high cost-benefit, BMP LL_4 is not considered a practical BMP for implementation.

4.8.5 Underground storage and reuse in subwatershed Lotus_Lake, LL_5

BMP LL_5 is a buried concrete structure in subwatershed Lotus_Lake in the open space near a beach just east of Frontier Trail designed to temporarily store up to 2.8 inches of runoff from the 5.2 acres of untreated contributing impervious area for later use. The expected possible use is irrigation of nearby lawns or parks. The buried storage container is proposed to be approximately 0.4 acres and about 3 feet deep. The storm sewer systems along both Frontier Trail and Laredo Drive would be routed into this storage container. The storage and reuse system is estimated to remove 18.7 pounds of TP per year based on 30-year modeling results. Based on the proximity of the BMP to Lotus Lake and the general focus on runoff reduction, the estimated reduction of TP load to the lake is also about 18.7 pounds of TP per year. The cost-benefit of this BMP is estimated to be about $4,950 per pound of TP, assuming the BMP functions for 30 years. Because of the relatively high cost, BMP LL_5 is not recommended for the watershed, even though it would have other benefits such as reducing the runoff volume from the contributing watershed.

4.8.6 Internal load control in Lotus Lake, LL_6

BMP LL_6 is a method for reducing the internal loading within the lake, likely with an alum treatment to bind mobile TP in the lake sediment. The treatment within the lake is expected to initially reduce the internal TP loading by approximately 80% (Welch & Cooke, 1999), resulting in a reduction of 586 pounds per year. The dose needed to achieve this reduction is estimated to be approximately 1,500 gallons per acre, based on 2005 samples of mobile TP in the sediment cores of Lotus Lake (Barr Engineering, 2005). The cost-benefit of this BMP is estimated to be about $70 per pound of TP, assuming treatment is not needed again for at least another 15 years (Huser, et al., 2015). Two treatments will likely be needed over 30 years and the total cost of both treatments is estimated to be $1,258,000 (Table 4.5). Because of the significant load reduction and the low cost, BMP LL_6 is recommended for the lake after external loads are controlled in order to maximize the design life of the application.

4.8.7 Iron enhanced sand filter in subwatershed LL-8B, LL_7

BMP LL_7 is converting an existing wet pond into an iron enhanced sand filter in subwatershed LL-8B just north of Bighorn Drive. This BMP receives runoff from approximately 8.9 acres of untreated impervious area. This iron enhanced sand filter is proposed to be approximately 0.8 acres at the surface and about 1.6 feet deep. The iron enhanced sand filter is estimated to remove an additional 58.7 pounds of TP per year based on 30-year modeling results. Based on the proximity of the BMP to Lotus Lake, the actual TP reduction reaching the lake is also estimated to be about 58.7 pounds of TP per year. The cost-benefit of this BMP is estimated to be about $530 per pound of TP, assuming the BMP functions for 30 years. Because of the efficiency of the BMP and the relatively low cost-benefit, BMP LL_7 is recommended for further consideration.

If BMP LL_7 is combined with proposed BMP LL_3, the total TP reduction to the lake is 73.5 lbs. The combined cost-benefit for both LL_3 and LL_7 is $740 per pound of TP, assuming the BMPs function for 30 years. Because of the efficiency of these BMPs and the relatively low cost-benefit, constructing both BMP LL_3 and BMP LL_7 is recommended for further consideration.

4.8.8 Enhanced wet pond in subwatershed LL-11C1, LL_8

BMP LL_8 is the enhancement and enlargement of an existing wet pond in subwatershed LL-11C1 just to the west of Frontier Trail that receives runoff from 12.1 acres of untreated impervious area. This pond is proposed to be approximately 0.45 acres at the surface with an average depth of about 3 feet. The pond is estimated to remove an additional 8.7 pounds of TP per year based on the 30-year modeling simulation. Based on the location of the BMP in the watershed relative to Lotus Lake, the TP reduction to the lake is simulated to be less, about 6.7 pounds of TP per year. The cost-benefit of this BMP for Lotus Lake is estimated to be about $1,130 per pound of TP, assuming the BMP functions for 30 years. Because of the efficiency of the BMP and the relatively low cost-benefit, BMP LL_8 is recommended for the watershed.

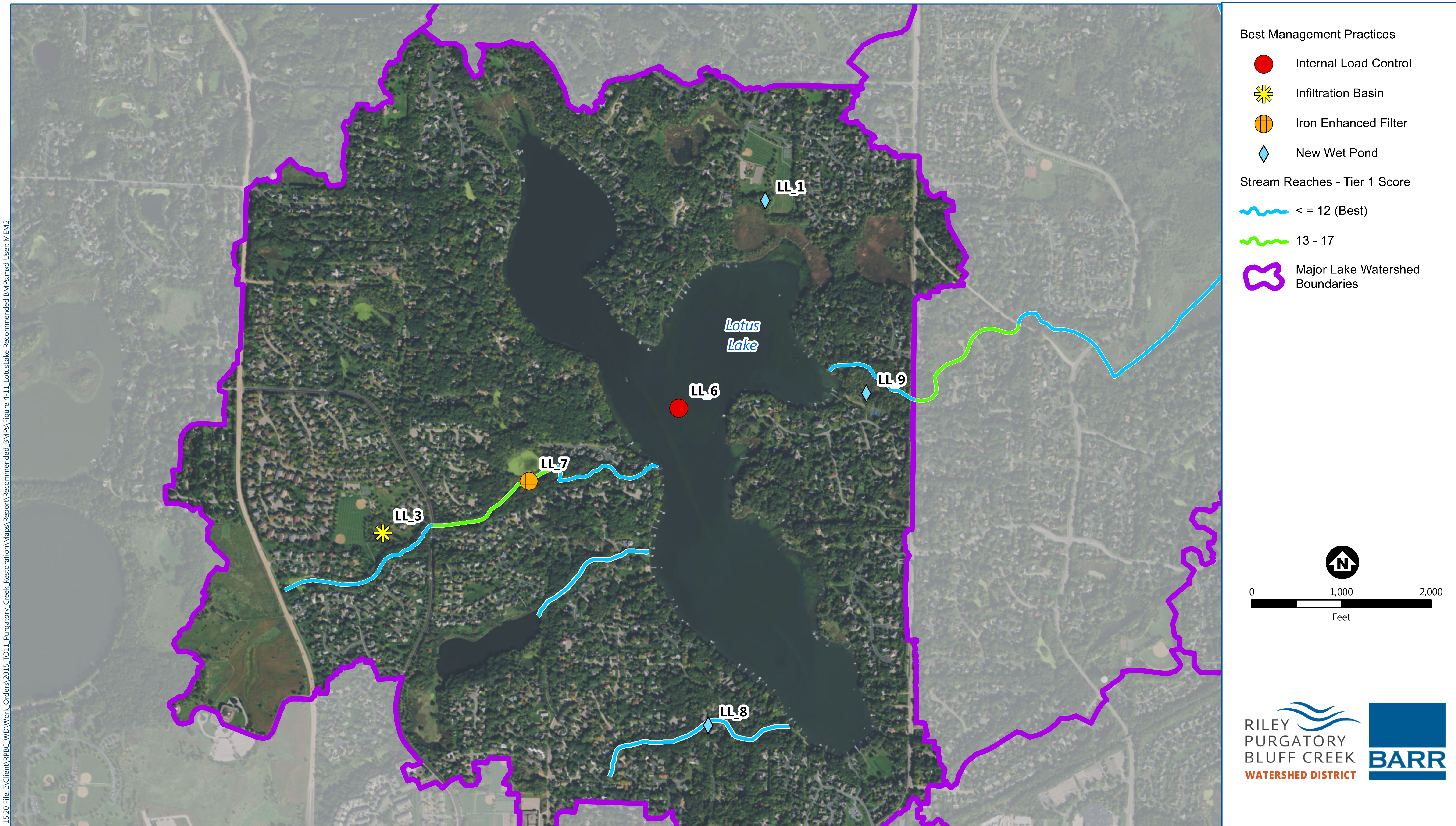
4.8.9 New wet pond in subwatershed Lotus_Lake, LL_9

BMP LL_9 is a new wet pond in subwatershed Lotus_Lake near Chanhassen Road and Choctaw Circle. This BMP would receive runoff from 4.2 acres of untreated impervious area. The site of the pond is currently a six-foot mound, which causes the excavation quantities to be significant and costly. This pond is proposed to be approximately 0.9 acres at the surface and about 4 feet deep. The pond would have one inlet from re-routed storm sewer, and one 30-inch outlet. Simulations suggest that the pond will remove 10 pounds of TP per year. Because this BMP is relatively close to Lotus Lake, the TP reduction to the lake is also estimated to be 10 pounds of TP per year. The cost-benefit of this BMP for Lotus Lake is estimated to be about $2,960 per pound of TP, assuming the BMP functions for 30 years. Because of the efficiency of the BMP, LL_9 is recommended for the watershed.

4.9 Recommendations for Water Quality Goal Attainment

To reach the water quality goal for Lotus Lake (Section 4.5.3), the water quality modeling results call for an overall TP load reduction of 399 pounds of TP per year. It is recommended that the TP load reduction is split between watershed load reduction (97 lbs/yr) and internal load reduction (302 lbs/yr). The recommended BMPs for Lotus Lake are listed below along with the percent of the overall load reduction goal that each individual BMP provides. The recommended BMPs are also shown in Figure 4.11. The TP reduction expected by the recommended watershed BMPs is 96.6 pounds per year if both LL_3 and LL_7 are constructed and 586 pounds per year internally. The summary below is intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment TP release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. This is consistent with the district's "ONE WATER Watershed Management Approach" (Section 2.3.4 of (RPBCWD, 2011)).

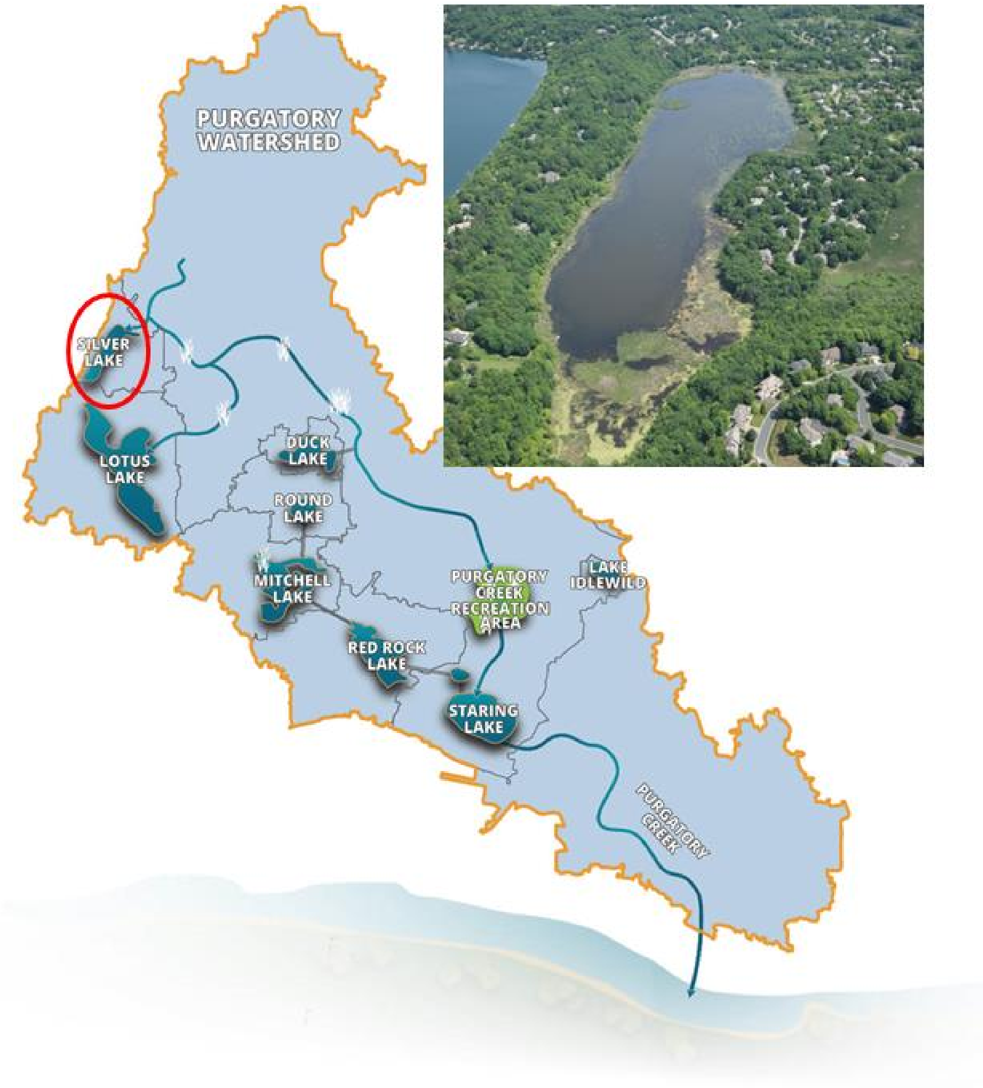
- LL_1, new wet pond in subwatershed Lotus_Lake, ~2% of the total load reduction goal
- LL_3, new infiltration basin in subwatershed LL-8E1, ~12% of the total load reduction goal if LL_7 is not installed. If both are constructed their combined removal is ~18% of the total load reduction goal.
- LL_6, internal load control in Lotus Lake, ~147% of the total load reduction goal
- LL_7, iron enhanced sand filter in subwatershed LL-8B, ~15% of the total load reduction goal if LL_3 is not installed. If both are constructed their combined removal is ~18% of the total load reduction goal.
- LL_8, new wet pond in subwatershed LL-11C1, ~2% of the total load reduction goal
- LL_9, new wet pond in subwatershed Lotus_Lake, ~3% of the total load reduction goal



RECOMMENDED BMPs, LOTUS LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 4.11

5.0 Silver Lake



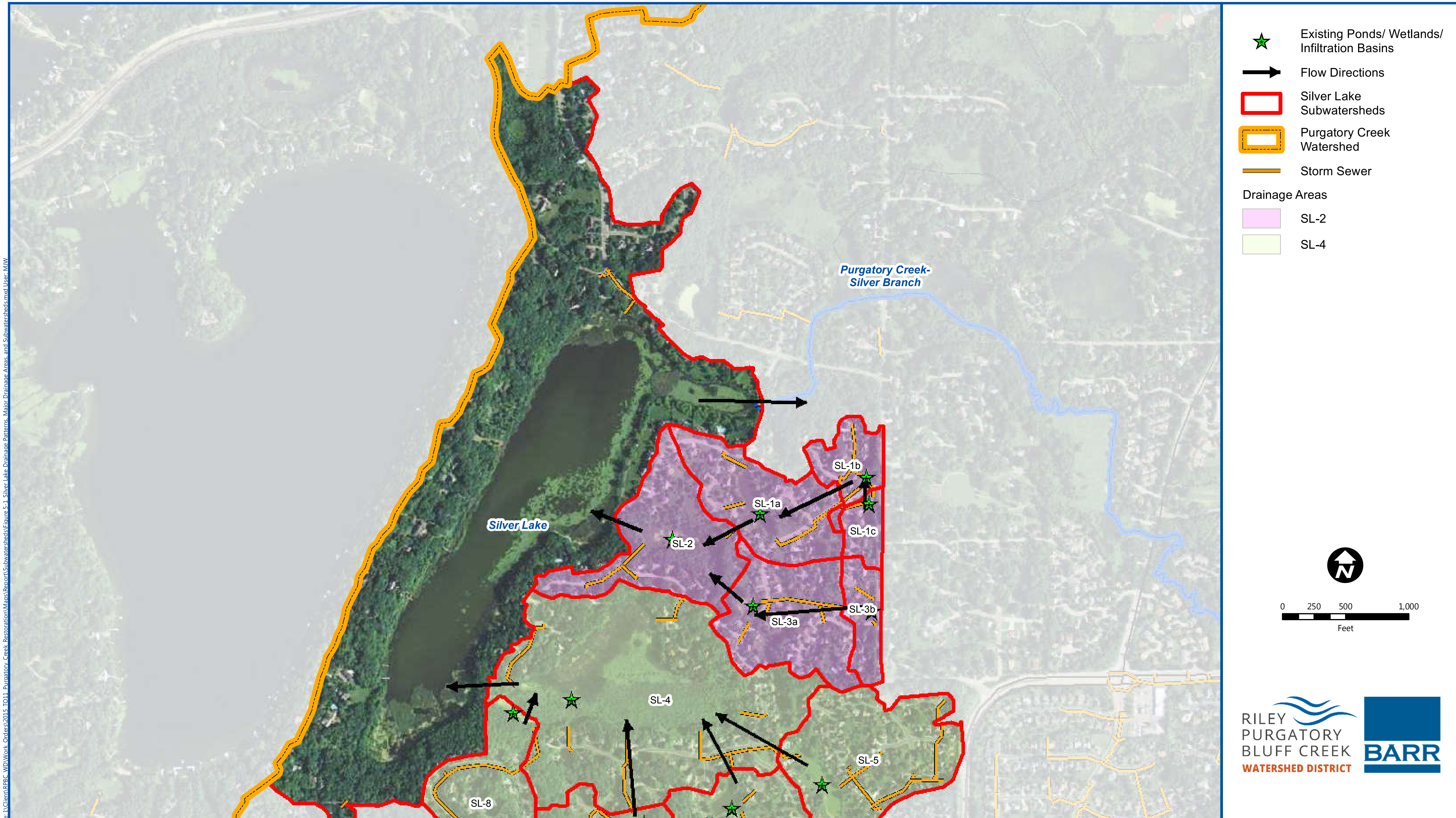
5.1 Watershed Characteristics

Silver Lake is one of two headwater lakes to Purgatory Creek. Silver Lake lies mostly within the boundaries of the City of Shoreview with the southern part of the watershed in the city of Chanhassen. The watershed area contributing runoff to Silver Lake is 407 acres including the lake surface area of 71 acres (Figure 5.1).

5.1.1 Drainage Patterns

The stormwater conveyance system in the Silver Lake watershed is comprised of storm sewer networks, constructed stormwater detention ponds, and natural wetlands within the watersheds tributary to the lake (Figure 5.1). Most of the constructed stormwater ponds within the Silver Lake watershed are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows.

The Silver Lake watershed was divided into subwatersheds based on updated topographical data (MDNR, 2011), storm sewer data, BMP locations, and other information from the cities of Shoreview and Chanhassen. The subwatersheds were grouped into 2 major drainage areas within the Silver Lake watershed (Figure 5.1). Each major drainage area is named after the terminating watershed in each conveyance network. The two contributing drainage areas each drain to existing wetlands before entering Silver Lake. In addition to the major drainage areas is the lakes direct watershed. The direct watershed includes areas along the shoreline of the lake that contribute flow directly to the lake through surface flow as well as small stormsewered sections that do not receive treatment before discharging into the lake.



SILVER LAKE SUBWATERSHEDS AND STORMSEWER ALIGNMENTS

FIGURE 5.1

5.1.2 Land Use

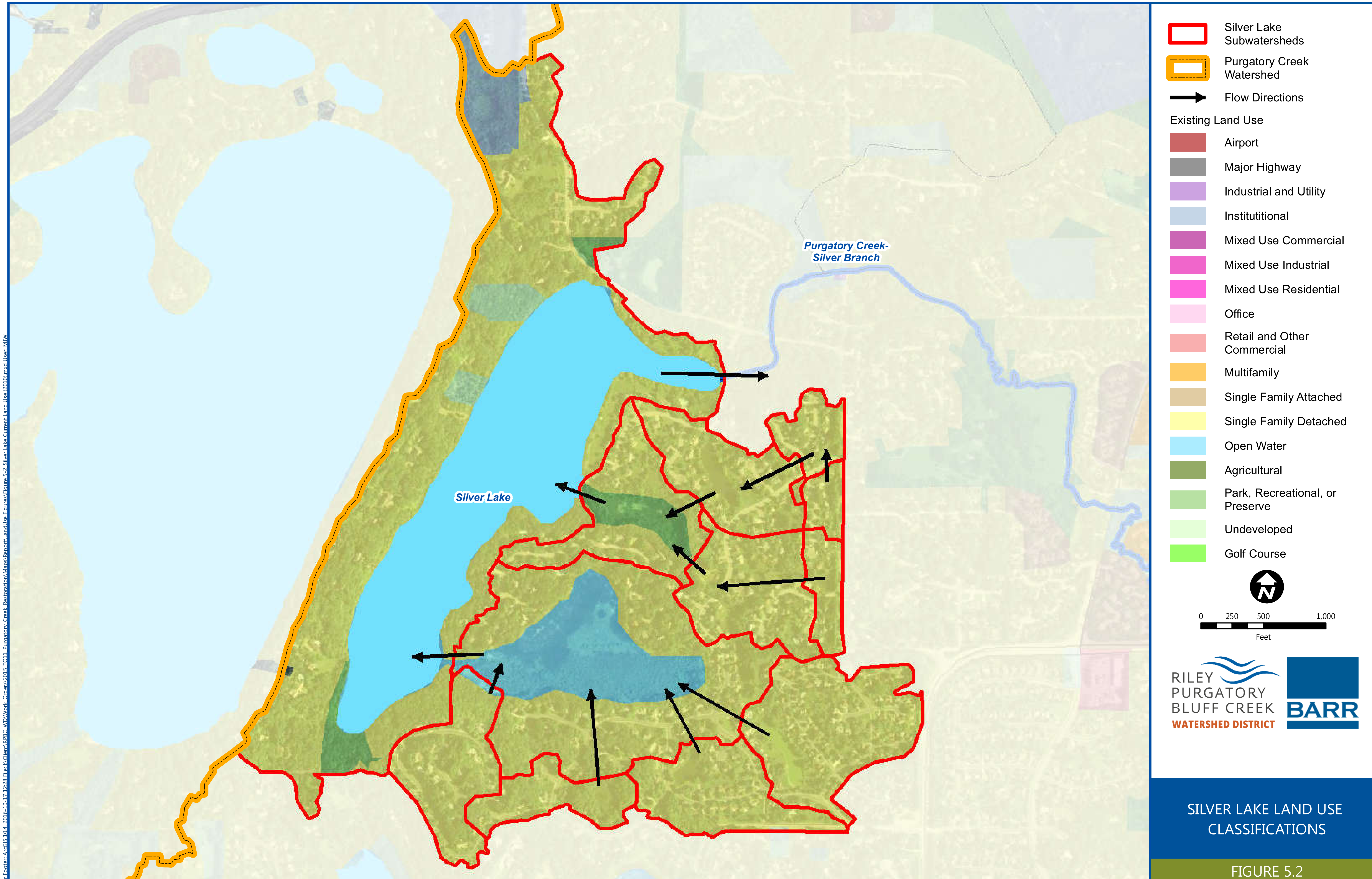
Land use within a lake's watershed can impact the hydrology and water quality of a lake. Varying land uses contribute different quantities of sediments and TP to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

Existing land-use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council. The land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix D.

The majority of the Silver Lake watershed is covered by single family residential land use (72%). Figure 5.2 shows the existing land uses present in the Silver Lake watershed.

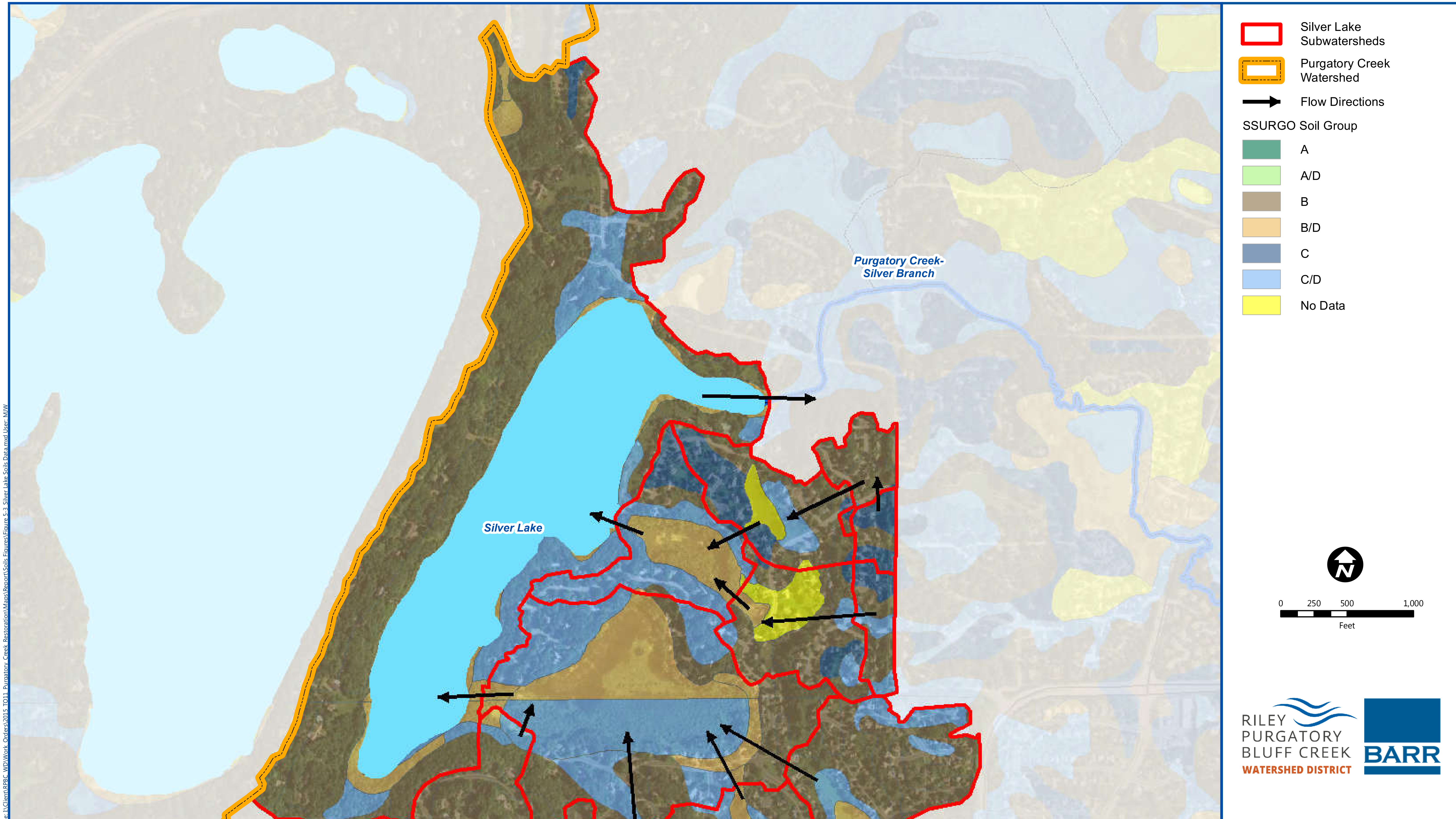
5.1.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database map for Carver and Hennepin counties, the underlying soils in the Silver Lake watershed are predominantly classified as hydrologic soil group (HSG) B with moderate infiltration rates (Figure 5.3). The remaining areas in the watershed near the two wetlands are coved by HSG C/D or B/D soils with low infiltration rates. High infiltration rate A soils are not present in the watershed besides a small section in the southern portion of the watershed.



SILVER LAKE LAND USE CLASSIFICATIONS

FIGURE 5.2



SILVER LAKE SOILS CLASSIFICATIONS

FIGURE 5.3

5.2 Lake Characteristics

Table 5.1 provides a summary of the physical characteristics for Silver Lake. Silver Lake has an open-water surface area of approximately 71 acres. The lake is shallow, with a maximum depth of approximately 14 feet and mean depth of approximately 5 feet. The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 901.03 feet mean sea level (MSL) (2012) to a low measurement of 894.78 feet MSL (1972). Since 2011 water levels in Silver Lake have averaged 899.3 feet mean sea level (MSL). The outlet of Silver Lake is a control structure that feeds into Purgatory Creek with a control elevation of 898.54. At the average water elevation of 899.3 feet the total water volume in Silver Lake is 190 acre-ft.

Table 5.1 Silver Lake Physical Characteristics

Lake Characteristic	Silver Lake
Lake MDNR ID	27-0136-00
MPCA Lake Classification	None
Water Level Control Elevation (feet MSL)	898.54
Average Water Elevation (feet MSL)	899.3
Surface Area (acres)	71
Mean Depth (feet)	5
Maximum Depth (feet)	14
Littoral Area (acres)	71
Volume (at normal water elevation) (acre-feet)	190
Thermal Stratification Pattern	polymictic
Estimated Residence Time (years) – 2014-2015 climatic Conditions	0.9
Watershed Area Tributary to Upstream Lake	0
Total Watershed Area	407[2]
Subwatershed Area (acres)	407[2]
Trophic Status Based on 2015 Growing Season Average Water Quality Data	Hypereutrophic

1 – Average water elevation 1911-2015.
2 – Watershed area includes surface area of lakes

Given the depth of Silver Lake and the review of temperature and dissolved oxygen profiles suggest that Silver Lake is a polymictic lake. This means that the lake mixes multiple times throughout the year from wind mixing events. Temperature stratification forms resulting in anoxic conditions near the lake sediments; however wind mixing events during the summer can occur which are strong enough to completely mix the lake water column providing oxygen to the sediments and mixing TP throughout the water column.

Silver Lake was classified as a wetland by the MPCA. Silver Lake has also been classified as a Type 5 wetland by the MDNR indicating that it is comprised of shallow open water (Barr Engineering, 2003). However, according to the Riley Purgatory Creek Water Management Plan, the District goals for Silver Lake are equivalent to the MPCA goals for a shallow Lake (CH2M HILL, 2011).

5.3 Water Quality Conditions

Historical water quality data, in terms of growing-season (June – September) average TP concentrations, chlorophyll *a* concentrations, and Secchi disc transparency for Silver Lake are presented in Figure 5.4. Also shown in these figures are the MPCA water quality standards for a shallow lake for each parameter. The growing season average TP concentrations consistently failed to meet the MPCA water quality standards throughout the record. The most recent growing-season average TP concentration in year 2015 was calculated as 85 µg/L which is higher than the RPBCWD goal of 60 µg/L. The 2015 value is the second lowest growing season average concentration on record since concentrations were recorded in 1996. The lowest TP concentration was 72 µg/L recorded in 2011. TP concentrations reached a maximum value of 210 µg/L in 2000.

Historically Chl-a concentrations in Silver Lake have exceeded the District goal of 20 µg/L every year on record. The 2015 growing season average concentrations was 36 µg/L, this was lowest value on record. The highest average value recorded was 220 µg/L in 2000.

Historical Secchi depths in Silver Lake have not achieved the goal of 1.0 meter. The growing season average Secchi depth in 2015 was 0.78 meters. This was the highest (best) value on record. The lowest (worst) value calculated was 0.22 meters in 2000.

Trends in the water quality data were determined by calculating a Thiel-Sen slope on the annual average growing season values and the significance of the trend was tested using the Mann-Kendall non parametric test at the 95% confidence internal. Improving trends are present in all three parameters when examining the record since 1999. The only trend that is statistically significant is for Secchi depth (Table 5.2).

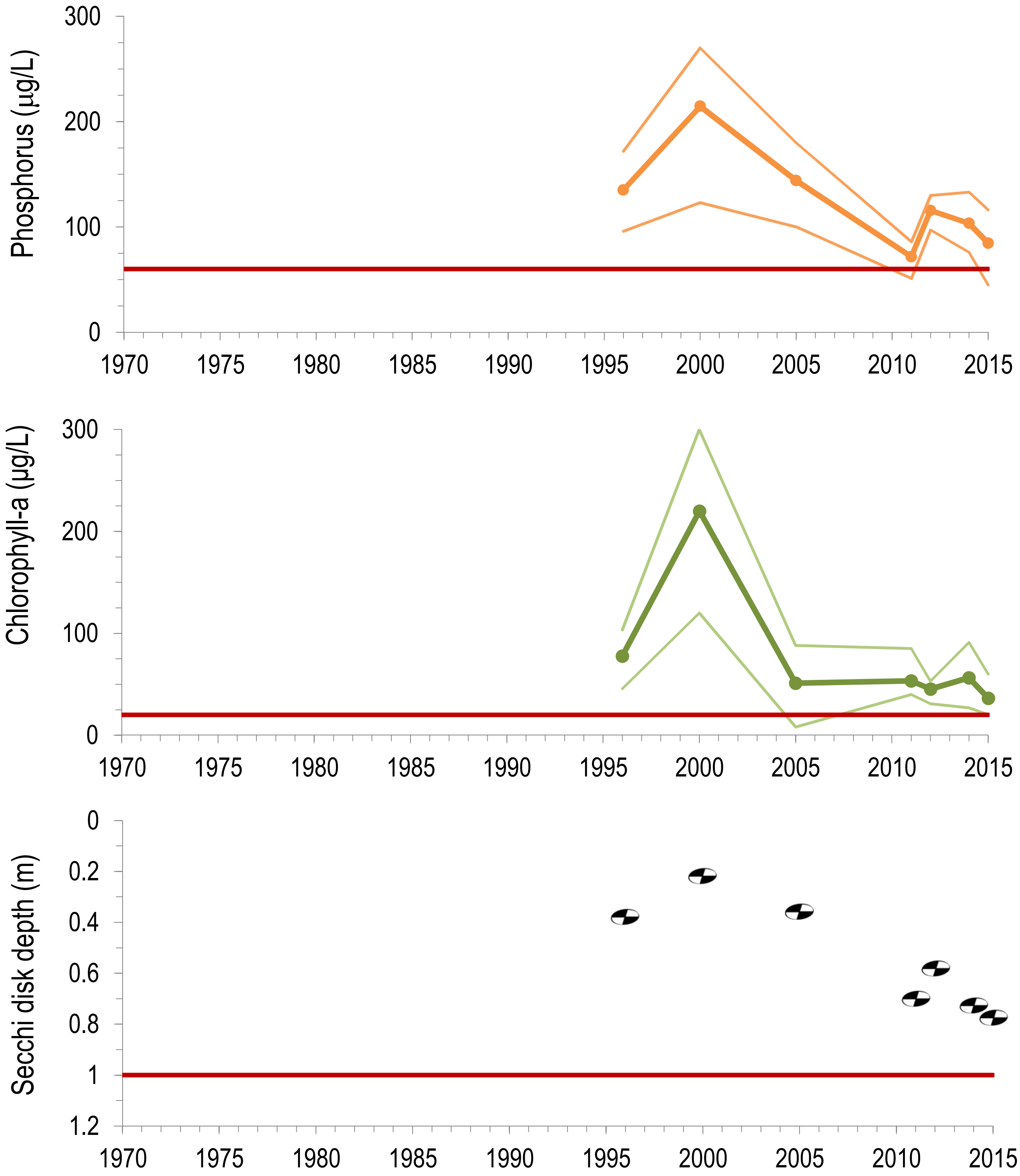


Figure 5.4
Silver Lake Water Quality Growing Season (June - September) Average, Min and Max Values

Table 5.2 Silver Lake water quality parameter Thiel-Sen trends for year 1999-2015

Parameter	1999-2015
TP (µg/L/yr)	-8
Chl-a (µg/L/yr)	-4.3
Secchi Depth (m/yr)	0.04*

Notes:
* Designates significant trends at the 95% confidence level using Mann-Kendall significance test

5.3.1 Paleolimnology

In 2014 the district contracted with St. Croix Watershed Research Station to use paleolimnological techniques to reconstruct the trophic and sedimentation history of Silver Lake (Ramstack Hobbs & Edlund, 2015). A sediment core was collected from the lake, and lead-210 activity was analyzed to develop a dating model and determine the sediment accumulation rate over the past 150 to 200 years.

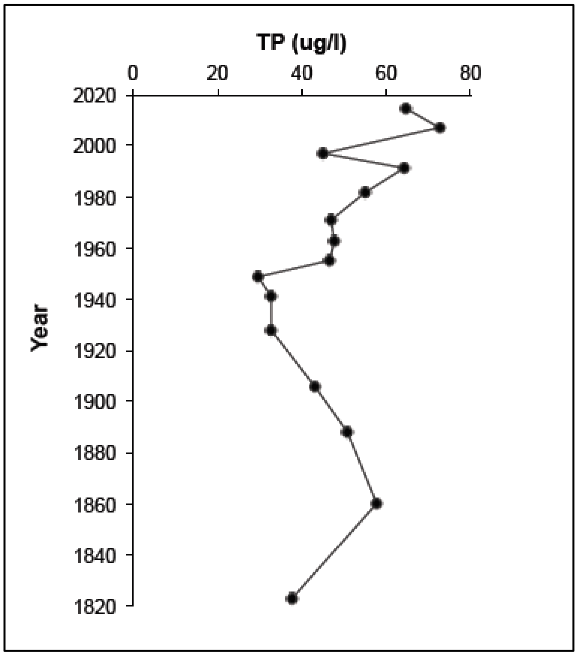


Figure 5.5 Silver Lake diatom-inferred TP reconstruction (Ramstack Hobbs & Edlund, 2015).

The data suggests that Silver Lake has been eutrophic for over 200 years with a rise in TP concentrations in recent years (Figure 5.5). Reconstructed TP concentration have risen since the 1950's to present with current (2015) concentrations higher than pre-settlement values.

5.3.2 Water Quality Relationships

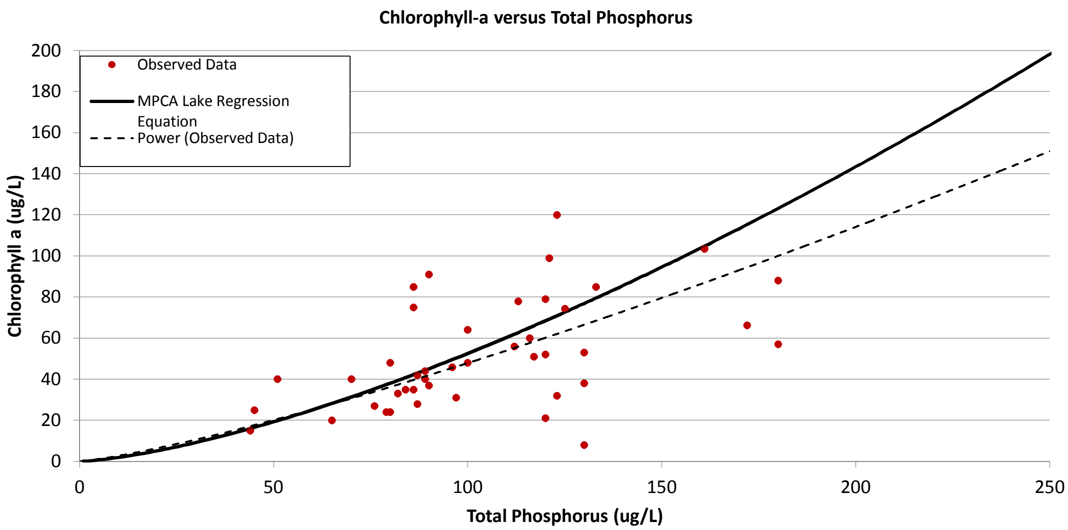
The compiled data for the water quality variables from Silver Lake were analyzed to develop relationships between the water quality parameters: TP, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season averages. In addition to developing the water quality relationships based on the observed data, the regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) were also plotted against the lake data.

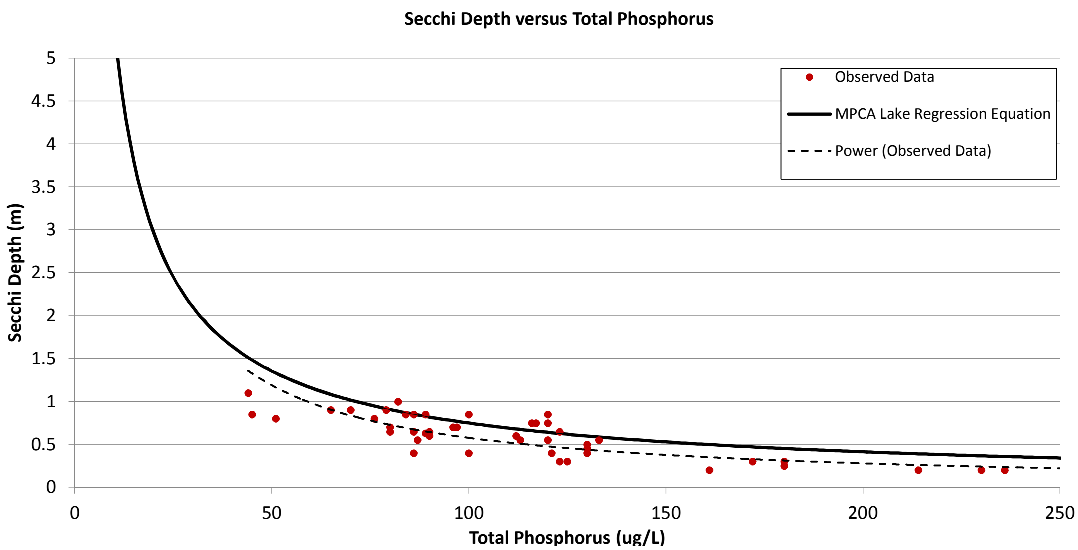
The relationships between the various water quality parameters for the actual Silver Lake data did indicate some correlation between the water quality parameters (Figure 5.6). The MPCA regression equations resulted in similar fit for the chlorophyll *a*, Secchi disc transparency data, and TP. For this reason the MPCA statewide regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Silver Lake based on TP concentration.

Figure 5.6 shows the individual water quality data points for Silver Lake, along with plots of the MPCA statewide regression equations.

The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla (µg/L) = 1.31 Log10 TP (µg/L) – 0.95
- Log10 Secchi (meters) = -0.59 Log10 Chla (µg/L) + 0.89
- Log10 Secchi (meters)= -0.81 Log10 TP (µg/L) + 1.51





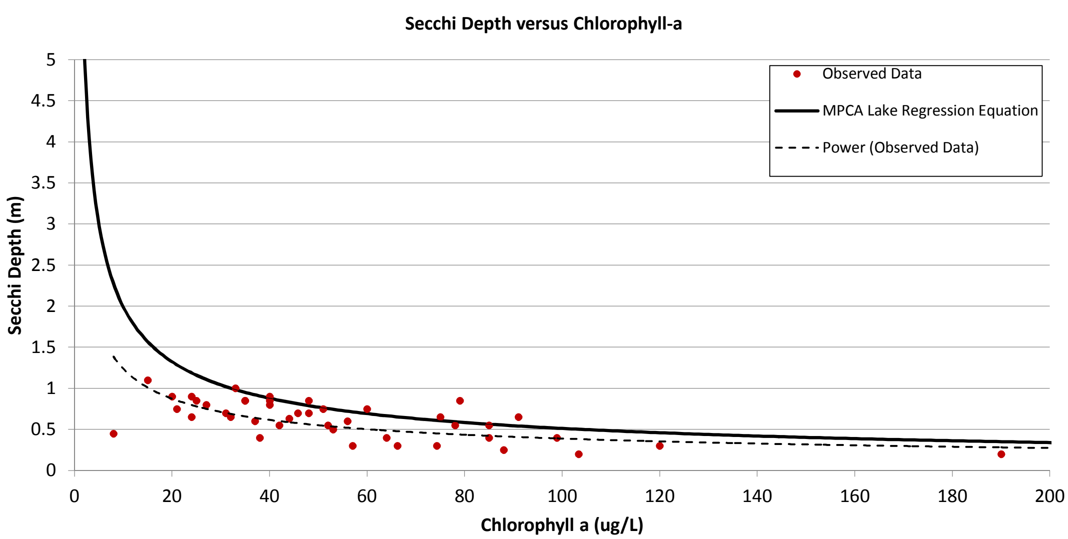


Figure 5.6
Silver Lake Individual Samples
Water Quality Parameter
Regression Relationships

5.4 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

5.4.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess TP loads.

RPBCWD has collected phytoplankton data in Silver Lake for years: 1996 and 2000. Additionally, phycocyanin (cyanobacteria (blue-green algae) pigment) readings have been collected in years 2011 - 2013. During the 1996 and 2000 plankton surveys cyanobacteria were the most abundant plankton species throughout the monitoring months (Barr Engineering, 2003). Peak algae volumes were found during the month of August with higher algae volumes observed in the 2000 survey than the 1996 survey.

While green algae are edible to zooplankton and serve as a valuable food source, cyanobacteria are considered a nuisance type of algae because they:

- Are generally inedible to fish, waterfowl, and most zooplankters
- Float at the lake surface in expansive algal blooms
- May be toxic to animals when occurring in large blooms
- Can disrupt lake recreation because they are most likely to be present during the summer months

5.4.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or

enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

The most recent analysis of zooplankton in Silver Lake occurred in years 1996 and 2000 (Barr Engineering, 2003). The zooplankton population was dominated by small bodied organisms that were unable to control algal growth. Large bodied zooplankton (cladocera) compromised less than 1% of the total zooplankton community for both surveys. The low numbers of zooplankton have minimized the biological control of the lake's phytoplankton populations.

5.4.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

Plant surveys were conducted in Silver Lake during 1996, 2000, 2005 and most recently in 2013. Each survey found the presence of two invasive species curlyleaf pondweed and purple loosestrife. Curlyleaf pondweed was found at low to moderate densities in the lake. Purple loosestrife was found to be dense in the northern end of the lake. All of the plant surveys also found the presence of wild rice dispersed around the lake.

The presence of wild rice is a unique feature that will require protection and/or enhancement. MPCA is currently undergoing rule revisions for its sulfate standard, which is intended to protect wild rice waters and formalize how wild rice waters are designated. Based on field data collected from 108 lakes as part of the Wild Rice Study, the MPCA concluded that three independent variables are correlated with wild rice occurrence. They include porewater sulfide, water transparency, and water temperature. Furthermore, through analysis of field data from the Wild Rice Study, structural equation modeling, the MPCA concluded that sediment concentration of total organic carbon (TOC) and total extractable iron (TEFe) affect the relationship between sulfate and sulfide. Therefore, the MPCA is developing a strategy that relies on sulfate, TOC, and TEFe to assure that sulfide concentrations remain in the porewater at levels protective of wild rice. The MPCA also acknowledges that other factors are known to influence wild rice including invasive species (e.g. carp), water movement, ground water inflows, perennial vegetation, abrupt changes in water level, climate change, and residential development. Silver Lake is not currently listed as a wild rice water and it isn't clear if the wild rice density would meet the MPCA's draft criteria which requires that a lake, stream or wetland must have at least one of the following attributes:

- It contains a natural bed of wild rice of at least:
    - 0.25 acres in an area with stem density of at least 8 stems per square meter; or
    - 0.5 acres in an area with a stem density of ate least 4 stems per square meter
- It has a documented history of wild rice harvest occurring after November 28, 1975.

5.4.4 Fishery

Fish surveys have not been conducted recently on Silver Lake by the MDNR. The MDNR believes that Silver Lake is unsuitable for gamefish (Barr Engineering, 2003). Silver Lake was previously stocked with fish between 1916 and 1943. Fish stocking ceased in 1943. A carp fish survey conducted by the University of Minnesota in 2011 and 2012 found zero occurrences of carp in Silver Lake (Sorensen, et al., 2015).

5.5 TP Source Assessment

Watershed and in-lake water quality models were developed to assess both the external and internal TP loads in Silver Lake for the 2015 water year (October 2014 – September 2015). A detailed discussion of the modeling methods used is presented in Section 2.2.2 and Appendix D. Possible lake external loads of TP include atmospheric deposition, stormwater runoff from the lake watershed, erosion from ravines/channels contributing to the lake, surficial groundwater interactions with the lake waters and internal loads from upstream ponds and wetlands.

External loads that applied to Silver Lake are atmospheric deposition and watershed loads. Based on the 2015 water balance it appeared that there was no net surficial groundwater inflow meaning the inflow of groundwater likely equals the outflow, Silver Lake is not downstream from another major waterbody/lake, and small channels with erosion potential contribute to the lake. Internal loading within the ponds and wetlands was not evaluated for this study. Internal TP loads can come from sediment TP release, curlyleaf pondweed, or benthivorous fish activity.

Figure 5.7 summarizes the 2015 annual water year TP budgets for Silver Lake, including the relative contributions of the external and internal TP loads. This budget explains the sources of TP to the lake and help inform implementation strategies. Each of the sources are discussed further in the following section(s).

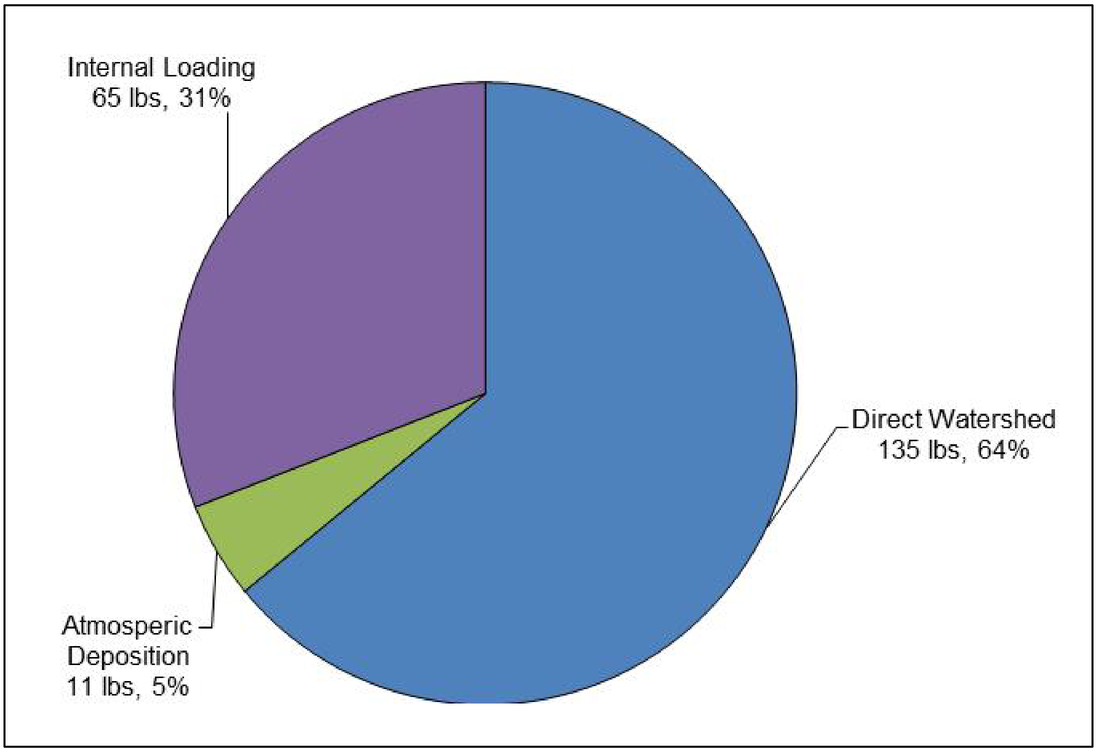


Figure 5.7 Silver Lake TP load sources for 2015 water year

5.5.1 External Loads

5.5.1.1 Atmospheric Deposition

Atmospheric deposition of TP onto the lake water surface was calculated by using the estimated statewide TP atmospheric deposition rate of 0.17 kg/ha/year (Barr Engineering, 2004). For Silver Lake, this loading rate was applied to the combined open water area. The daily rate was applied to the surface area of the lake based on the modeled lake water elevation from the lake water balance model. The resulting atmospheric deposition TP load for the 2015 water year was 11 pounds which amounted to 5% of the TP load to Silver Lake (Figure 5.7).

5.5.1.2 Watershed Loads

The P8 watershed model estimated surface runoff from Silver Lake's subwatersheds (not passing through upstream lakes) based on observed climatic data (precipitation and temperature). The total untreated watershed load from the watersheds in Silver Lake for the 2015 water year was modeled to be 181 pounds. The watershed load travels through existing stormwater ponds, wetlands, infiltration practices, and other BMPs located throughout the watershed providing treatment resulting in a load of 115 pounds reaching the lake. This represents a 37% removal being provided by existing treatment practices in the watershed. An additional 20 pounds of TP was estimated through erosion estimates along the steep slopes west of Silver Lake. With the addition of the erosion estimates the total load reaching Silver Lake from watershed sources were determined to be 135 pounds TP representing 64% of the total annual TP load to Silver Lake (Figure 5.7).

To help evaluate areas that might benefit from additional treatment watershed loads to the lake were calculated for each of Silver Lake's individual subwatersheds. The load to the lake is defined as the amount of TP load from that watershed reaching the lake without being removed by an existing BMP within the subwatershed or downstream from the subwatershed. The P8 results were used to calculate the total annual average untreated watershed TP loads from each subwatershed. Next the watershed load to the lake was calculated. This was accomplished by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each subwatershed that reached the lake without being removed by an existing BMP. The watershed load to the lake for each subwatershed is shown in Figure 5.8.

5.5.2 Internal Loads

Internal loading in Silver Lakes represented 31% (65 pounds) of the TP load in the 2015 water year (Figure 5.7). The internal loading sources to Silver Lake appear to be primarily from sediment P release with minor influence from curlyleaf pondweed.

5.5.2.1 Curlyleaf Pondweed

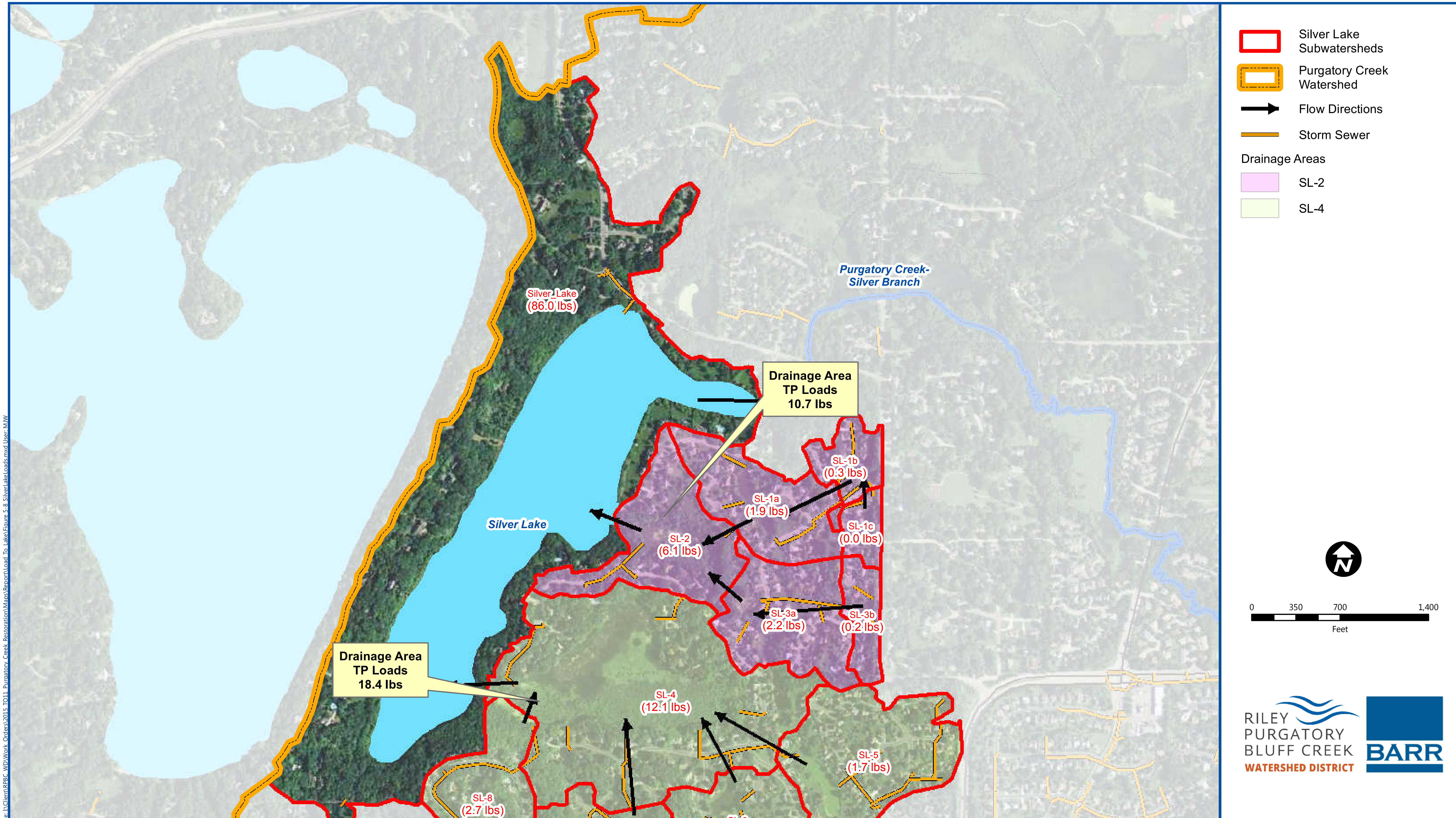
Because of the relatively low occurrence in Silver Lake TP loading from curlyleaf pondweed was not explicitly modeled for this study. The internal loading calibration parameter was used to simulate this release along with other sources of internal loading.

5.5.2.2 Benthivorous Fish Activity

In fish surveys of Silver Lake in 2011 and 2012 by the University of Minnesota zero adult or young carp were found (Sorensen, et al., 2015). As a result, this analysis assumes that the activities of carp and other benthivorous fish are not a significant source of TP in Silver Lake and were not quantified as part of the in-lake water quality modeling in 2015.

5.5.2.3 Sediment Release

Due to the determination that loading due to curlyleaf pondweed and benthivorous fish are negligible, the entire modeled internal loading rate was applied to sediment phosphorus release. Internal loading through sediment release occurs during anoxic conditions. A review of dissolved oxygen profiles in Silver Lake showed periodic anoxic conditions in the sediments reaching a depth of 6.6 feet from the lakes water surface during the middle summer months. Anoxic conditions are present at times during the summer months, but wind mixing regularly occurs re-oxygenating the lakes sediments and distributing any internal load of TP throughout the water column.



SILVER LAKE SUBWATERSHED TP LOADS TO THE LAKE

FIGURE 5.8

5.5.3 TP Load Reductions

The in-lake model was used to determine TP load reductions needed to meet the water quality goal for Silver Lake. Table 5.3 shows the measured and modeled growing season average (June – September) concentration, the TP load to the lake under existing conditions, the water quality goal, the TP loading capacity for meeting the water quality standard and the required percent reduction needed to meet the TP goal. Under existing conditions Silver Lake is not meeting the water quality goal for a shallow lake of 60 µg/L. Modeled and measured growing season average concentrations in the lake surfaces waters for the 2015 water year was 91 µg/L and 85 µg/L respectively. Silver Lake was modeled as a completely mixed waterbody. Therefore the modeled concentrations represent the volumetric average concentrations for the entire water column. The TP load under existing conditions was 214 pounds for the 2015 water year. To achieve the TP goal the load to Silver Lake would need to be reduced to 179 pounds, resulting in a 16% TP load reduction.

Table 5.3 Silver Lake estimated load reductions required to meet TP water quality goal for 2015 water year

Measured growing season average TP concentration (µg/L)	Modeled growing season average TP concentration (µg/L)	Estimate 2015 TP loading rate (lbs/yr)	TP concentration goal (µg/L)	Estimated Loading Capacity to meet WQ goal (lbs/yr)	Percent reduction needed to achieve goal (%)
85	91[a]	214	60	179	16%

[a] Volumetric average concentration for entire water column

Figure 5.9 shows how lake concentrations react to lake TP load reductions. The calibrated in-lake TP model was used to determine in-lake water quality based on the amount of TP load to the lake. TP concentrations were calculated using the in-lake model. Chl-a and Secchi depth concentrations were determined based on the water quality relationships discussed in Section 5.3.2. The figure shows how incremental load reductions would impact the water quality in Silver Lake. A TP load reduction of 30 pounds could reduce the lake TP concentration to 65 µg/L. A TP load reduction of 50 pounds could reduce the lake concentration to 47 µg/L.

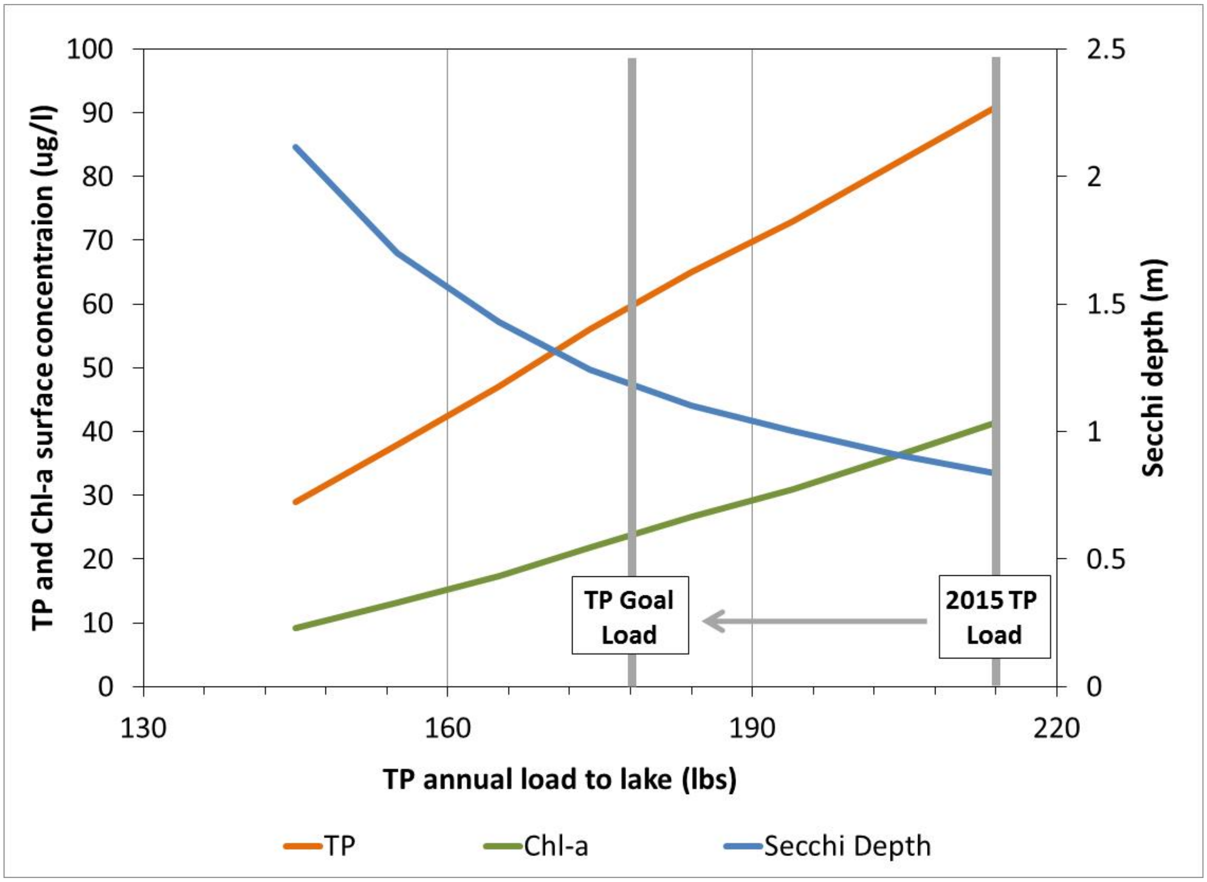


Figure 5.9 **Silver Lake TP load relationship with lake water quality (TP, Chl-a and clarity)**

5.6 Summary of Diagnostic Findings

Table 5.4 provides a summary of the key water-quality findings for Silver Lake.

Table 5.4 Diagnostic Findings for Silver Lake

Topic	Silver Lake
Water Quality Standards and Goals	- Classified as a wetland by MPCA - Does not meet RPBCWD goals or long term vision
Baseline Water Quality	- Water quality concentrations are elevated above reconstructed concentrations from predevelopment time periods
Water Quality Trends	- Significant improving trend in Secchi Depth since 1999. - No significant trends in TP of Chl-a
Watershed Runoff	- Represents approximately 64% of annual TP load - Watershed load estimated to be reduced by 37% by existing BMPs, ponds, and wetlands located throughout the watershed.
Macrophyte Status	- Wild rice is an unique macrophyte found at various locations in the lake and will require protection and/or enhancement - Curlyleaf pondweed is present in low densities
Fishery Status	- Believed to be unsuitable for game fish - No carp found in recent U of M survey
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer
Internal Loading from sediments	- Anoxic conditions above deep sediment found during summer months. Wind mixing events are strong to periodically re-oxygenate sediments during summer months. - Internal loading from sediment estimated to be 31% of annual TP load
Methylmercury in Fish Tissues	- No studies have been conducted, not currently listed as impaired - No consumption advisories

Additional discussion of the diagnostic findings in relation to the sources of TP and water quality of the lake based on the data analyses, watershed and in-lake modeling, and review of recent studies and information is included. These conclusions influenced the implementation strategies evaluated for the management of Silver Lake water quality (see Section 5.8).

- Approximately 52 percent of the watershed of Silver Lake receives treatment prior to entering Silver Lake due to the number of stormwater ponds and other waterbodies within the watershed. As stormwater runoff passes through the constructed stormwater ponds and natural wetlands in the watershed, removal of TP associated with particulates in the runoff occurs due to particle settling and infiltration. Modeling suggests that 37% of the watershed load is removed by existing BMPs or wetlands before reaching Silver Lake. Some areas surrounding the lake remain untreated and should be examined for treatment potential. In addition erosion along the steep slopes on the west side of the lake have been detected and are areas to consider for further TP load reduction.

- The watershed phosphorous load to Silver Lake represented 64 percent of the total annual TP budget to the lake during the 2015 water year, internal loading represented another 31 percent of the total annual TP budget (see Figure 5.7)

- Water quality data collected along the depth profile of Silver Lake indicates that the interface along the bottom sediments can become anoxic during the summer supporting that internal loading is a source of TP in Silver Lake. Regular wind mixing event throughout the summer months appear to redistribute the internal TP load into the water column periodically.

- Figure 5.8 shows the estimated TP loading from the major drainage basins in the Silver Lake watershed. The watershed modeling suggests that 75 percent of the watershed load to Silver Lake is from Silver's Lake direct watershed. The other 25 percent of the load passes through existing ponds and wetlands before reaching Silver Lake. Silver Lakes direct drainage area appears to provide the best opportunity for the implementation of additional watershed BMPs to reduce the TP load.

- Wild rice is present in Silver Lake at various locations which is a unique feature that may require management actions to protect or enhance habitat. The most recent plant surveys in Silver Lake also indicate that invasive species curlyleaf pondweed and purple loosestrife were found in the lake.

- The carp population was analyzed in Silver Lake in 2011 and 2012 as part of the University of Minnesota's study for Purgatory Creek (Sorensen, et al., 2015). Zero occurrences of carp either adult or young were found in Silver Lake.

5.7 Current and Past Management Actions

The following includes a summary of BMPs either implemented or analyzed in the Silver Lake watershed:

- A sanitary sewer line adjacent to Silver Lake was repaired in 2011 for leaks. The leaks resulted in groundwater and/or Silver Lake water entering the sanitary sewer pipe. Sanitary water was not recorded as leaking out of the pipe into Silver Lake. The pipe will be inspected again in 2016 (correspondence with Metropolitan Council May 5, 2015).
- BMP and mitigation measures suggested for Silver Lake as part of the "One Water" Water Management Plant (CH2M HILL, 2011) included:
    - control curlyleaf pondweed mechanically and through herbicide treatment,
    - control internal loading of phosphorus and mercury methylation through oxygenation, aeration, sediment oxygenation or a combination of methods,
    - control purple loosestrife with beetles,

- control cyanobacteria through destratification,
- and control phytoplankton through bio-manipulation and fisheries management

- Pond 41, analyzed in the Silver Lake watershed over years 2012 and 2013, was determined to have TP concentration above 0.250 mg/l and could benefit from remediation measures (RPBCWD, 2014).
- Carp were not found in Silver Lake as part of surveys conducted in 2011 and 2012 (Sorensen, et al., 2015).

5.8 Evaluation of Water Quality Improvement Options

All of the BMPs identified for Silver Lake are listed and described in detail in the following subsections. Table 5.5 provides a list of the potential BMPs and Figure 5.10 shows the identified potential BMP locations in the Silver Lake watershed.

5.8.1 Underground filtration in subwatershed Silver_Lake, SiL_1

BMP SiL_1 is a buried pre-cast container in subwatershed Silver_Lake at the north end of Silver Lake along Covington Road, filled with a sand filter material, designed to treat 6.0 acres of impervious area. There may already be a grit chamber in this location designed to settle out solids. If this is the case, the grit chamber may be retrofitted to be converted to a sand filter. This underground sand filter is proposed to be approximately 0.6 acres and about 1.5 feet deep. Simulations indicate the sand filter could reduce the annual TP loading to the lake by 16.3 pounds of TP per year based on 30-year modeling results. The cost-benefit of this BMP for Silver Lake is estimated to be about $2,650 per pound of TP, assuming the BMP functions for 30 years.

5.8.2 Sand filter in subwatershed Silver_Lake, SiL_2

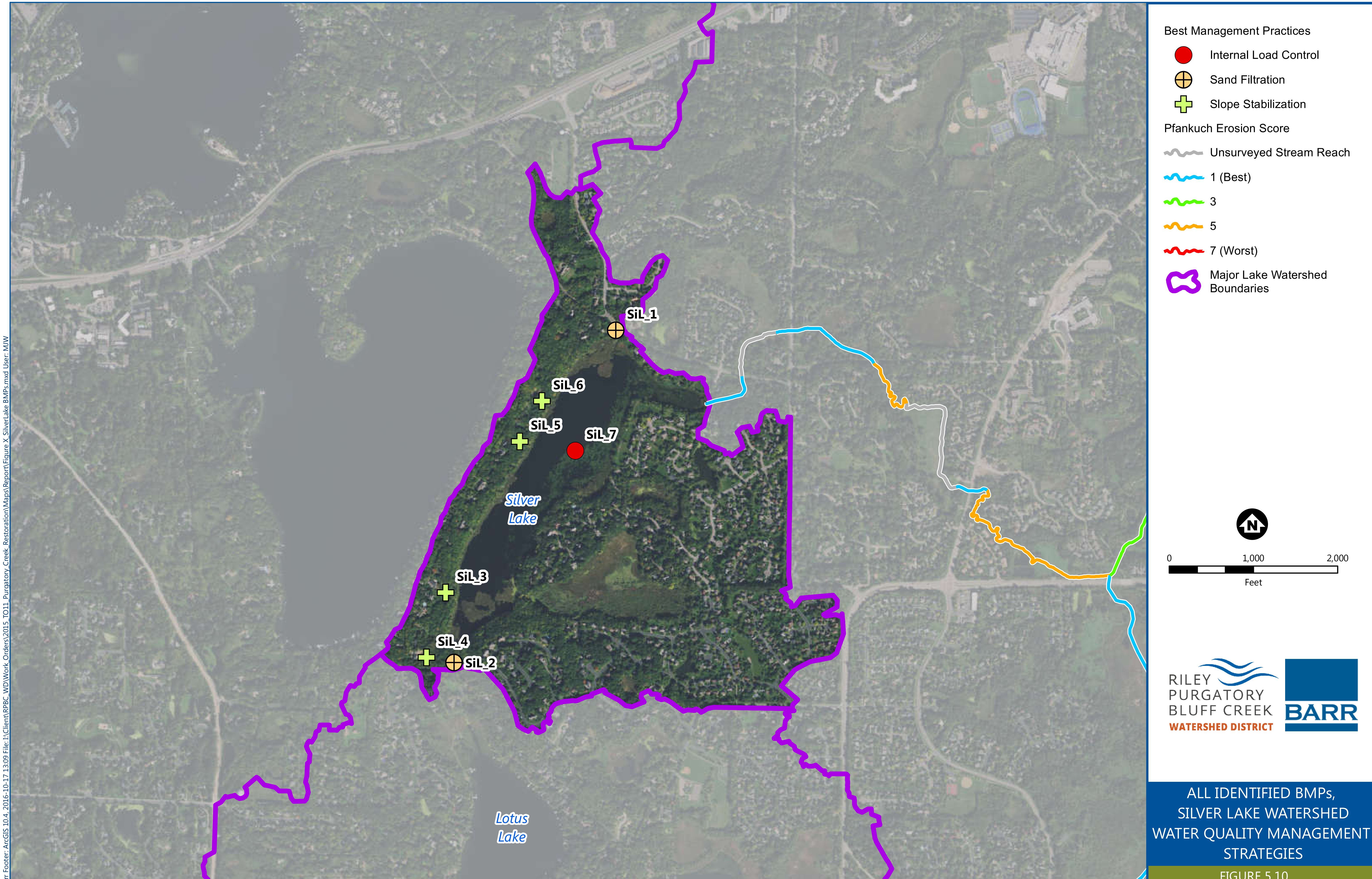
BMP SiL_2 is a sand filter in subwatershed Silver_Lake just north of Pleasantview Road. This BMP is designed to treat runoff from impervious areas along Pleasantview Road and Ridge Road. This sand filter is proposed to be approximately 0.4 acres at the surface. The road runoff would be routed to the sand filter which would filter out solids and particulates and slow down the flow before it runs down the slope and into Silver Lake. The BMP would have two 18-inch inlets and SAFL Baffles, and one 27-inch outlet. The sand filter could potentially remove 6.3 pounds of TP per year and reduce the annual loading to Silver Lake by a similar amount. The cost-benefit of this BMP is estimated to be about $4,530 per pound of TP, assuming the BMP functions for 30 years.

Table 5.5 - Summary of Silver Lake BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
SiL_1	Underground Filtration - *Construct / retrofit a 0.6 acre, 1.5-foot deep underground iron enhanced sand filter designed to treat 6.0 acres of impervious area*	16.3	16.3	47%	$810,700 ($649,000 - $1,135,000)	$16,200 ($13,000 - $22,700)	$2,650 ($2,120 - $3,710)	$2,650 ($2,120 - $3,710)
SiL_2	Sand Filter - *A 0.4-acre area that treats road runoff before it runs down the slope to Silver Lake*	6.3	6.3	18%	$534,700 ($428,000 - $749,000)	$10,700 ($8,600 - $15,000)	$4,530 ($3,620 - $6,340)	$4,530 ($3,620 - $6,340)
SiL_3	Slope Stabilization - *Stabilization of an eroding slope*	16	10	29%	$86,000 ($43,000 - $172,000)	$1,700 ($900 - $3,400)	$290 ($140 - $570)	$460 ($230 - $910)
SiL_4	Slope Stabilization - *Stabilization of an eroding slope*	6	3	9%	$80,000 ($40,000 - $160,000)	$1,600 ($800 - $3,200)	$710 ($360 - $1,420)	$1,420 ($710 - $2,840)
SiL_5	Slope Stabilization - *Stabilization of an eroding slope*	6	4	11%	$80,000 ($40,000 - $160,000)	$1,600 ($800 - $3,200)	$710 ($360 - $1,420)	$1,070 ($530 - $2,130)
SiL_6	Slope Stabilization - *Stabilization of an eroding slope*	4	3	9%	$52,000 ($26,000 - $104,000)	$1,000 ($500 - $2,100)	$680 ($340 - $1,370)	$910 ($460 - $1,820)
SiL_7	Internal Load Control - *Two treatments of a sediment-phosphorus precipitant*	52	52	149%	$332,000 ($266,000 - $464,000)	$0	$210 ($170 - $300)	$210 ($170 - $300)

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. Overall load reduction goal for Silver Lake is 35 pounds of phosphorus per year.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.



ALL IDENTIFIED BMPs, SILVER LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 5.10

5.8.3 Slope stabilization in subwatershed Silver_Lake, SiL_3, SiL_4, SiL_5, & SiL_6

There are multiple opportunities for reducing erosion on the west side of Silver Lake, and BMPs SiL_3 through SiL_6 are all slope stabilization BMPs. One of these locations is visible through aerial photography, and the other three have been selected based on LiDAR contours and site visits. The specific locations can be seen in Figure 5.11. The cost estimates for these are rough estimates because the extent of the work that would be needed to stabilize the slopes is unknown. At this point, the cost is assumed to be $400 per lineal foot of slope, a cost estimate similar to that of creek restoration and stabilization. Because of the erosion that is occurring from the steep western slope of Silver Lake, and the subsequent TP that is loading the lake with each erosive event, these BMPs are recommended for the watershed.

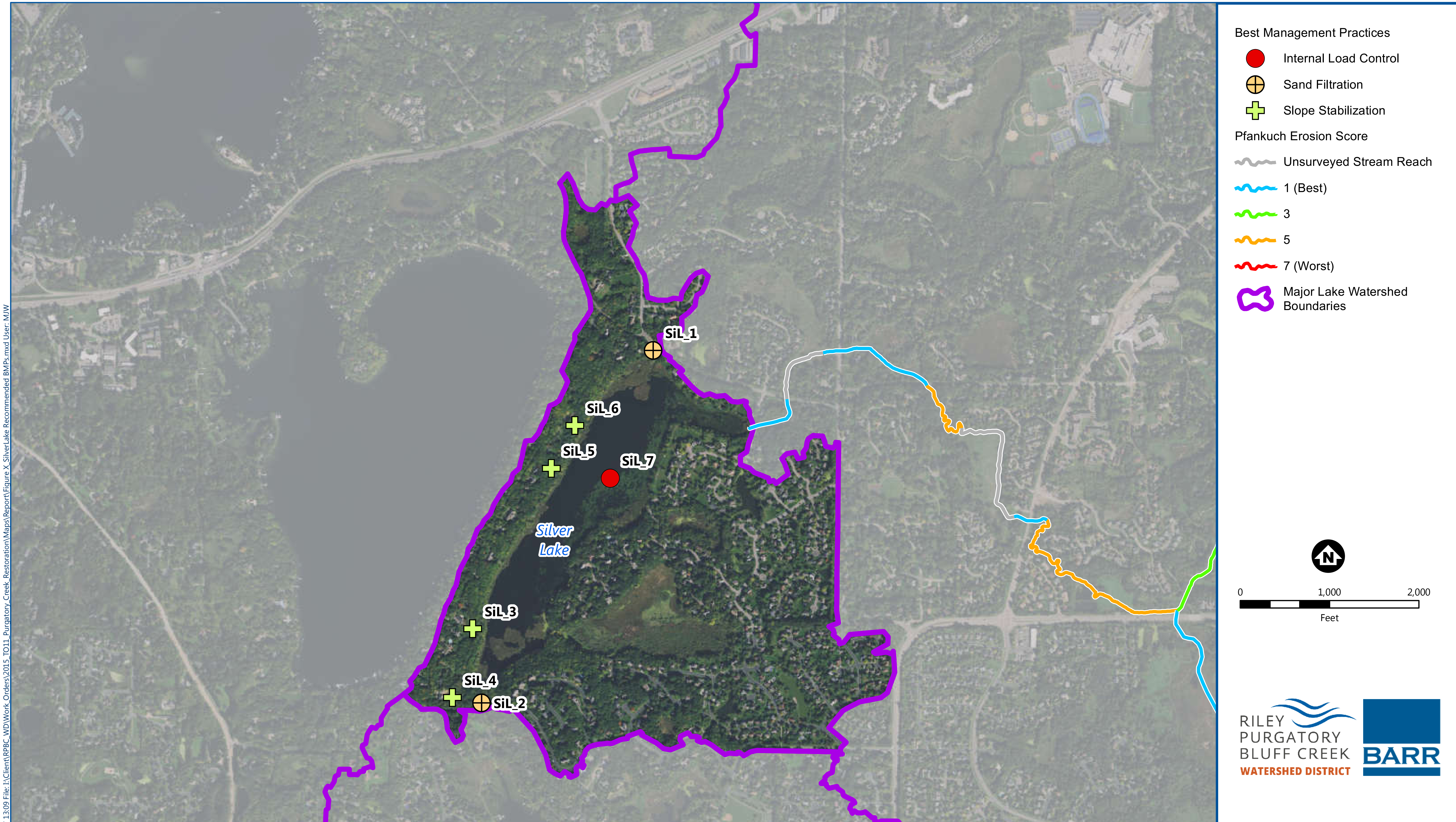
5.8.4 Internal load control in Silver Lake, SiL_7

BMP SiL_7 is a method for reducing the internal loading within the lake. Because of the unique presence of wild rice, a standard alum treatment is likely not appropriate for the lake. The treatment proposed for Silver Lake would involve an alternative sediment-phosphorus precipitant that would not adversely affect the sediment sulfide concentration. The treatment within the lake is expected to initially reduce the internal TP loading by approximately 80% (Welch & Cooke, 1999), resulting in a reduction of 52 pounds per year. The dose needed to achieve this reduction is estimated to be approximately 580 gallons per acre, based on 2005 samples of mobile phosphorus in the sediment cores of Silver Lake (Barr Engineering, 2005). In addition, the soft substrate on the lake bottom could impact the dosing rate and effectiveness of a sediment-phosphorus precipitant. This migration could enhance the treatment by inactivating a large portion of the phosphorus in the sediment as the material move through substrate rather than only the phosphorus in the top few centimeters. Additional laboratory testing is needed to assess the potential migration of the material into the substrate. The cost-benefit of this BMP is estimated to be about $210 per pound of TP, assuming treatment is not needed again for at least another 15 years (Huser, et al., 2015). Two treatments will likely be needed over 30 years and the total cost of both treatments is estimated to be $332,000 (Table 5.5). Because of the significant load reduction and the low cost, BMP SiL_7 is recommended for the lake after external loads are controlled in order to maximize the design life of the application.

5.9 Recommendations for Water Quality Goal Attainment

The overall load reduction for Silver Lake is recommended to be 35 pounds of TP per year to achieve the district's TP goal (Section 5.5.3). The recommended BMPs for the Silver Lake watershed are in the bullet list below along with the percent of the overall load reduction goal that each individual BMP provides. The recommended BMPs are also shown in Figure 5.11. The total reduction expected by the recommended BMPs is 42.6 pounds per year from the watershed, and 52 pounds per year internally. The summary below is intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment phosphorus release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. This is consistent with the district's "ONE WATER Watershed Management Approach" (Section 2.3.4 of (RPBCWD, 2011)).

- SiL_1, underground sand filter in subwatershed Silver_Lake, ~47% of the total load reduction goal
- SiL_2, sand filter in subwatershed Silver_Lake, ~18% of the total load reduction goal
- SiL_3, slope stabilization in subwatershed Silver_Lake, ~29% of the total load reduction goal
- SiL_4, slope stabilization in subwatershed Silver_Lake, ~9% of the total load reduction goal
- SiL_5, slope stabilization in subwatershed Silver_Lake, ~11% of the total load reduction goal
- SiL_6, slope stabilization in subwatershed Silver_Lake, ~9% of the total load reduction goal
- SiL_7, internal load control in Silver Lake, ~149% of the total load reduction goal



RECOMMENDED BMPs, SILVER LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 5.11

6.0 Duck Lake


PURGATORY WATERSHED
SILVER LAKE
LOTUS LAKE
DUCK LAKE
ROUND LAKE
MITCHELL LAKE
RED ROCK LAKE
PURGATORY CREEK RECREATION AREA
LAKE IDLEWILD
STARING LAKE
PURGATORY CREEK

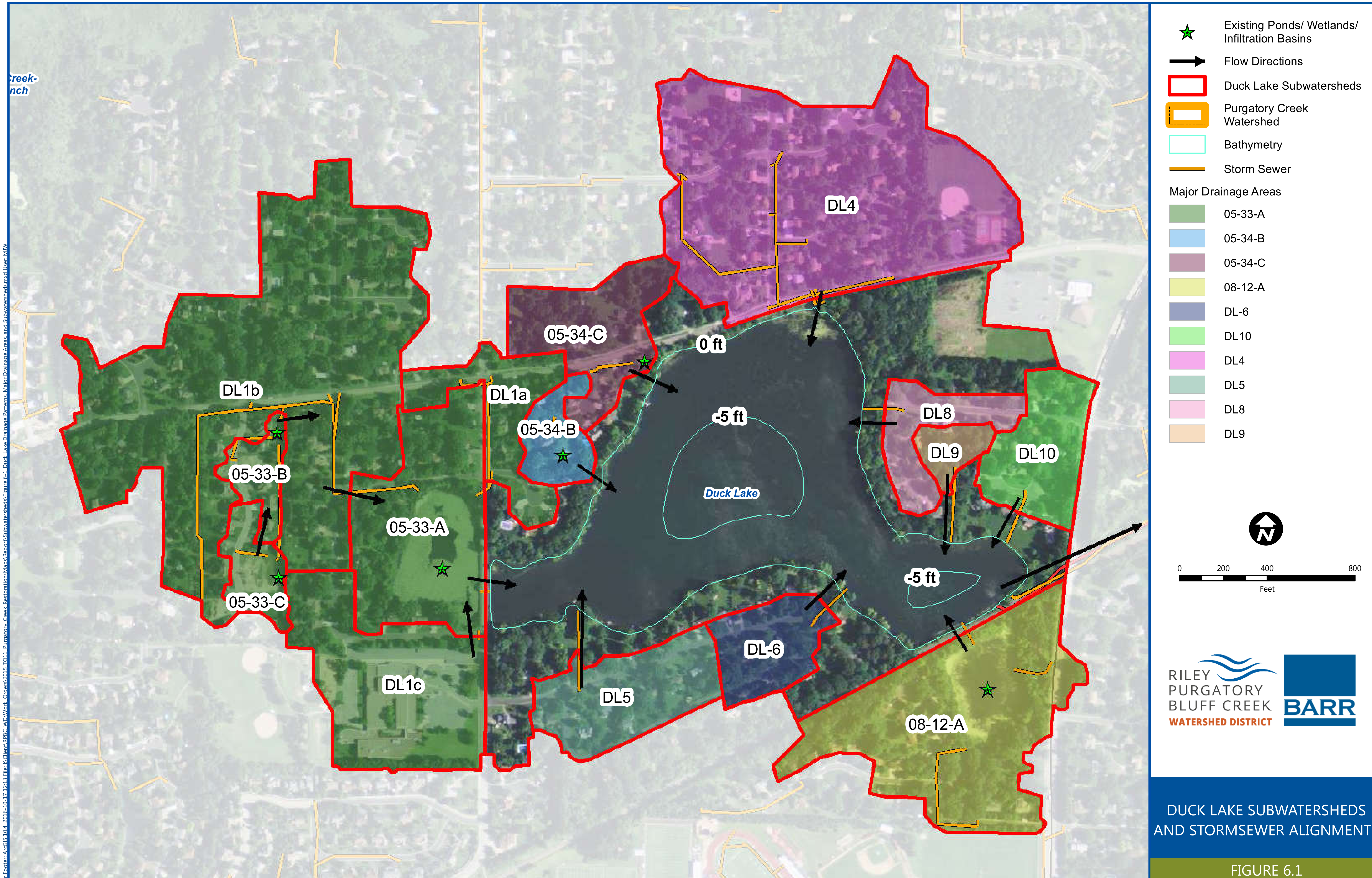
6.1 Watershed Characteristics

Duck Lake lies entirely within the boundaries of the City of Eden Prairie. The watershed area contributing to Duck Lake is 233 acres including the lake surface area of 41 acres (Figure 5.1). Duck Lake does not have any upstream lakes contributing flow. The flow from Duck Lake exits through a control structure into a storm sewer pipe that drains into Purgatory Creek.

6.1.1 Drainage Patterns

The stormwater conveyance system in the Duck Lake watershed is comprised of storm sewer networks, constructed stormwater detention ponds, and natural wetlands within the watersheds tributary to the lake (Figure 6.1). Most of the constructed stormwater ponds within the Duck Lake watershed are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows.

The Duck Lake watershed was divided into subwatersheds based on updated topographical data (MDNR, 2011), storm sewer data, BMP locations, and other information from the city of Eden Prairie. The subwatersheds were grouped into 10 major drainage areas within the Duck Lake watershed (Figure 6.1). Each major drainage area is named after the terminating watershed in each conveyance network. In addition to the major drainage areas is the lakes direct watershed. The direct watershed includes areas along the shoreline of the lake that contribute flow directly to the lake through surface flow as well as small stormsewered sections that do not receive treatment before discharging into the lake.



DUCK LAKE SUBWATERSHEDS AND STORMSEWER ALIGNMENTS

FIGURE 6.1

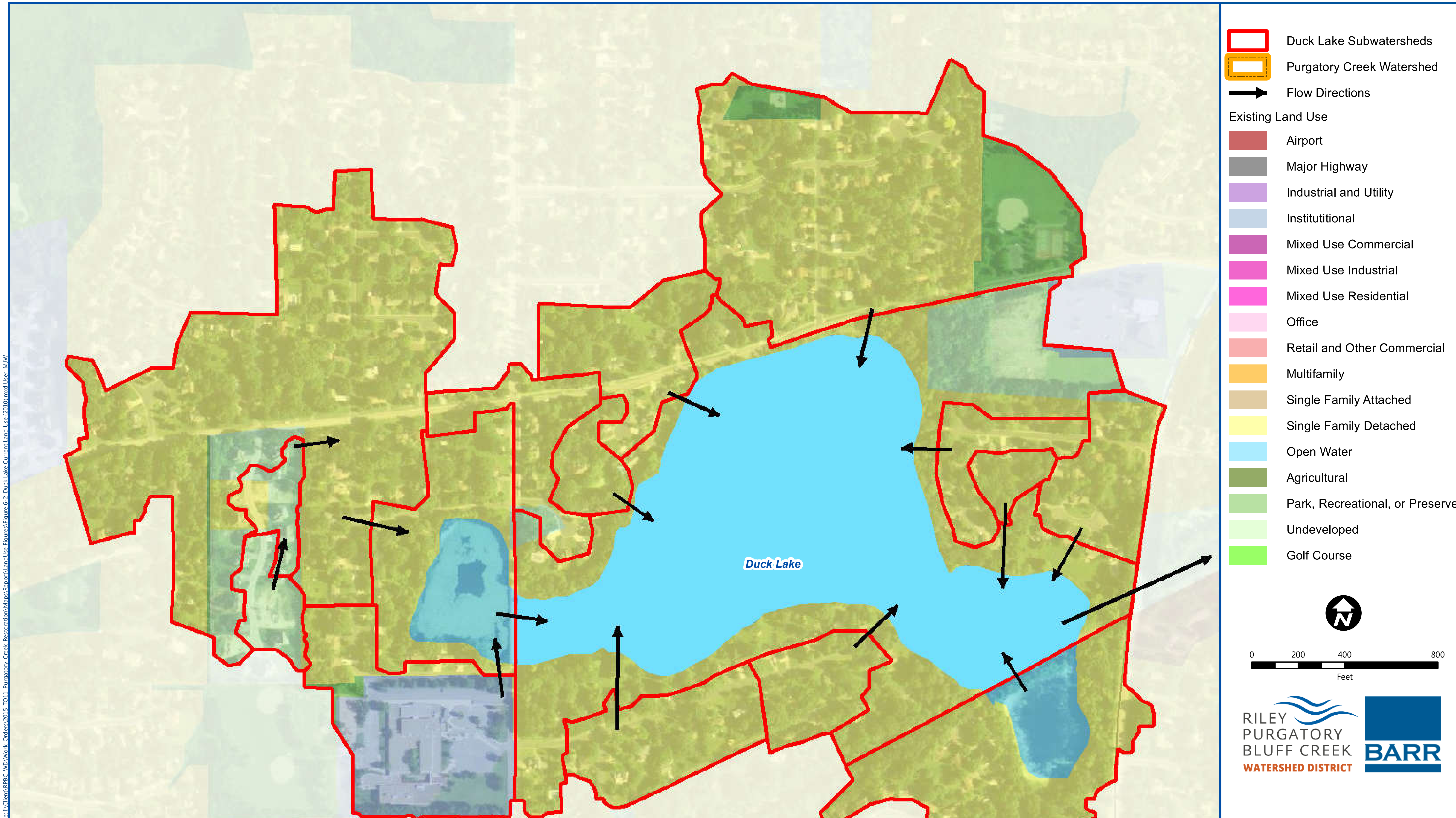
6.1.2 Land Use

Land use within a lake's watershed can impact the hydrology and water quality of a lake. Varying land uses contribute different quantities of sediments and TP to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

Existing land-use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council. The land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix D. The majority of the Duck Lake watershed is covered by single family residential land use (80%). Figure 5.2 shows the existing land uses present in the Duck Lake watershed.

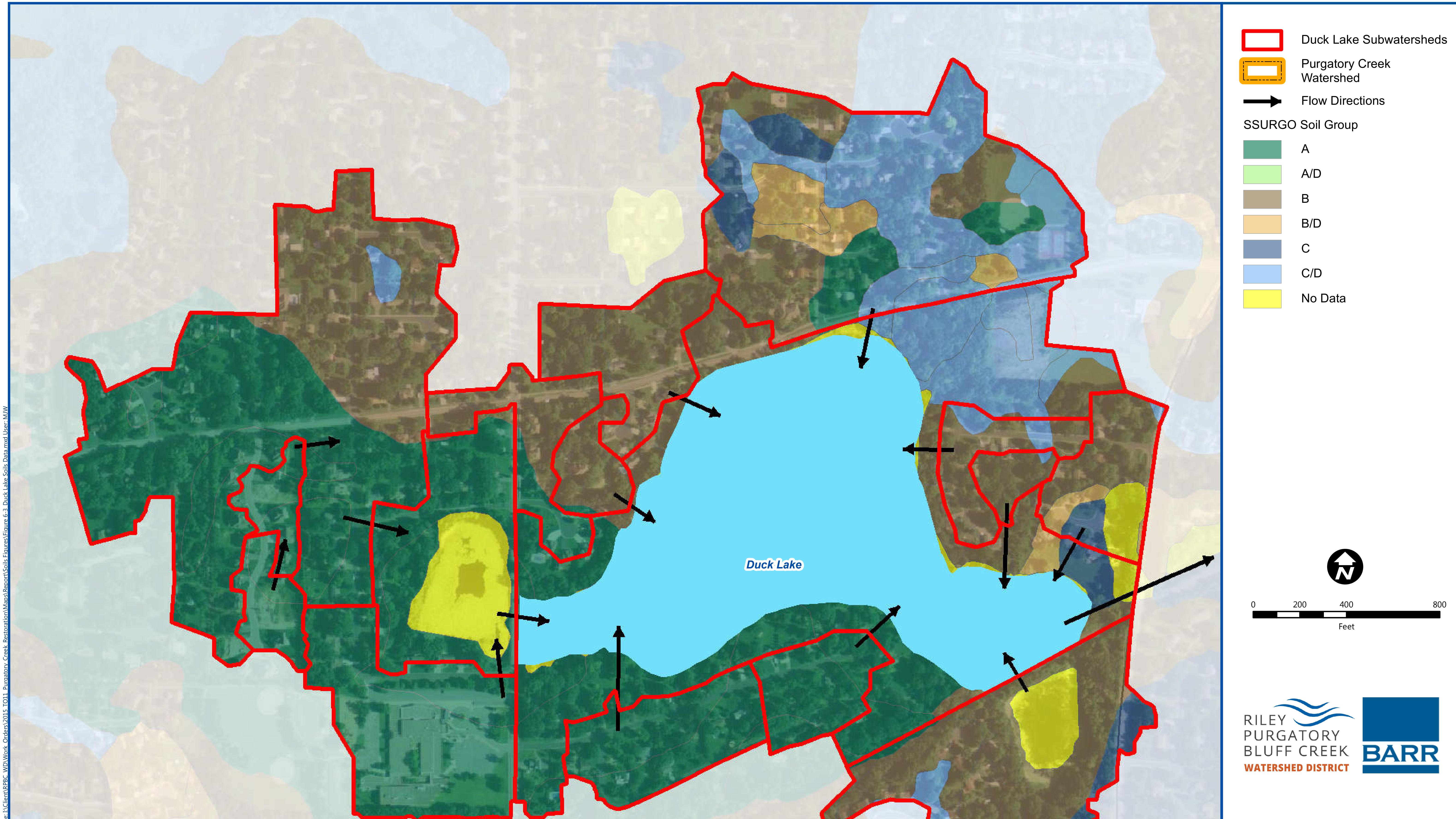
6.1.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database map for Carver and Hennepin counties, the underlying soils in the Duck Lake watershed are predominantly classified as hydrologic soil group (HSG) A with high infiltration rates and B with moderate infiltration rates (Figure 6.3). The entire south west corner of the watershed has A soils with B soils being the predominant soil type in the rest of the watershed.



DUCK LAKE LAND USE CLASSIFICATIONS

FIGURE 6.2



DUCK LAKE SOILS CLASSIFICATIONS

FIGURE 6.3

6.2 Lake Characteristics

Table 6.1 provides a summary of the physical characteristics for Duck Lake. Duck Lake has an open-water surface area of approximately 41 acres. The lake is shallow, with a maximum depth of approximately 8 feet and mean depth of approximately 3.4 feet. The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 916.12 (2014) feet MSL to a low measurement of 911.26 feet MSL (1988). Since 2011 water levels in Duck Lake have averaged 914.25 feet MSL. The outlet of Duck Lake is a manmade structure that conveys water to Purgatory Creek. The outlet is an elevation of 914.35 feet. At the average water elevation of 914.25 feet the total water volume in Duck Lake is 131 acre-ft.

Table 6.1 Duck Lake Physical Characteristics

Lake Characteristic	Duck Lake
Lake MDNR ID	27-0069-00
MPCA Lake Classification	Shallow
Water Level Control Elevation (feet MSL)	914.35
Average Water Elevation (feet MSL)	914.25
Surface Area (acres)	41
Mean Depth (feet)	3.4
Maximum Depth (feet)	8
Littoral Area (acres)	41
Volume (at normal water elevation) (acre-feet)	131
Thermal Stratification Pattern	Polymictic
Estimated Residence Time (years) – 2014-2015 climatic Conditions	1.0
Watershed Area Tributary to Upstream Lake	0
Total Watershed Area	233[2]
Subwatershed Area (acres)	233[2]
Trophic Status Based on 2015 Growing Season Average Water Quality Data	Eutrophic

1 – Average water elevation 2011-2015.
2 – Watershed area includes surface area of lakes

Given the depth of Duck Lake and the review of temperature and dissolved oxygen profiles suggest that Duck Lake is a polymictic lake. This means that the lake mixes multiple times throughout the year from wind mixing events. Temperature stratification does form resulting in anoxic conditions near the lake sediments; however wind mixing events during the summer can be strong enough to completely mix the lake water column providing oxygen to the sediments and mixing phosphorus throughout the water column.

6.3 Water Quality Conditions

Historical water quality data, in terms of growing-season (June – September) average TP concentrations, chlorophyll *a* concentrations, and Secchi disc transparency for Duck Lake are presented in Figure 6.4. Also shown in these figures are the MPCA water quality standards for a shallow lake for each parameter. Historically the growing season average TP concentrations consistently failed to meet the MPCA water quality standards. However, four of the five years since 2011 have all meet the 60 µg/L shallow lake standard. The most recent growing-season average TP concentration in year 2015 was calculated as 40 µg/L, thus achieving the standard. The lowest average concentration was recorded in 2014 at 32 µg/L. The highest average concentration was recorded in 1988 at 240 µg/L.

Chl-a concentrations have followed the same pattern as TP concentrations. Historical growing season average values before 2009 were all above the water quality standard of 20 µg/L. Since 2009, five of the six average concentration values were below the standard. The most recent value in 2015 was 10 µg/L. The lowest value was in 2014 with an average concentration of 3 µg/L. The highest value was in 1998 with an average summer value of 82 µg/L.

Prior to 2008, Secchi depths in Duck Lake did not meet the MPCA water quality standard of 1.0 meter. Since 2008 six of the seven growing season average concentrations have met the standard. The 2015 average depth was 1.7 meters. The highest (best) recorded average depth of 2.4 occurred in year 2013. The lowest (worst) average depth of 0.4 meters occurred in 1981.

Trends in the water quality data were determined by calculating a Thiel-Sen slope on the annual average growing season values and the significance of the trend was tested using the Mann-Kendall non parametric test at the 95% confidence internal. Improving water quality trends were present in all parameters for each of the time periods (since 1999 and the entire record). Statistically significant trends were present in the TP concentrations since 1999 and the chl-a concentration for the entire record (Table 6.2).

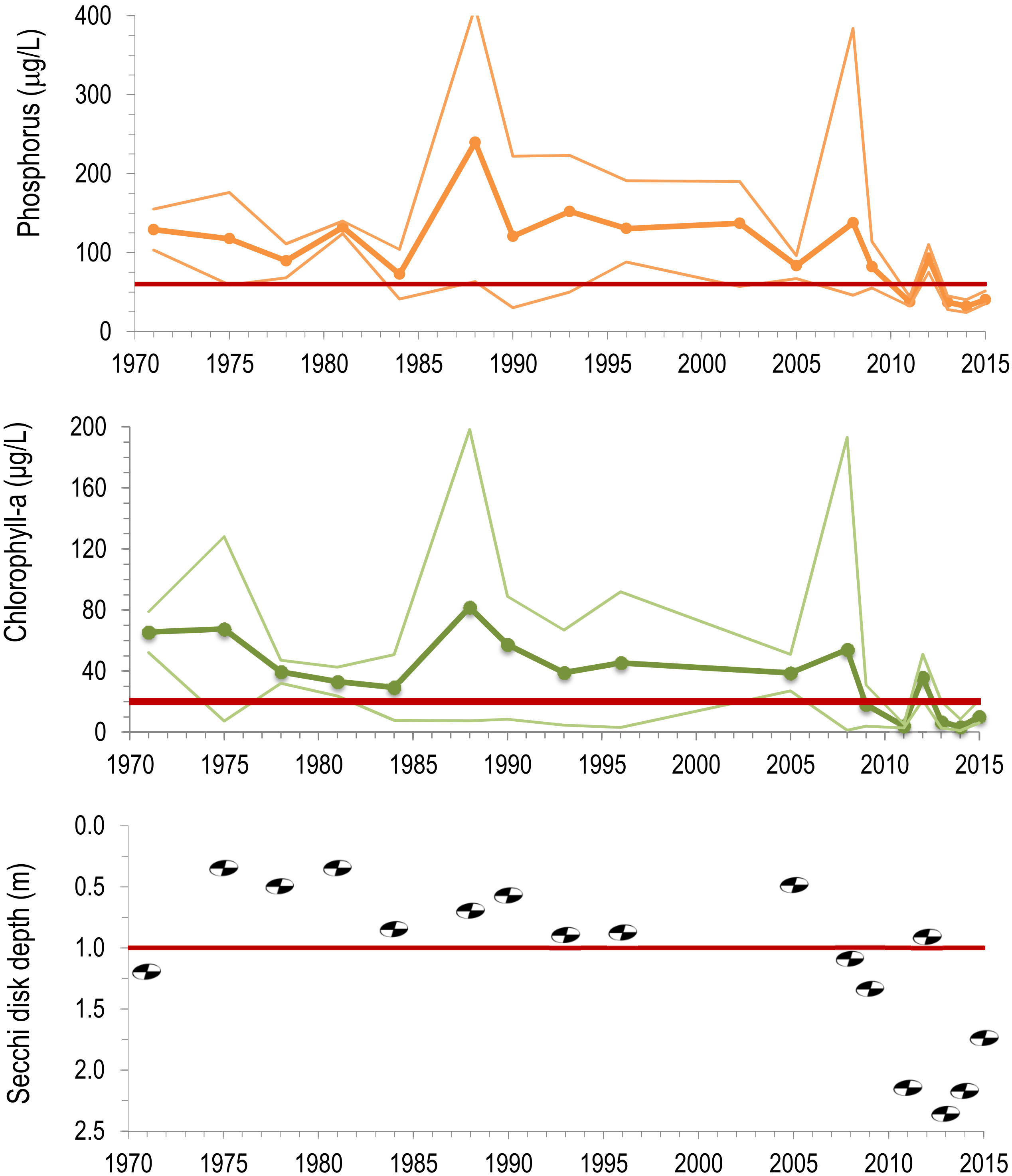


Figure 6.4
Duck LakeWater Quality Growing Season (June - September) Average, Min and Max Values

Table 6.2 Duck Lake water quality parameter Thiel-Sen trends

Parameter	1999-2015	Entire Record
TP (µg/L/yr)	-8*	-2
Chl-a (µg/L/yr)	-3.6	-1.1*
Secchi Depth (m/yr)	0.2	0.03

* Designates significant trends at the 95% confidence level using Mann-Kendall significance test

6.3.1 Water Quality Relationships

As previously discussed, phosphorus often acts as the limiting nutrient for algal growth (as measured by chlorophyll *a*), which in turn, affects lake water clarity (Secchi depth). This section describes how incremental phosphorus load reductions would be expected to impact perceptible changes in lake water quality. The compiled data for the water quality variables from Duck Lake were analyzed to develop relationships between the water quality parameters: TP, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season averages. In addition to developing the water quality relationships based on the observed data, the regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) were also plotted against the lake data.

The relationships between the various water quality parameters for the actual Duck Lake data did indicate some correlation between the water quality parameters (Figure 6.5). The MPCA regression equations resulted in similar fit for the chlorophyll *a*, Secchi disc transparency data, and TP. For this reason the MPCA statewide regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Duck Lake based on TP concentration.

Figure 6.5 shows the individual water quality data points for Duck Lake, along with plots of the MPCA statewide regression equations.

The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla (µg/L) = 1.31 Log10 TP (µg/L) – 0.95
- Log10 Secchi (meters) = -0.59 Log10 Chla (µg/L) + 0.89
- Log10 Secchi (meters)= -0.81 Log10 TP (µg/L) + 1.51

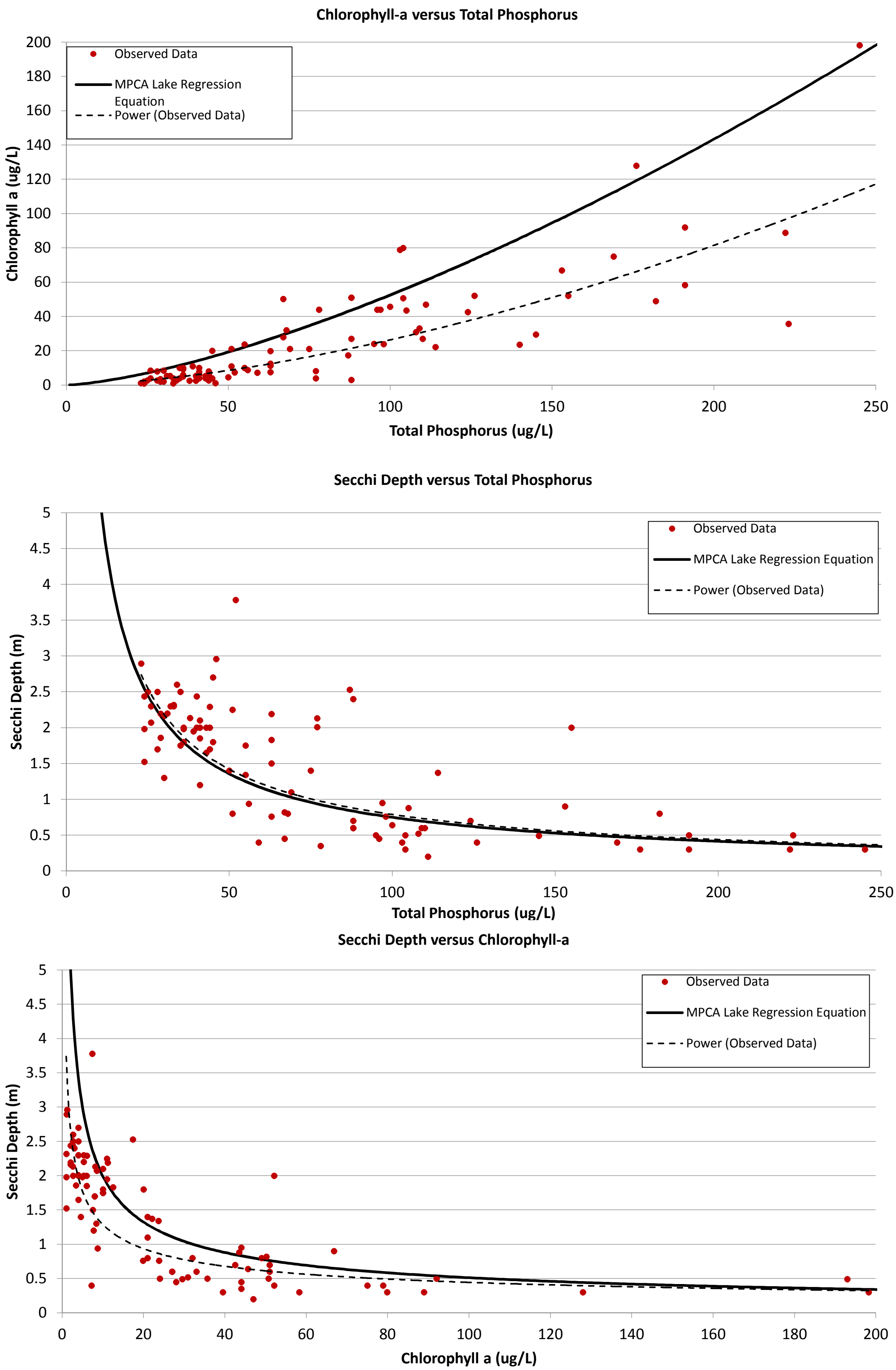


Figure 6.5
Duck Lake Individual Samples
Water Quality Parameter
Regression Relationships

6.4 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores)). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

6.4.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess TP loads.

Plankton surveys have been collected on Duck Lake for the years: 1981, 1984, 1988, 1990, 1993 and 2002. Additionally, phycocyanin (cyanobacteria (blue-green algae) pigment) readings were collected in the years 2011 - 2013. During the most recent plankton survey in June 2002 the plankton community was found to be dominated by small bodied algae allowing the zooplankton to graze and control algae levels (Barr Engineering, 2005). In July through September the small bodied algae plankton were replaced by large bodied cyanobacteria that were inedible to the zooplankton preventing the control of the algae community. A more recent plankton survey was not available.

While green algae are edible to zooplankton and serve as a valuable food source, cyanobacteria are considered a nuisance type of algae because they:

- Are generally inedible to fish, waterfowl, and most zooplankters
- Float at the lake surface in expansive algal blooms
- May be toxic to animals when occurring in large blooms
- Can disrupt lake recreation because they are most likely to be present during the summer months

6.4.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or

enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

The most recent analysis of zooplankton in Duck Lake occurred in 2002 (Barr Engineering, 2005). In the surveys conducted throughout the monitoring season all three zooplankton groups were well represented. During the June through early August surveys the structure began to change when larger bodied cladocera decreased significantly and small bodied cladocera increased. The observed drop in large bodied cladocera was likely caused by the predation by newly hatched fish, called young-of-the-year. During this time estimated grazing rates decreased from 17 percent in June to 4 percent of the plankton community in August (Barr Engineering, 2005).

6.4.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

The most recent plant survey in Duck Lake was conducted by the Blue Water Science for the City of Eden Prairie in year 2013 (Blue Water Science, 2013). Two surveys were conducted at the beginning and end of the summer (May and August). In the May survey curlyleaf pondweed was found throughout the lake in up to 9 feet of water depth. In the deeper waters curlyleaf pondweed was more scattered. In the August survey curlyleaf pondweed had died back and was only found in three locations. Overall the survey found six species of macrophytes in the May survey and four species in the August survey resulting in a modest plant diversity condition. Curlyleaf pondweed was the most abundant species in the May survey with coontail being the most abundant plant in the late summer survey. This same pattern was observed in previous surveys in 2004 and 2009.

6.4.4 Fishery

The MDNR developed a classification system for Minnesota Lake relative to the chemical and physical properties of each lake class and the fishery that is supported by each lake (Schupp, 1992). According to its ecological classification, Duck Lake is a Class 40 lake. Class 40 lakes are typically shallow and productive lakes with fish assemblages that include perch, bluegills, walleye, bullhead, carp, northern pike, and crappie (Schupp, 1992). The most recent fish survey conducted on Duck Lake was in 1996. During this survey it was found that the fishery in Duck Lake consisted of panfish and rough fish (Barr Engineering, 2005). The species found were black crappie, bluegill, and black bullhead. The fish community was dominated by black bullheads. Since this survey, the MDNR has stocked Duck Lake with black crappies, bluegills, largemouth bass, and white crappies in years 2008, 2010, 2011, 2013, and 2014. A more recent survey of the carp population conducted by the University of Minnesota in 2011 and 2012 found zero occurrences of carp in Duck Lake (Sorensen, et al., 2015). A full fish survey has not been conducted in Duck Lake since 1996.

6.5 TP Source Assessment

The watershed and in-lake water quality models were developed to assess both the external and internal TP loads in Duck Lake for the 2015 water year (October 2014 – September 2015). A detailed discussion of the modeling methods used is presented in Section 2.2.2 and Appendix D. Possible lake external loads of TP include atmospheric depositions, stormwater runoff from the lake watershed, surficial groundwater interactions with the lake waters, internal loads from upstream ponds and wetlands, and load from any upstream lakes that might flow into the waterbody.

External loads that applied to Duck Lake are atmospheric deposition and watershed loads. Based on the 2015 water balance it appeared that there was no net surficial groundwater inflow meaning the inflow of groundwater likely equals the outflow, Duck Lake is not downstream from another major waterbody/lake, and no channels with erosion potential contribute the Duck Lake. While the RPBCWD has collected water quality data in several ponds within the Duck Lake watershed, the internal loading within the ponds and wetlands was not evaluated for this study. Internal TP loads can come from sediment TP release, curlyleaf pondweed, or benthivorous fish activity.

Figure 6.6 summarizes the 2015 annual water year TP budgets for Duck Lake, including the relative contributions of the external and internal TP loads. This budget explains the sources of TP to the lake and helps to identify implementation strategies. Each of the sources are discussed further in the following section(s).

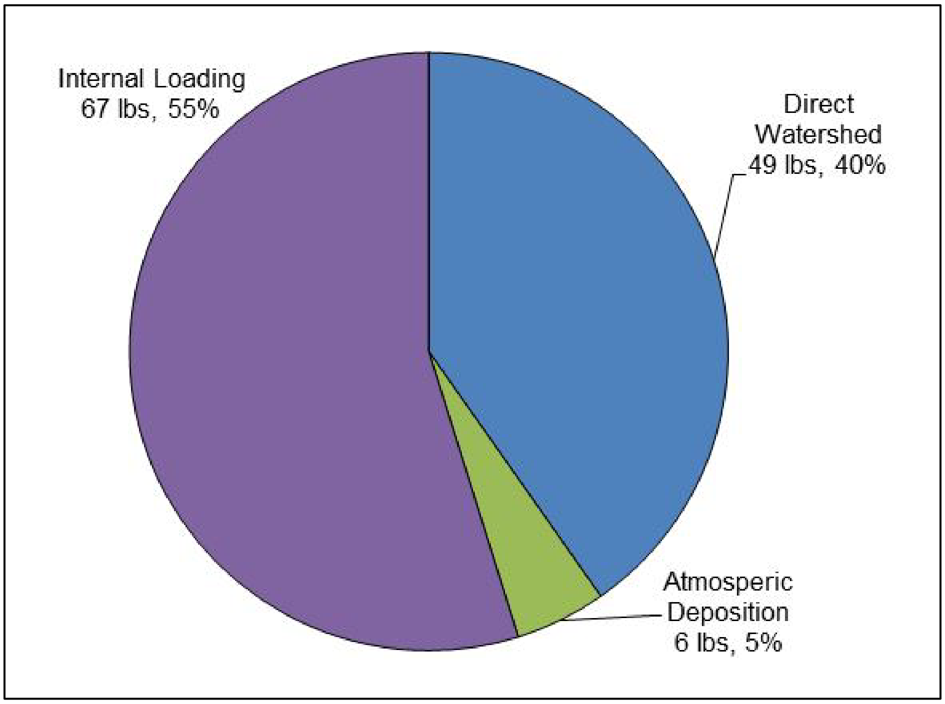


Figure 6.6 Duck Lake TP load sources for 2015 water year

6.5.1 External Loads

6.5.1.1 Atmospheric Deposition

Atmospheric deposition of TP onto the lake water surface was calculated by using the estimated statewide TP atmospheric deposition rate of 0.17 kg/ha/year (Barr Engineering, 2004). For Duck Lake, this loading rate was applied to the combined open water area. The daily rate was applied to the surface area of the lake based on the modeled lake water elevation from the lake water balance model. The resulting atmospheric deposition TP load for the 2015 water year was 6 pounds which amounted to 5% of the TP load to Duck Lake (Figure 6.6).

6.5.1.2 Watershed Loads

The P8 watershed model estimated surface runoff from Duck Lake's subwatersheds (not passing through upstream lakes) based on observed climatic data (precipitation and temperature). The total untreated watershed load from the watersheds in Duck Lake for the 2015 water year was modeled to be 79 pounds of TP. The watershed load travels through existing stormwater ponds, wetlands, infiltration practices, and other BMPs located throughout the watershed providing treatment resulting in a TP load of 49 pounds reaching the lake. This represents a 38% removal being provided by existing treatment practices in the watershed. The 49 pounds TP load reaching the lake from the watershed load represented 40% of the total TP load to Duck Lake (Figure 6.6).

To help evaluate areas that might benefit from additional treatment watershed loads to the lake were calculated for each of Duck Lake's individual subwatersheds. The load to the lake is defined as the amount of TP load from that watershed reaching the lake without being removed by an existing BMP within the subwatershed or downstream from the subwatershed. The P8 results were used to calculate the total annual average untreated watershed TP loads from each subwatershed. Next the watershed load to the lake was calculated. This was accomplished by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each subwatershed that reached the lake without being removed by an existing BMP. The watershed load to the lake for each subwatershed is shown in Figure 6.7.

6.5.2 Internal Loads

Internal loading in Duck Lakes represented 55% (67 pounds) of the TP loads in the 2015 water year. The internal loading sources to Duck Lake are likely a combination of curlyleaf pondweed delay and sediment release.

6.5.2.1 Curlyleaf Pondweed

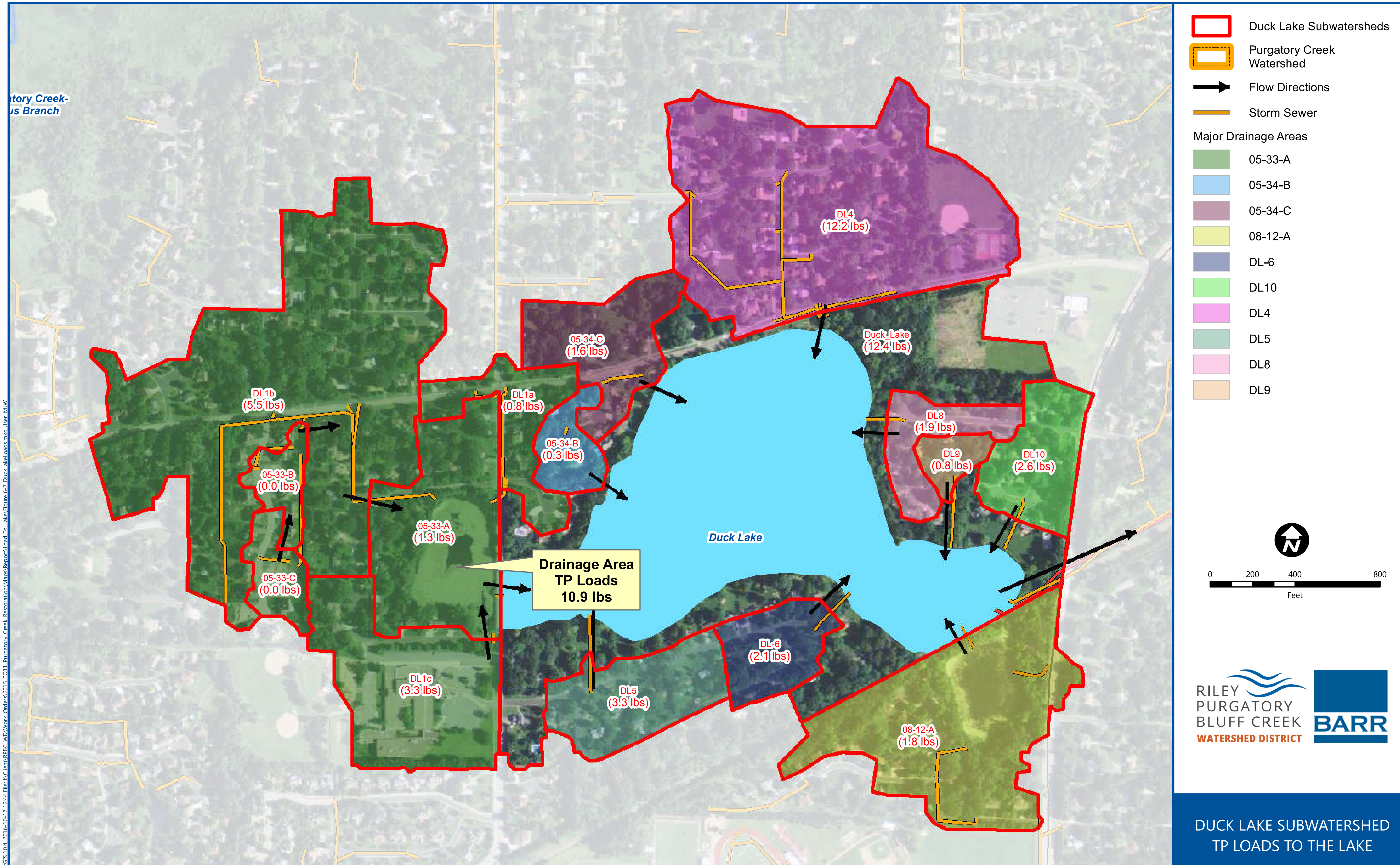
Because of the relatively high occurrence in Duck Lake, TP loading from curlyleaf pondweed may be significant during part of the summer, but was not explicitly modeled to quantify its potential impact for this study. The internal loading calibration parameter was used to simulate this release along with other sources of internal loading.

6.5.2.2 Benthivorous Fish Activity

In fish surveys of Duck Lake in 2011 and 2012 by the University of Minnesota zero carp were found (Sorensen, et al., 2015). As a result, this analysis assumes that the activities of carp and other benthivorous fish are not a significant source of TP in Duck Lake and were not quantified as part of the in-lake water quality modeling in 2015.

6.5.2.3 Sediment Release

Internal loading through sediment release occurs during anoxic conditions. A review of dissolved oxygen profiles in Duck Lake showed periodic anoxic conditions 7.4 feet below the lakes water surface during the middle summer months. Anoxic conditions in the sediment are present at times during the summer months, but wind mixing regularly occurs re-oxygenating the lakes sediments and distributing any internal load of TP throughout the water column.



DUCK LAKE SUBWATERSHED TP LOADS TO THE LAKE

FIGURE 6.7

6.5.3 TP Load Reductions

The in-lake model was used to determine TP load reductions needed to meet the water quality goal for Duck Lake. Table 6.3 shows the measured and modeled growing season average (June – September) concentration, the TP load to the lake under existing conditions, the TP goal, the TP loading capacity for meeting the water quality standard and the required percent reduction needed to meet the water quality goal. Under existing conditions Duck Lake is meeting the water quality goal for a shallow lake of 60 µg/L. Modeled and measured growing season average concentrations in the lake surfaces waters for the 2015 water year was 42 µg/L and 40 µg/L respectively. The TP load under existing conditions was 123 pounds for the 2015 water years. No reductions are needed in Duck Lake to meet the water quality goal for the analyzed time period. However protection measures should be considered to limit the potential for future degradation.

Table 6.3 Duck Lake estimated load reductions required to meet TP water quality goal for 2015 water year

Measured growing season average TP concentration (µg/L)	Modeled growing season average TP concentration (µg/L)	Estimate 2015 TP loading rate (lbs/yr)	TP concentration goal (µg/L)	Estimated Loading Capacity to meet WQ goal (lbs/yr)	Percent reduction needed to achieve goal (%)
40	42	123	60	Meets goal	0

Volumetric average concentration for entire water column

While load reduction is not required in Duck Lake to meet the water quality standard for the 2015 water year, BMPs to further reduce the TP concentrations in the lake could be implemented. Figure 6.8 shows how lake concentrations react to lake load reductions. The calibrated in-lake TP model was used to determine in lake water quality based on the amount of TP load to the lake. TP concentrations were calculated using the in-lake model. Chl-a and Secchi depth concentrations were determined based on the water quality relationships discussed in section 6.3.1. The figure shows how incremental load reductions would impact the water quality in Duck Lake. A TP load reduction of 10 pounds would reduce the lake TP concentration to 38 µg/L. A TP load reduction of 37 pounds could reduce the lake concentration to 30 µg/L.

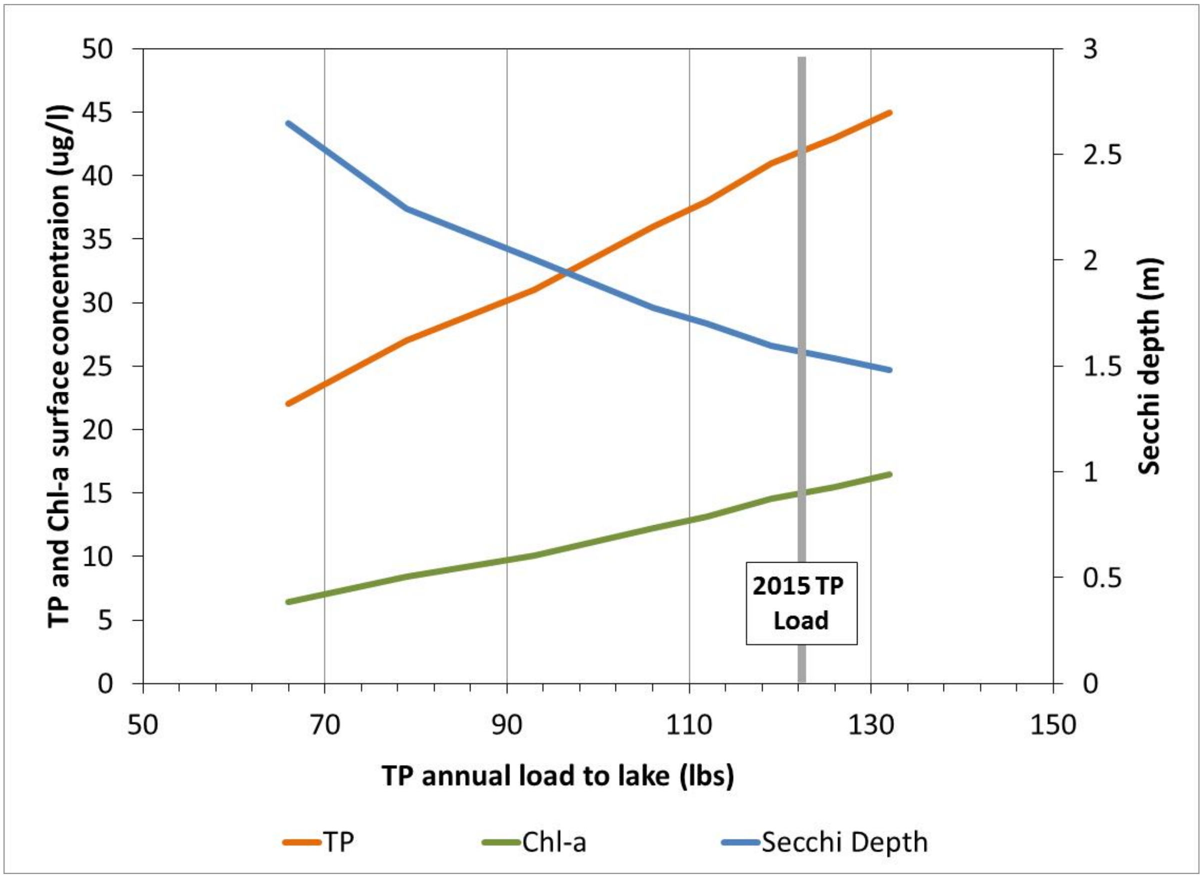


Figure 6.8 **Duck Lake TP load relationship with lake water quality (TP, Chl-a and clarity)**

6.6 Summary of Diagnostic Findings

Table 6.4 provides a summary of the key water-quality findings for Duck Lake.

Table 6.4 Diagnostic Findings for Duck Lake

Topic	Duck Lake
Water Quality Standards and Goals	- Meets the MPCA shallow lake water quality standards for TP, Chl-a and Secchi depth. - Does not meet RPBCWD long term vision for Secchi depth in 2015, but did meet the 2 m goal in 2013 and 2014.
Baseline Water Quality	- Reconstruction sediment core analysis has not been conducted on Duck Lake.
Water Quality Trends	- Statistically significant improving trend in TP since 1999. - Statistically significant improving trend in Chl-a since 1971
Watershed Runoff	- Represents approximately 40% of the annual TP load. - Watershed load is estimated to be reduced by 38% by existing BMPs, ponds, and wetlands located throughout the watershed.
Macrophyte Status	- Curlyleaf pondweed is present in high densities - No occurrences of the Eurasian watermilfoil
Fishery Status	- No carp found in recent survey
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer
Internal Loading from sediments	- Internal loading from sediment estimated to be 55% of annual TP load
Methylmercury in Fish Tissues	- No studies have been conducted, not currently listed as impaired - No consumption advisories

Additional discussion of the diagnostic findings in relation to the sources of TP and water quality of the lake based on the data analyses, watershed and in-lake modeling, and review of recent studies and information is included. These conclusions influenced the implementation strategies evaluated for the management of Duck Lake water quality (see Section 6.8).

- In 2015 Duck Lake met the MPCA shallow lake water quality standards for all three parameters (TP, Chl-a, and Secchi depth). A significant trend in improving TP concentrations was detected since 1999.

- Approximately 55 percent of the watershed runoff receives treatment prior to entering Duck Lake due to the number of stormwater ponds and other waterbodies within the watershed. As stormwater runoff passes through the many constructed stormwater ponds and natural wetlands in the watershed, removal of TP associated with particulates in the runoff occurs due to particle settling and infiltration. Modeling suggests that 38% of the watershed load is removed by existing BMPs or wetlands before reaching Duck Lake.

- The watershed phosphorous load to Duck Lake represented 40 percent of the total annual TP budget to the lake during the 2015 water year, internal loading represented another 55 percent of the total annual TP budget (see Figure 5.7)

- Figure 6.7 shows the estimated TP loading from the major drainage basins in the Duck Lake watershed. The watershed modeling suggests that 25 percent of the watershed load to Duck Lake comes from Duck Lake's direct watershed. Another 25 comes from watershed DL4 as well as 25% from the drainage areas to 05-33-A. These three areas appear to provide the best opportunities for watershed additional TP reductions.

- The most recent plant surveys in Duck Lake indicate that invasive species curlyleaf pondweed is present in the Lake at high densities. Curlyleaf pondweed is most active in the early summer and tends to die off in the late summer months (Blue Water Science, 2013).

- The carp population was analyzed in Duck Lake in 2011 and 2012 as part of the University of Minnesota's study for Purgatory Creek (Sorensen, et al., 2015). Zero occurrences of carp either adult or young were found in Duck Lake.

6.7 Current and Past Management Actions

The following includes a summary of BMPs either implemented or analyzed in the Duck Lake watershed:

- A stormwater basin inventory and analysis identified 7 stormwater ponds out of 74 basins in the Red Rock Lake and Duck Lake watersheds as high priority basins that should be routinely inspected and maintained (Wenck Associates, Inc, 2014).
- Pond 05-34-C, analyzed in the Duck Lake watershed over years 2012 and 2013, was determined to have TP concentration above 0.250 mg/l and could benefit from remediation measures (RPBCWD, 2014).
- BMP and mitigation measures suggested for Duck Lake as part of the "One Water" Water Management Plant (CH2M HILL, 2011) include:
  - o control external TP loading through stormwater infiltration basin construction
  - o control curlyleaf pondweed mechanically and through herbicide treatment,
  - o control internal loading of phosphorus and mercury methylation through oxygenation, aeration, sediment oxygenation, alum treatment or a combination of methods,
- Curlyleaf pondweed management was suggested to be explored before implementing large scale watershed improvements for water quality in Duck Lake (Wenck Associates, Inc, 2014).
- Carp were not found in Duck Lake as part of surveys conducted in 2011 and 2012 (Sorensen, et al., 2015).

6.8 Evaluation of Water Quality Improvement Options

All of the BMPs identified for Duck Lake are listed and described in detail in the following subsections. Table 6.5 provides a list of the potential BMPs and Figure 6.9 shows the identified potential BMP locations in the Duck Lake watershed.

6.8.1 New wet pond in subwatershed Duck_Lake, DL_1

BMP DL_1 is a new wet pond in subwatershed Duck_Lake immediately adjacent to Duck Lake along Duck Lake Trail. This BMP is designed to treat about 5.3 acres of impervious area north of Duck Lake Trail. This pond is proposed to be approximately 0.2 acres with an average depth of 3 feet. The pond would have two inlets and one 36-inch outlet into Duck Lake. The pond could potentially remove 6.6 pounds of TP per year based on 30-year modeling results and reduce the annual loading to the lake by a similar amount. The cost-benefit of this BMP for Duck Lake is estimated to be about $1,650 per pound of TP, assuming the BMP functions for 30 years. However, because of the location of the BMP (adjacent to the lake, on private property, etc.) and the potential permit requirements, implementation of this BMP would be challenging.

6.8.2 Internal load control in Duck Lake, DL_2

BMP DL_2 is a method for reducing the internal loading within the lake, likely with an alum treatment to bind mobile phosphorus in the lake sediment. The treatment within the lake could initially reduce the internal phosphorus loading by approximately 80% (Welch & Cooke, 1999), resulting in a reduction of 61 pounds per year. The dose needed to achieve this reduction is estimated to be approximately 530 gallons per acre, based on 2005 samples of mobile phosphorus in the sediment cores of Duck Lake (Barr Engineering, 2005). The cost-benefit of this BMP is estimated to be about $70 per pound of TP, assuming treatment is not needed again for at least another 15 years (Huser, et al., 2015). Two treatments would likely be needed over 30 years and the total cost of both treatments is estimated to be $134,000 (Table 6.5). While this BMP provides a significant load reduction at a low cost, BMP DL_2 is not recommended for the lake because lake water quality is currently meeting the goal.

6.8.3 Rainwater gardens in subwatershed DL1c, DL_3

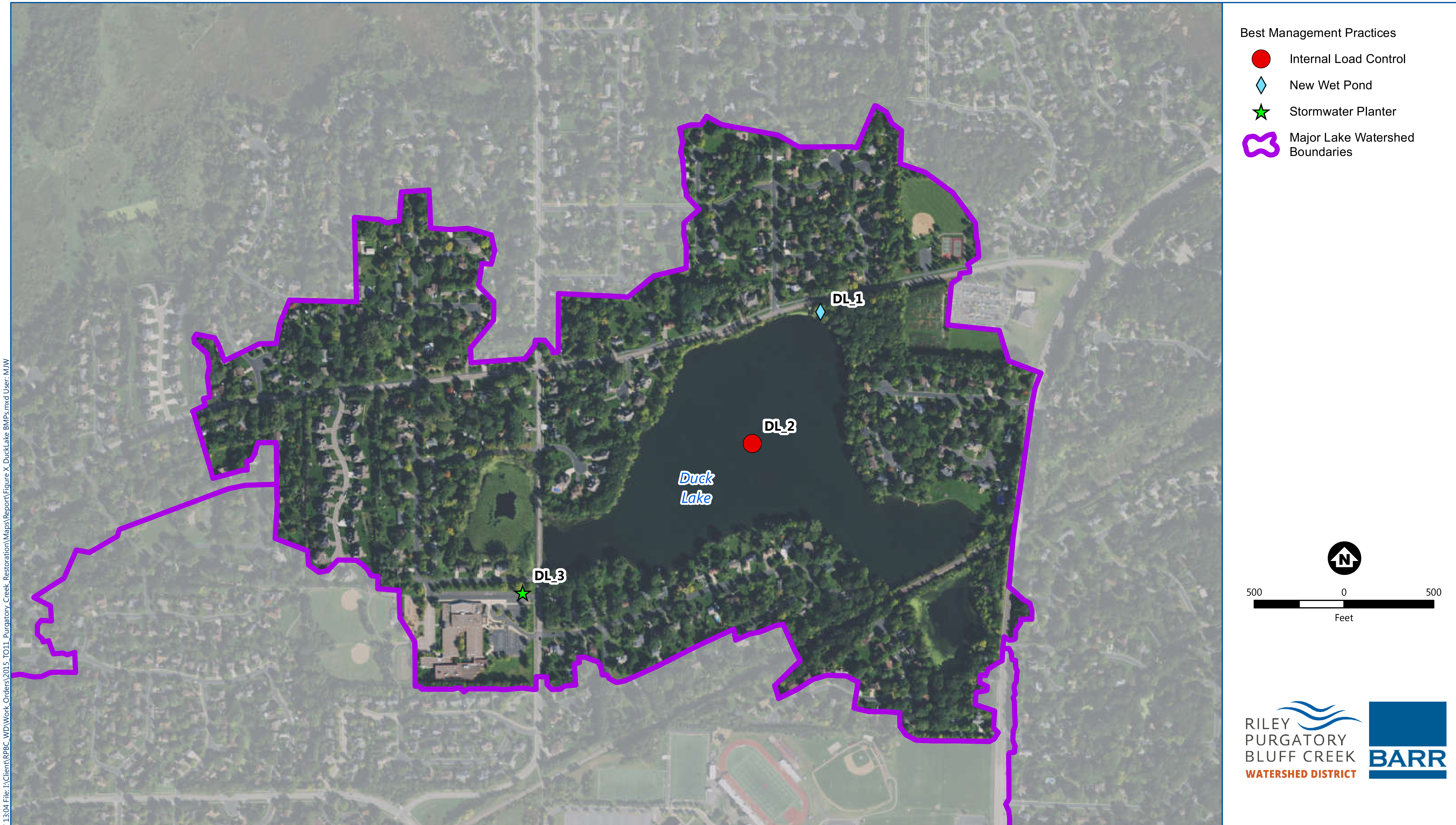
BMP DL_3 is a group of six rainwater gardens in subwatershed DL1c around Prairie View Elementary School. The rainwater gardens are designed to treat runoff from impervious areas along Peterborg Road, portions of Barberry Lane and Duck Lake Road, and the school property itself. The rainwater gardens are proposed to be approximately 0.1 acres in total, and about 1.5 feet deep. The soils in this area are “A” soils, with a high capacity to infiltrate water. The road runoff would be directed to the rainwater gardens through curb cuts. The rainwater gardens could potentially remove 8.1 pounds of TP per year. Based on the location of the BMP in the watershed relative to Duck Lake, the actual removal of TP from the lake is anticipated to be 2.4 pounds of TP per year. The cost-benefit of this BMP is estimated to be about $4,760 per pound of TP, assuming the BMP functions for 30 years. Because there is no other treatment currently in subwatershed DL1c, and the rainwater gardens have an added benefit of runoff volume reduction, BMP DL_3 is recommended for the watershed.

Table 6.5 - Summary of Duck Lake BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
DL_1	New Wet Pond *- A 0.2 acre, 3-foot deep wet pond designed to treat 5.3 acres of impervious area north of Duck Lake Trail*	6.6	6.6	N/A	$203,300 ($163,000 - $285,000)	$4,100 ($3,300 - $5,700)	$1,650 ($1,320 - $2,310)	$1,650 ($1,320 - $2,310)
DL_2	Internal Load Control *- Two treatments of a whole lake alum treatment*	61	61	N/A	$134,000 ($107,000 - $188,000)	$0	$70 ($60 - $100)	$70 ($60 - $100)
DL_3	Rainwater Gardens *- Six rainwater gardens totaling about 0.1 acres, designed to treat 4.5 acres of impervious around Prairie View Elementary School*	8.1	2.4	N/A	$213,400 ($171,000 - $299,000)	$4,300 ($3,400 - $6,000)	$1,410 ($1,130 - $1,970)	$4,760 ($3,800 - $6,660)

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. There is no overall load reduction goal for Duck Lake; this lake already meets the goal.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.



ALL IDENTIFIED BMPs, DUCK LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 6.9

6.9 Recommendations for Water Quality Goal Attainment

There is no overall load reduction goal for Duck Lake because this lake is already meeting water quality goals (Section 6.5.3). Even though a load reduction is not necessary, one or more of the identified BMPs would be beneficial for Duck Lake. Therefore, the one recommended BMP for the Duck Lake watershed is listed below along with the magnitude of the TP load reduction expected. The recommended BMP is also shown in Figure 6.10. The total reduction expected by the recommended BMP is 2.4 pounds per year from the watershed.

- DL_3, rainwater gardens in subwatershed DL1c, ~2.4 pounds TP per year

Best Management Practices

Stormwater Planter

Major Lake Watershed Boundaries

N

500 0 500

Feet

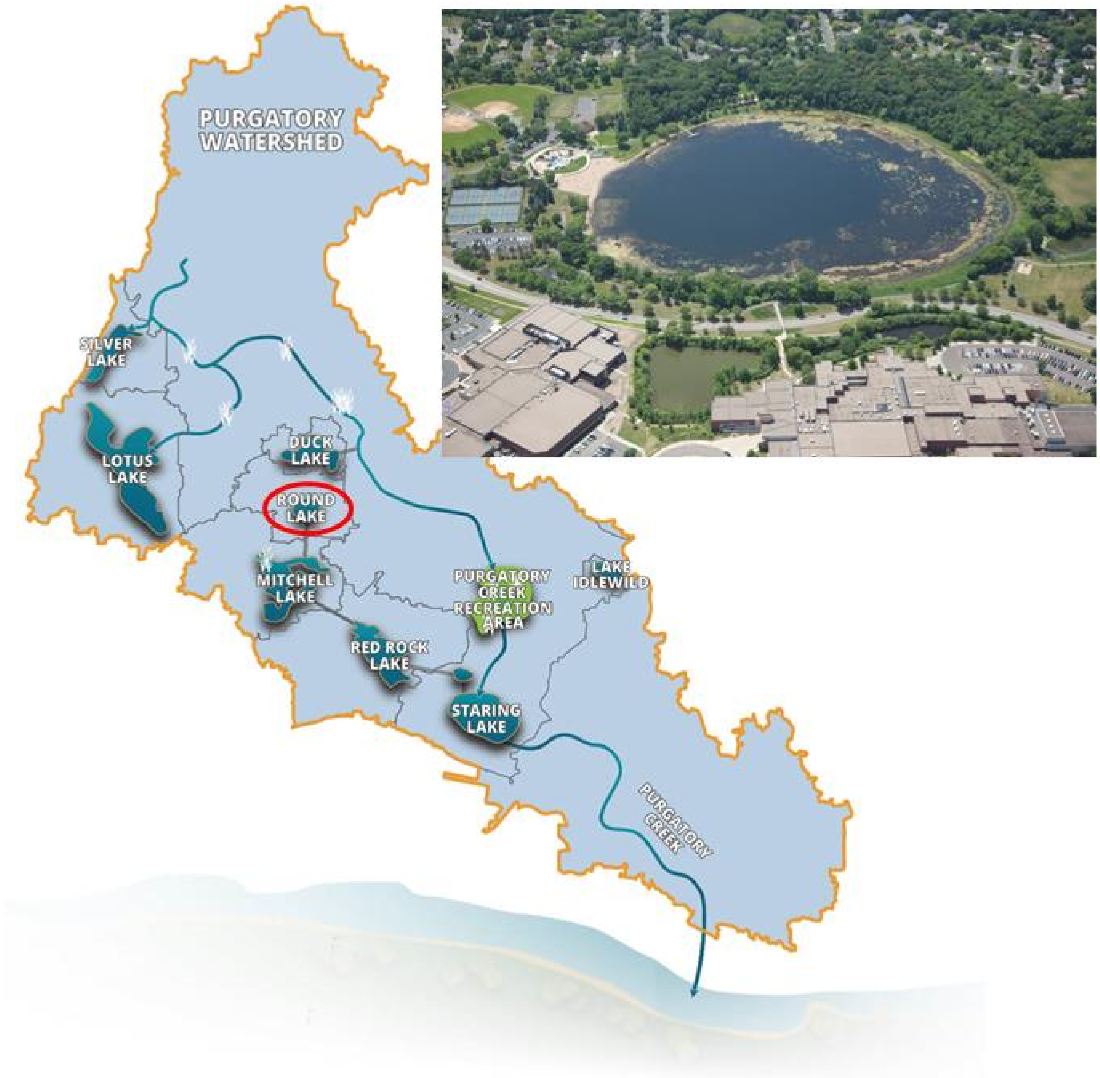
RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

BARR

RECOMMENDED BMPs, DUCK LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 6.10

7.0 Round Lake



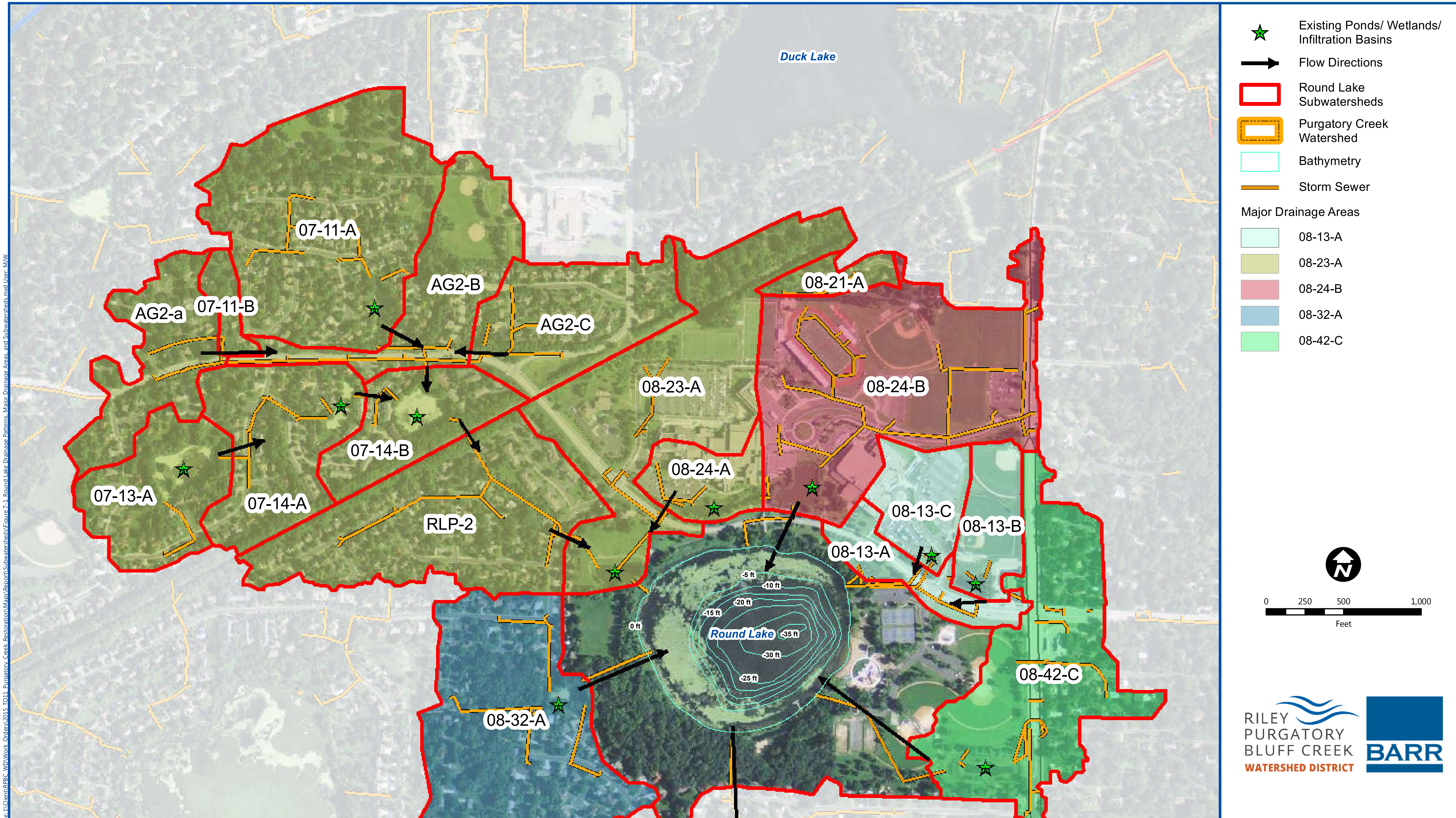
7.1 Watershed Characteristics

Round Lake lies completely within the boundaries of the city of Eden Prairie. Eden Prairie owns park land that completely surrounds the lake. The watershed area contributing to Round Lake is 475 acres including the lake surface area of 30 acres (Figure 7.1). Round Lake does not have any upstream lakes contributing flow. The flow from Round Lake exits through a control structure into a storm sewer pipe that drains through a series of ponds and wetlands before entering Mitchell Lake.

7.1.1 Drainage Patterns

The stormwater conveyance system in the Round Lake watershed is comprised of storm sewer networks, constructed stormwater detention ponds, and natural wetlands within the watersheds tributary to the lake (Figure 7.1). Most of the constructed stormwater ponds within the Round Lake watershed are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows.

The Round Lake watershed was divided into subwatersheds based on updated topographical data (MDNR, 2011), storm sewer data, BMP locations, and other information from the city of Eden Prairie. The subwatersheds were grouped into 5 major drainage areas within the Round Lake watershed (Figure 7.1). Each major drainage area is named after the terminating watershed in each conveyance network. In addition to the major drainage areas is the lake's direct watershed. The direct watershed includes areas along the shoreline of the lake that contribute flow directly to the lake through surface flow as well as small stormsewered sections that do not receive treatment before discharging into the lake.



ROUND LAKE SUBWATERSHEDS AND STORMSEWER ALIGNMENTS

FIGURE 7.1

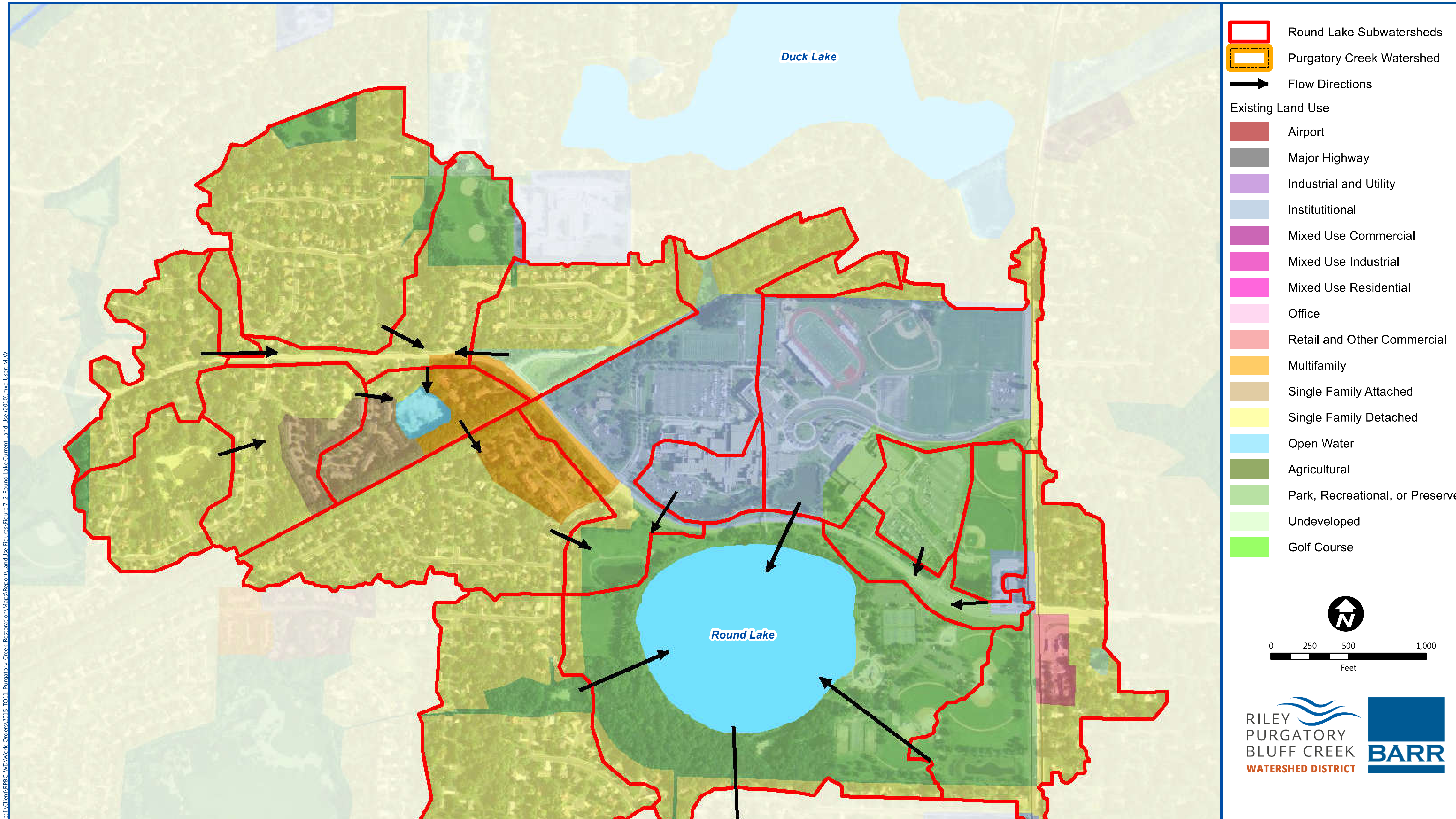
7.1.2 Land Use

Land use within a lake's watershed can impact the hydrology and water quality of a lake. Varying land uses contribute different quantities of sediments and TP to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

Existing land-use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council. The land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix D. About half of the Round Lake watershed is covered by single family residential land use. The other major land uses present are park, recreation, or preserve (24%) and institutional (17%). Figure 7.2 shows the exiting land uses present in the Round Lake watershed.

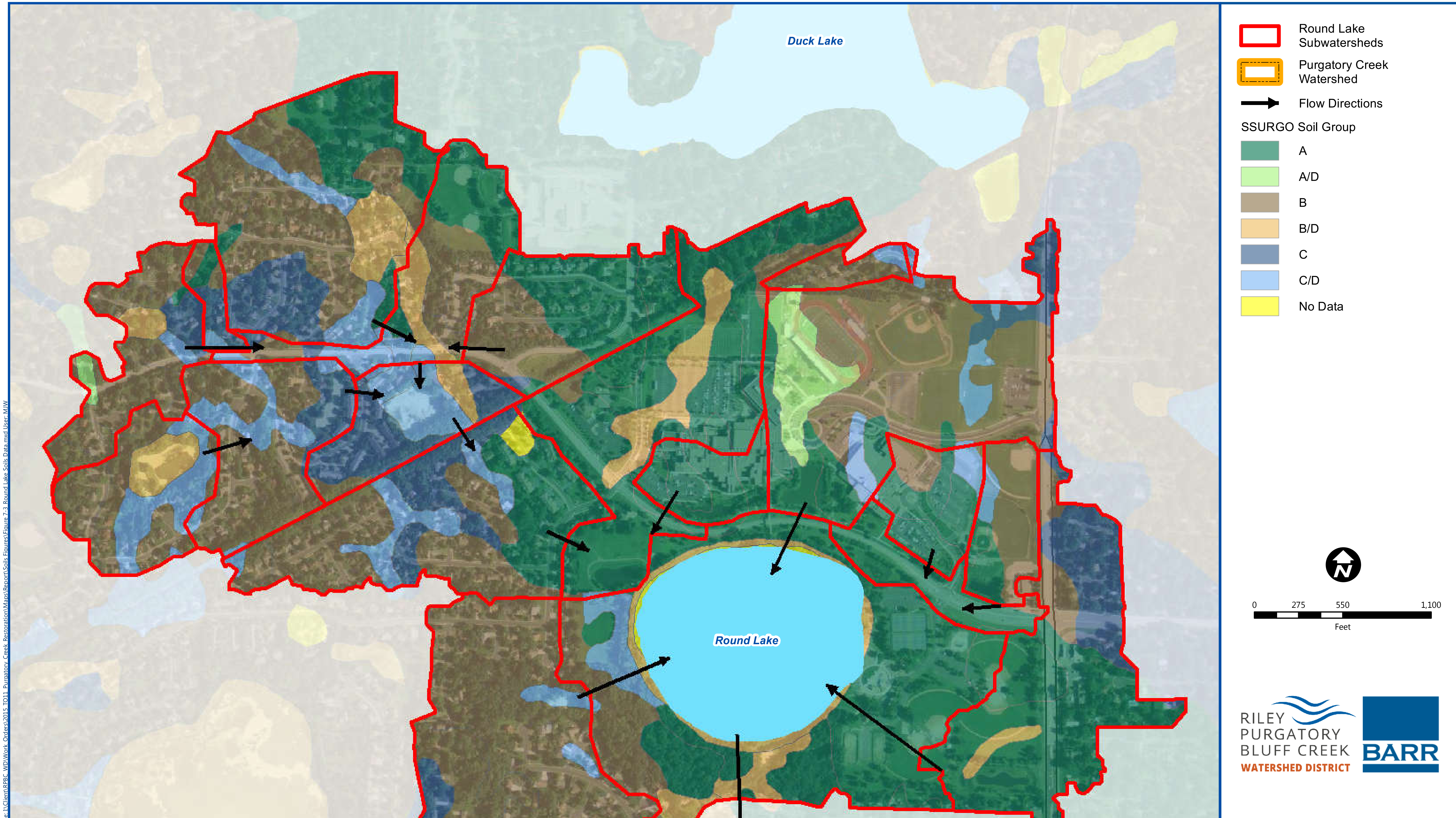
7.1.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database map for Hennepin County, the underlying soils in the Round Lake watershed are predominantly classified as hydrologic soil group (HSG) A with high infiltration rates and B with moderate infiltration rates (Figure 7.3). The remaining areas are mostly covered by HSG C and C/D soils with low infiltration rates.



ROUND LAKE LAND USE CLASSIFICATIONS

FIGURE 7.2



ROUND LAKE SOILS CLASSIFICATIONS

FIGURE 7.3

7.2 Lake Characteristics

Table 7.1 provides a summary of the physical characteristics for Round Lake. Round Lake has an open-water surface area of approximately 30 acres. The lake is deep, with a maximum depth of approximately 37 feet and mean depth of approximately 11 feet. The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 884.26 feet MSL (1987) to a low measurement of 875.29 feet MSL (1977). Since 2013 water levels in Round Lake have averaged 878.5 feet MSL. The outlet of Round Lake is a manmade structure that conveys water to Mitchell Lake. The outlet is an elevation of 879 feet. At the average water elevation of 878.5 feet the total water volume in Round Lake is 327 acre-ft.

Table 7.1 Round Lake Physical Characteristics

Lake Characteristic	Round Lake
Lake MDNR ID	27-0071-00
MPCA Lake Classification	deep
Water Level Control Elevation (feet MSL)	879
Average Water Elevation (feet MSL)	878.5
Surface Area (acres)	30
Mean Depth (feet)	11
Maximum Depth (feet)	37
Littoral Area (acres)	23
Volume (at normal water elevation) (acre-feet)	327
Thermal Stratification Pattern	Dimictic
Estimated Residence Time (years) – 2014-2015 climatic Conditions	1
Watershed Area Tributary to Upstream Lake	0
Total Watershed Area	475[2]
Subwatershed Area (acres)	475[2]
Trophic Status Based on 2015 Growing Season Average Water Quality Data	Eutrophic

1 – Average water elevation 2013-2015.
2 – Watershed area includes surface area of lakes

Given the depth of Round Lake and the review of temperature and dissolved oxygen profiles suggest that Round Lake is a dimictic lake. This means that the lake mixes twice a year in the fall and spring as surface water temperature reach the temperature of maximum density (~39^{o} F). During the summer months, temperature stratification is strong enough to prevent wind from fully mixing the lake water column.

7.3 Water Quality Conditions

Historical water quality data, in terms of growing-season (June – September) average TP concentrations, chlorophyll *a* concentrations, and Secchi disc transparency for Round Lake are presented in Figure 7.4. Also shown in these figures are the MPCA water quality standards for a deep lake for each parameter. From 1987 to 1997 TP concentrations did not meet the goal (Figure 7.4). Before 1987 and after 1997 TP concentrations have routinely switched between meeting and not meeting the goal. The most recent growing season average concentration in 2015 was 30 µg/L. The lowest average value of 16 µg/L occurred in 2009 and the highest value of 110 µg/L occurred in 1987. Since 2004 eight of the ten summer average TP concentrations met the water quality standard.

Chl-a growing season average concentrations in Round Lake have been hovering above and below water quality standard of 14 µg/L for a deep lake throughout the record (Figure 7.4). Average concentrations for each of the past 3 years have been below the standard. In 2015 the average concentration was 8 µg/L. The lowest recorded average concentration of 5.2 µg/L occurred in 1972. The highest value of 30 µg/L occurred in 1987.

Looking at growing season average Secchi depth values before 1987 all values meet the deep water standard of 1.4 meters (Figure 7.4). After 1987 values have been alternating above and below the standard. Since 2006, all summer average depths have achieved the standard with the 2015 summer average Secchi depth reaching 2.3 meters. The lowest (worst) value on record occurred in 1991 with an average value of 1 meter. The highest (best) depth occurred in 1986 with an average value of 2.8 meters.

Trends in the water quality data were determined by calculating a Thiel-Sen slope on the annual average growing season values and the significance of the trend was tested using the Mann-Kendall non parametric test at the 95% confidence internal (see Table 6.2). A trend does not exist for TP concentrations both since 1999 and over the entire record. Chl-a concentrations have an improving trend since 1999 however it was not statistically significant. The only statistically significant trend is in Secchi depths for the entire record since 1971. This shows a slight degrading water quality trend of decreasing Secchi depth values. However, the trend for the most recent data points since 1999 in Secchi depth show improving water quality although this trend is not statistically significant.

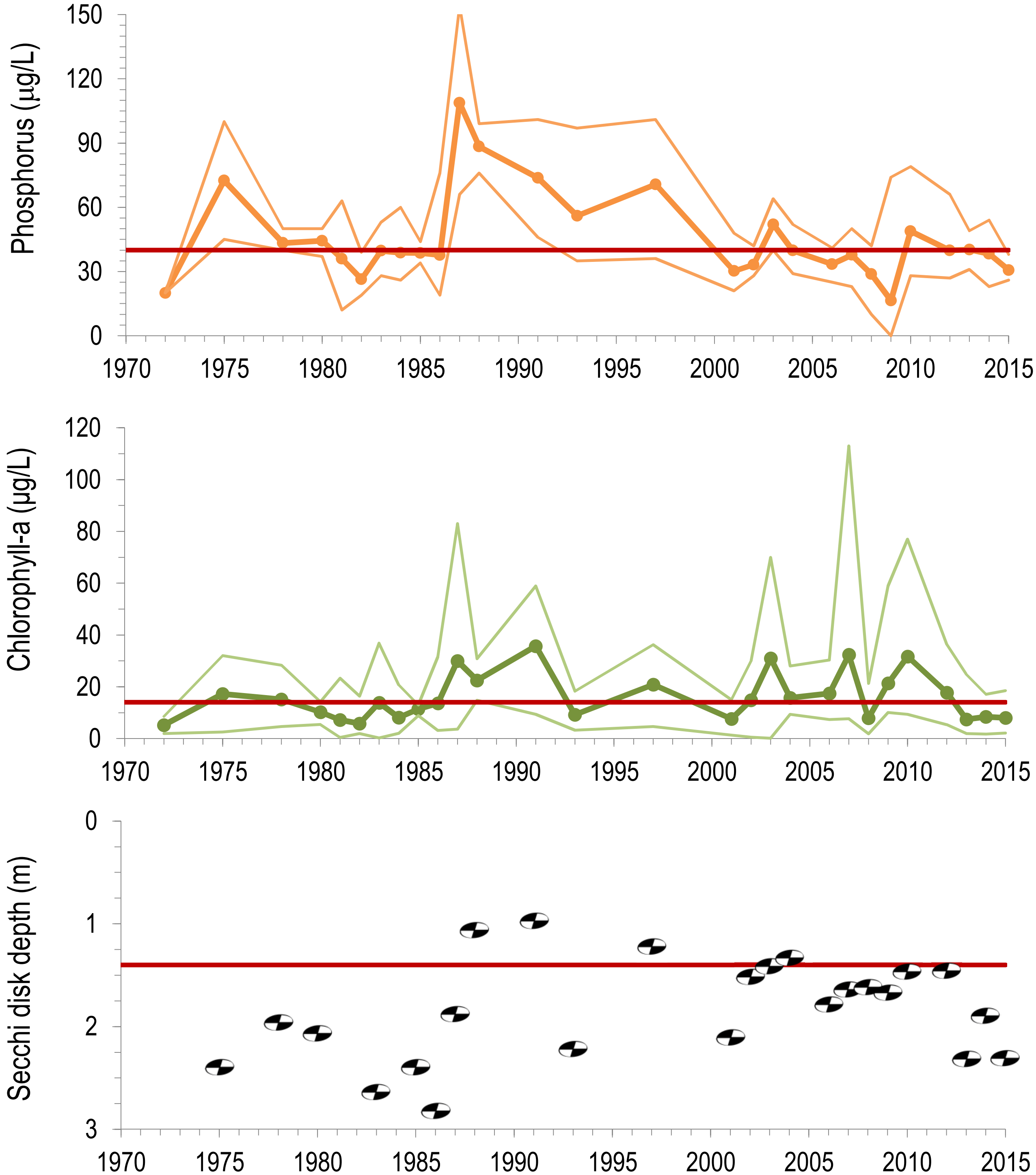


Figure 7.4
Round Lake Water Quality
Growing Season (June - September) Average, Min and Max

Table 7.2 Round Lake water quality parameter Thiel-Sen trends

Parameter	1999-2015	Entire Record
TP (µg/L/yr)	0	0
Chl-a (µg/L/yr)	0.2	-0.2
Secchi Depth (m/yr)	0.02	-0.03*

* Designates significant trends at the 95% confidence level using Mann-Kendall significance test

The city of Eden Prairie conducted an Alum treatment in Round Lake in November of 2012. Since that time growing season average concentrations in the surface waters have decreased from 40 µg/L in 2012 to 31 µg/L in 2015. Chl-a concentrations have decreased from 18 µg/L in 2012 to 8 µg/L in 2015. The most dramatic changes have occurred in the hypolimnion concentrations. Before the alum treatment, concentrations near the bottom sediments averaged 692 µg/L in 2009 and 2012 between May-September (Blue Water Science, 2015). In 2015 and 2014 concentrations in the hypolimnion average 94 µg/L and 88 µg/L, respectively, from May – September.

7.3.1 Paleolimnology

In 2011 the district contracted with St. Croix Watershed Research Station to use paleolimnological techniques to reconstruct the trophic and sedimentation history of Round Lake (Ramstack & Edlund, 2011). A sediment core was collected from the lake, and lead-210 activity was analyzed to develop a dating model and determine the sediment accumulation rate over the past 150 to 200 years.

The Round Lake TP reconstruction show that the TP concentrations pre-settlement below the most recent values in 2010. Concentrations were elevated in the 1950s through the 1960s with reductions observed in the 1970s-1990s. The lake did experience an increase in the sedimentation are in the 1920s and remained elevated until the early1990s, with the peak rate occurring in 1966. It is difficult to determine the reason for the increase in concentration in the 1950s and 1960s, it could be tied to the increase in sediment entering the lake due to adjacent agricultural practices. Concentrations were stable through the 2000's (Figure 7.5). The reconstructed values in the 2000s exceed the actual measured concentrations in the lake during this time period (Ramstack & Edlund, 2011).

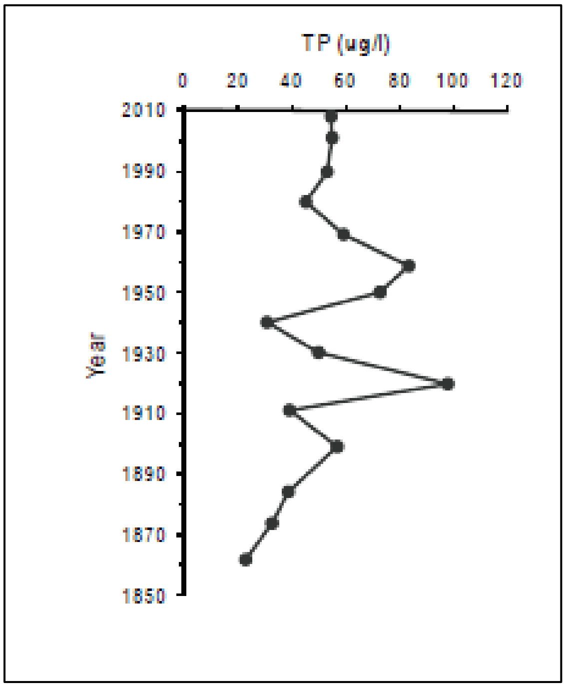


Figure 7.5 **Round Lake Diatom-inferred TP reconstruction (Ramstack & Edlund, 2011).**

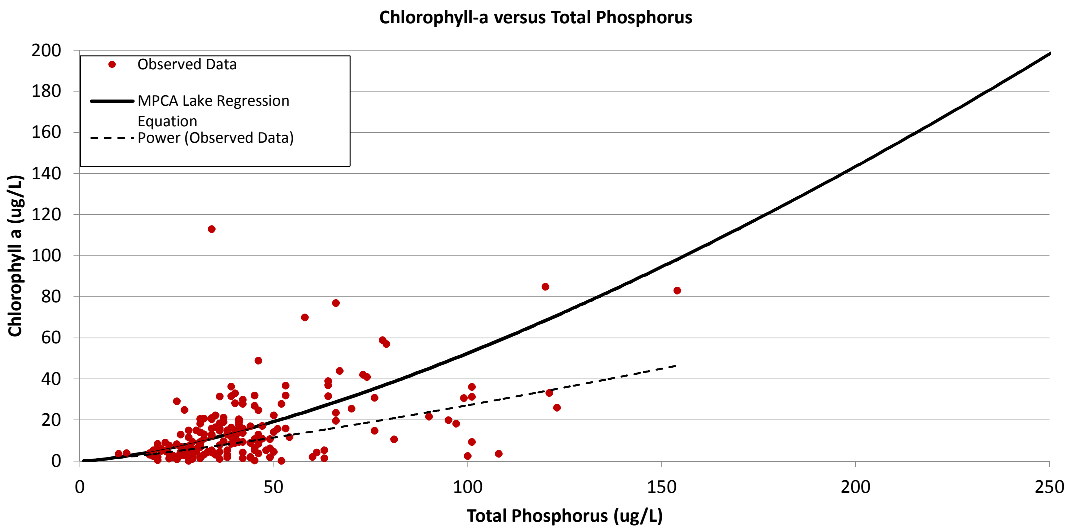
7.3.2 Water Quality Relationships

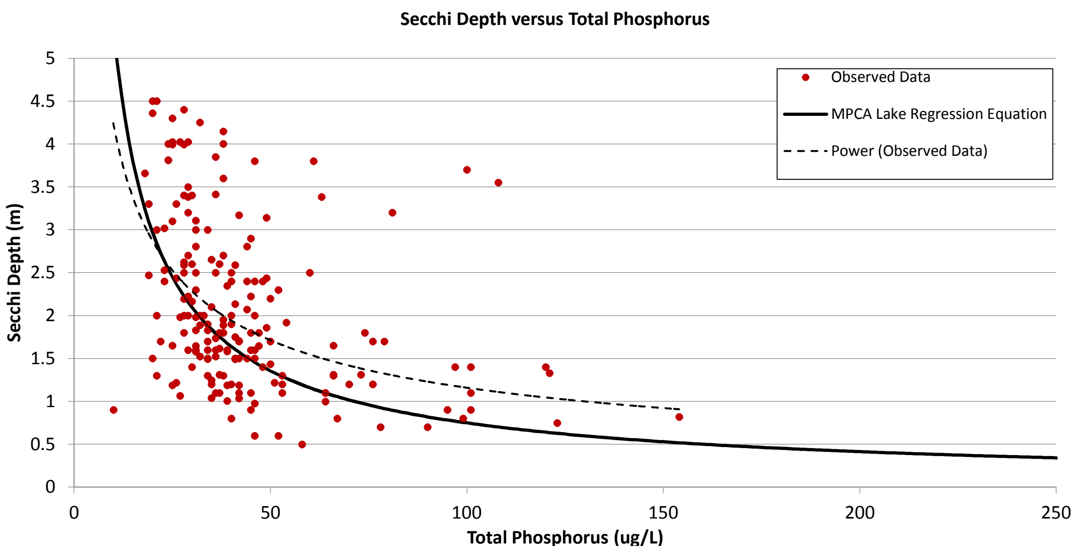
As previously discussed, phosphorus often acts as the limiting nutrient for algal growth (as measured by chlorophyll *a*), which in turn, affects lake water clarity (Secchi depth). This section describes how incremental phosphorus load reductions would be expected to impact perceptible changes in lake water quality. The compiled data for the water quality variables from Round Lake were analyzed to develop relationships between the water quality parameters: TP, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season averages. In addition to developing the water quality relationships based on the observed data, the regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) were also plotted against the lake data.

The relationships between the various water quality parameters for the actual Round Lake data did indicate some correlation between the water quality parameters (Figure 7.6). The MPCA regression equations resulted in similar fit for the chlorophyll *a*, Secchi disc transparency data, and TP. For this reason the MPCA statewide regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Round Lake based on TP concentration.

Figure 7.6 shows the individual water quality data points for Round Lake, along with plots of the MPCA statewide regression equations. The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla (µg/L) = 1.31 Log10 TP (µg/L) – 0.95
- Log10 Secchi (meters) = -0.59 Log10 Chla (µg/L) + 0.89
- Log10 Secchi (meters)= -0.81 Log10 TP (µg/L) + 1.51





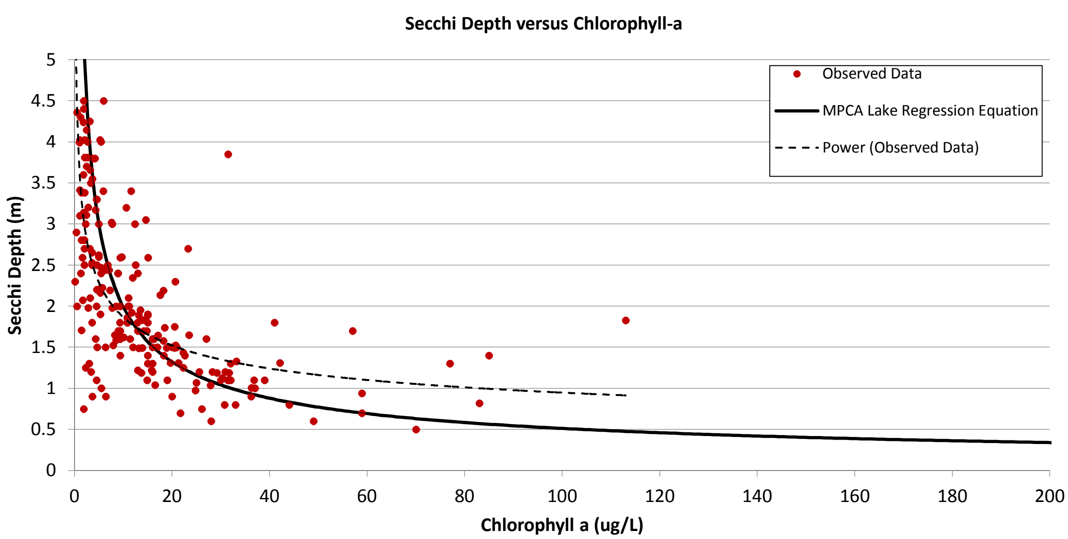


Figure 7.6
Round Lake Individual Samples
Water Quality Parameter
Regression Relationships

7.4 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores)). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

7.4.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess TP loads.

Plankton surveys have been collected on Round Lake for years: 1997, 2001, 2003, 2004, 2008, and 2009. Additionally, phycocyanin (cyanobacteria (blue-green algae) pigment) readings have been collected in years 2009 - 2011. Plankton surveys in Round Lake as part of the UAA found that algae blooms were exacerbated by the lack of a zooplankton population (Barr Engineering, 1999). A survey of plankton in 2008 (CH2M HILL, 2009) determined that the phytoplankton density was 91% cyanobacteria.

While green algae are edible to zooplankton and serve as a valuable food source, cyanobacteria are considered a nuisance type of algae because they:

- Are generally inedible to fish, waterfowl, and most zooplankters
- Float at the lake surface in expansive algal blooms
- May be toxic to animals when occurring in large blooms
- Can disrupt lake recreation because they are most likely to be present during the summer months

7.4.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or

enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

The zooplankton population was found to be dominated by small bodied organisms that were unable to graze on the large bodied blue green algae, allowing for algae growth to be intensified (CH2M HILL, 2009).

7.4.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

A plant survey conducted by Blue Water Science for the City of Eden Prairie in Round Lake found moderate plant diversity with 6 species of submerged plants observed in the spring and 8 species in the later summer (Blue Water Science, 2014). Three species of invasive macrophytes were observed in Round Lake: curlyleaf pondweed, Eurasian watermilfoil and Brittle naiad. Eurasian water milfoil was first found in Round Lake is 1995. In the 2014 survey Eurasian watermilfoil was found to be growing at low to moderate densities with plants being found at 29% of the early summer sites and 12% of the late summer sites. This level does not require control at this time (Blue Water Science, 2014). Brittle naiad was first observed in Round Lake is 2010. In 2014 brittle naiad was not found at any sites in the early summer survey, but was found at 9 late summer sites which represent light to moderate densities. Curlyleaf pondweed was found at 29% of the early summer sites and only 6 % of the late summer sites in the 2014 surveys. This level does not require control at this time (Blue Water Science, 2014). The most abundant plant species found in Round Lake was coontail at ~65% of the sample sites in both the early and late summer surveys.

7.4.4 Fishery

In 1992 the MDNR classified Round Lake and other Minnesota lakes relative to fisheries. According to the ecological classification, Round Lake was found to be a Class 30 lake, which signifies a good permanent fishery (Schupp, 1992). Based on the classification, the primary fish species in Round Lake should be northern pike, bluegill, and carp. Neither northern pike nor carp have been found in Round Lake.

MDNR conducted the most recent fish survey in Round Lake in year 2012. They found that Bluegill sunfish represented 93% of the fish sampled during the analysis. The study found 1.8% of the sample was black crappie as well as a marginal largemouth bass population. Other fish found in low numbers were pumpkinseed and hybrid sunfish, and black bullhead. Fish stocking took place in Round Lake prior to 1992. The lake had been stocked with walleye, rainbow trout, and hybrid (tiger) muskellunge. None of these fish have been observed in the lake since 2000. Fish surveys in 2011 and 2012 found zero occurrences of carp in Round Lake (Sorensen, et al., 2015).

7.5 TP Source Assessment

The watershed and in-lake water quality models were developed to assess both the external and internal TP loads in Round Lake for the 2015 water year (October 2014 – September 2015). A detailed discussion of the modeling methods used is presented in Section 2.2.2 and Appendix D. Possible lake external loads of TP include atmospheric depositions, stormwater runoff from the lake watershed, surficial groundwater interactions with the lake waters, internal loads from upstream ponds and wetlands, and load from any upstream lakes that might flow into the waterbody.

External loads that applied to Round Lake are atmospheric deposition and watershed loads. Based on the 2015 water balance it appeared that there was no net surficial groundwater inflow meaning the inflow of groundwater likely equals the outflow. In addition, Round Lake is not downstream from another major waterbody/lake and no creeks with erosion potential contribute the Round Lake. While the RPBCWD has collected water quality data in several ponds within the Round Lake watershed, the internal loading within the ponds and wetlands was not evaluated for this study. Internal TP loads can come from sediment TP release, curlyleaf pondweed, or benthivorous fish activity.

Figure 7.7 summarizes the 2015 annual water year TP budgets for Round Lake, including the relative contributions of the external and internal TP loads. This budget explains the sources of TP to the lake and help direct and prioritizes implementation strategies. Each of the sources are discussed further in the following section(s).

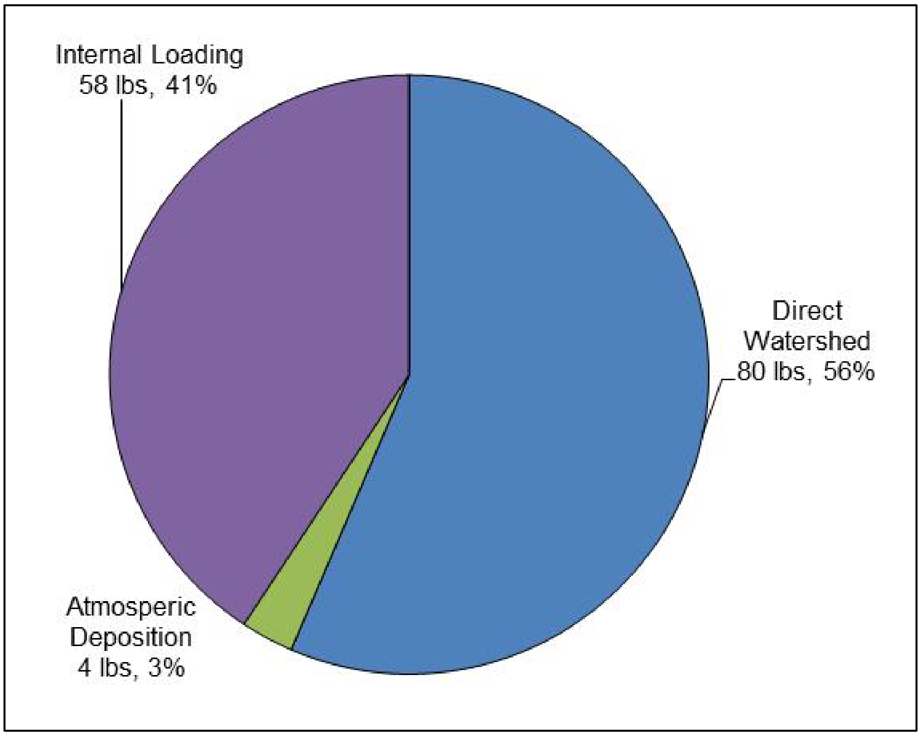


Figure 7.7 Round Lake TP load sources for 2015 water year

7.5.1 External Loads

7.5.1.1 Atmospheric Deposition

Atmospheric deposition of TP onto the lake water surface was calculated by using the estimated statewide TP atmospheric deposition rate of 0.17 kg/ha/year (Barr, 2004). For Round Lake, this loading rate was applied to the combined open water area. The daily rate was applied to the surface area of the lake based on the modeled lake water elevation from the lake water balance model. The resulting atmospheric deposition TP load for the 2015 water year was 4 pounds which equates to 3% of the TP load to Round Lake (Figure 7.7).

7.5.1.2 Watershed Loads

The P8 watershed model estimated surface runoff from Round Lake's subwatersheds based on observed climatic data (precipitation and temperature). The total watershed load from the watersheds in Round Lake for the 2015 water year was modeled to be 209 pounds. The watershed load travels through existing stormwater ponds, wetlands, infiltration practices, and other BMPs located throughout the watershed providing treatment resulting in an estimate load of only 80 pounds reaching the lake. This represents a 61% removal being provided by existing treatment practices in the watershed. The 80 pounds TP load reaching the lake from the watershed load represented 56% of the total TP load to Round Lake (Figure 7.7).

To help evaluate areas that might benefit from additional treatment, watershed loads to the lake were calculated for each of Round Lake's individual subwatersheds. The load to the lake is defined as the amount of TP load from that watershed reaching the lake without being removed by an existing BMP within the subwatershed or downstream from the subwatershed. The P8 results were used to calculate the total annual average untreated watershed TP loads from each subwatershed. Next the watershed load to the lake was calculated. This was accomplished by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each subwatershed that reached the lake without being removed by an existing BMP. The watershed load to the lake for each subwatershed is shown in Figure 7.8.

7.5.2 Internal Loads

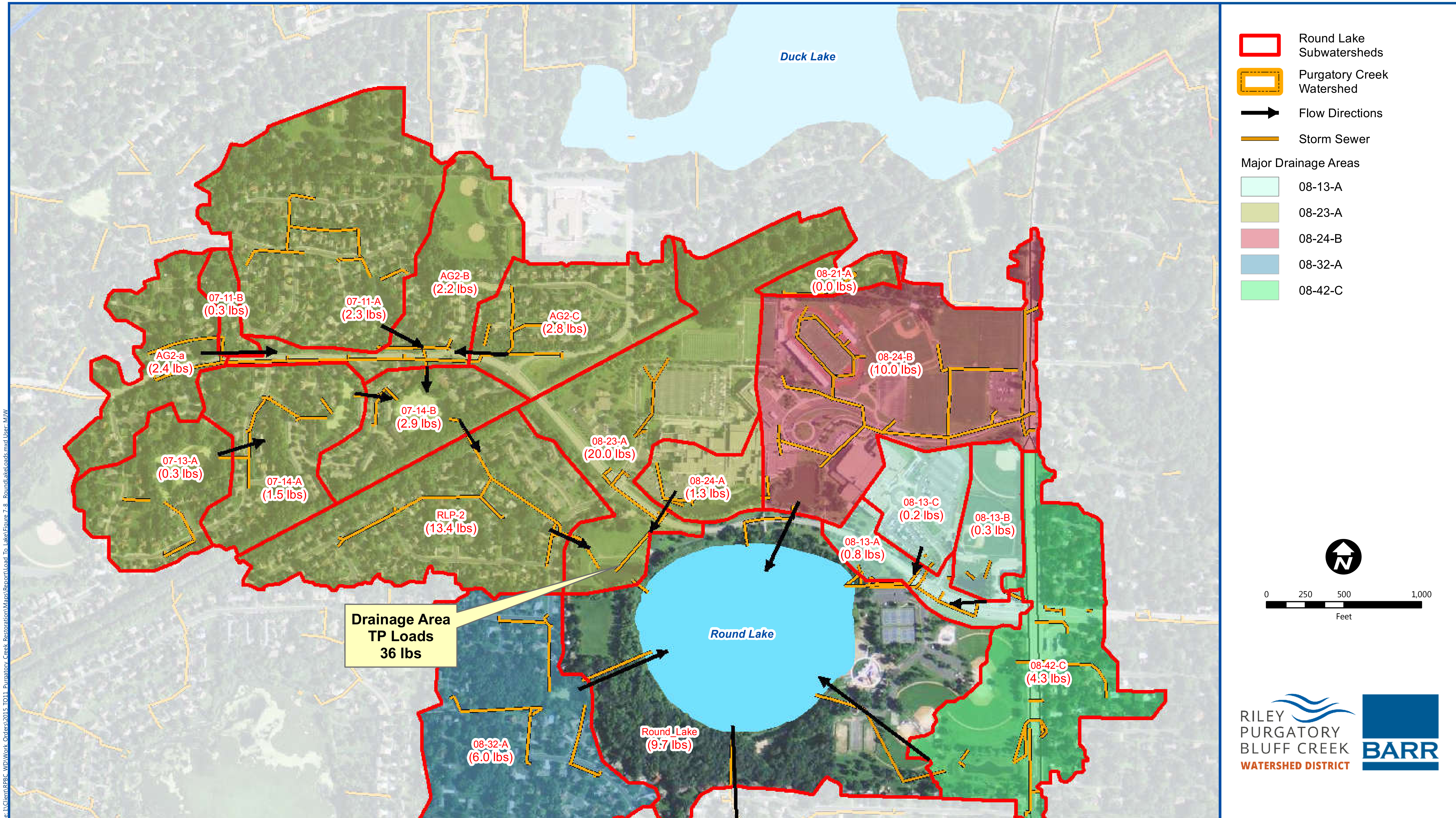
Internal loading in Round Lakes represented 41% (58 pounds) of the TP loads in the 2015 water year (Figure 7.7). The internal loading sources to Round Lake appear to primarily be sediment release with only minor contributions from curlyleaf pondweed.

7.5.2.1 Curlyleaf Pondweed

Because of the relatively low occurrence in Round Lake TP loading from curlyleaf pondweed was not explicitly modeled for this study. The internal loading calibration parameter was used to simulate this release along with other sources of internal loading. In 2014 curlyleaf pondweed was found to be in Round Lake but at levels that are not of concern (Blue Water Science, 2014). Due to the low levels it is likely that curlyleaf pondweed is a very minor source of TP to Round Lake.

7.5.2.2 Benthivorous Fish Activity

In fish surveys of Round Lake in 2011 and 2012 by the University of Minnesota no adult or young carp were found (Sorensen, et al., 2015). As a result, this analysis assumes that the activities of carp and other benthivorous fish are not a significant source of TP in Round Lake and were not quantified as part of the in-lake water quality modeling in 2015.



ROUND LAKE SUBWATERSHED TP LOADS TO THE LAKE

FIGURE 7.8

7.5.2.3 Sediment Release

Internal loading through sediment release occurs during anoxic conditions. A review of dissolved oxygen profiles in Round Lake showed anoxic conditions reaching a depth of 13 feet from the lakes water surface during the middle summer months. Persistent stratification in Round Lakes occurs throughout the summer with mixing events only happening in the late fall and early spring. The stratification and subsequent anoxic conditions in the hypolimnion allow for the release of phosphorus throughout the growing season months. Elevated TP concentrations have been recorded in the lake hypolimnion corresponding to anoxic conditions. TP concentrations in the hypolimnion reached as high as 300 µg/L in 2015 during the end of September. As the lake mixes during turnover in the fall from temperature changes this phosphorus load is distributed throughout the water column impacting surface water concentrations.

7.5.3 TP Load Reductions

The in-lake model was used to determine TP load reductions needed to meet the water quality goal for Round Lake. Table 7.3 shows the measured and modeled growing season average (June – September) concentration, the TP load to the lake under existing conditions, the water quality goal, the TP loading capacity for meeting the water quality standard and the required percent reduction needed to meet the water quality goal. Under existing conditions, Round Lake is meeting the water quality goal for a deep lake of 40 µg/L. Modeled and measured growing season average concentrations in the lake surfaces waters for the 2015 water year was 29 µg/L and 30 µg/L respectively. The TP load under existing conditions was 142 pounds for the 2015 water years. No reductions are needed in Round Lake to meet the water quality goal for the analyzed time period. While load reductions are not required in Round Lake to meet the water quality standard for the 2015 water year, BMPs to further reduce the TP concentrations in the lake could be implemented to protect and enhance the health of the resource.

Table 7.3 Round Lake estimated load reductions required to meet TP water quality goal for 2015 water year

Measured growing season average TP concentration (µg/L)	Modeled growing season average TP concentration (µg/L)	Estimate 2015 TP loading rate (lbs/yr)	TP concentration goal (µg/L)	Estimated Loading Capacity to meet WQ goal (lbs/yr)	Percent reduction needed to achieve goal (%)
30	29	142	40	Meets goal	0

Figure 7.9 shows how lake concentrations react to lake load reductions. The calibrated in-lake TP model was used to determine in lake water quality based on the amount of TP load to the lake. TP concentrations were calculated using the in-lake model. Chl-a and Secchi depth concentrations were determined based on the water quality relationships discussed in Section 7.3. The figure shows how incremental load reductions would impact the water quality in Round Lake. A TP load reduction of 20 pounds would reduce the lake TP concentration to 25 µg/L. A TP load reduction of 40 pounds could reduce the lake concentration to 20 µg/L.

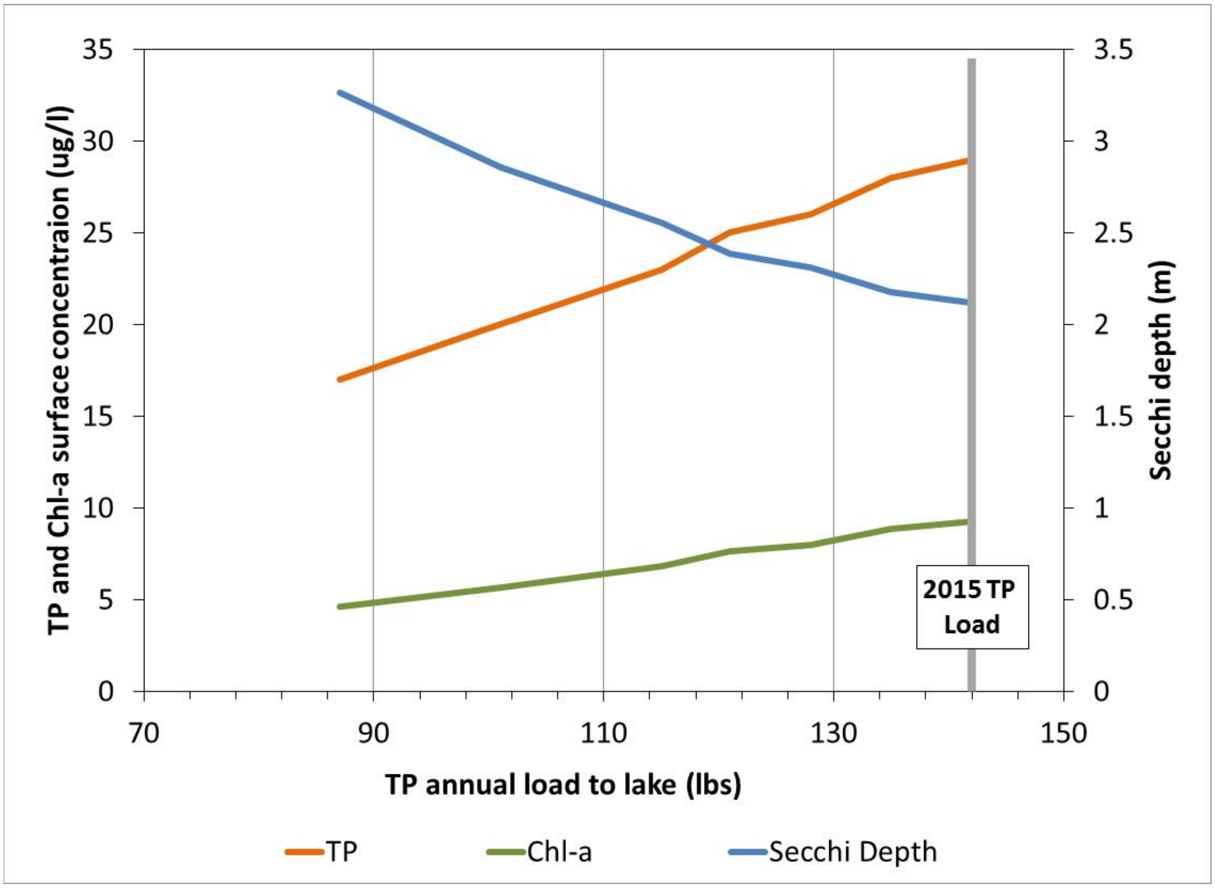


Figure 7.9 **Round Lake TP load relationship with lake water quality (TP, Chl-a and clarity)**

7.6 Summary of Diagnostic Findings

Table 7.4 provides a summary of the key water-quality findings for Round Lake.

Table 7.4 Diagnostic Findings for Round Lake

Topic	Round Lake
Water Quality Standards and Goals	- Meets the MPCA deep lake water quality standards for TP and Chl-a in 2015. - Does not meet the RPBCWD long term vision for Secchi depth of 2 meters.
Baseline Water Quality	- TP concentration of 30 ug/l in 2015 is equivalent with historical reconstructed TP concentrations.
Water Quality Trends	- No significant water quality trends since 1999.
Watershed Runoff	- Represents approximately 56% of the annual TP load. - Watershed load is estimated to be reduced by 61% by existing BMPs, ponds, and wetlands located throughout the watershed.
Macrophyte Status	- Invasive species curlyleaf pondweed, Eurasian watermilfoil and Brittle naiad are present in moderate to low densities
Fishery Status	- No carp found in recent survey by U of M
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer
Internal Loading from sediments	- Internal loading from sediment estimated to be 41% of annual TP load
Methylmercury in Fish Tissues	- Listed as impaired for aquatic consumption due to mercury in fish tissue in 2002 - A TMDL plan was approved in 2008 by the MPCA.

Additional discussion of the diagnostic findings in relation to the sources of TP and water quality of the lake based on the data analyses, watershed and in-lake modeling, and review of recent studies and information is included. These conclusions influenced the implementation strategies evaluated for the management of Round Lake water quality (see Section 7.8).

- In 2015 Round Lake achieved the MPCA shallow lake water quality standards for all TP and Chl-a concentrations. Secchi Depth did not achieve the MPCA goal in 2015 but did meet the goal for years 2006-2014. A significant trend in water quality parameters were not detected for the time period 1999-2015.

- Approximately 95 percent of the watershed runoff receives treatment prior to entering Round Lake due to the number of stormwater ponds and other waterbodies within the watershed. As stormwater runoff passes through the many constructed stormwater ponds and natural wetlands in the watershed, significant removal of TP associated with particulates in the runoff occurs due to particle settling and infiltration. Modeling suggests that 61% of the watershed load in removed in existing BMPs before reaching Round Lake. As a result, the watershed modeling suggests that a significant portion of the TP in the watershed runoff reaching the lake is in a soluble form or associated with very small particles that are difficult to settle. Therefore, treatment practices that can remove dissolved phosphorus such as infiltration and enhanced filtration practices should be examined in addition to practices in currently untreated areas.

- The watershed phosphorous load to Round Lake represented 56 percent of the total annual TP budget to the lake during the 2015 water year. Internal loading represented another 41 percent of the total annual TP budget.

- Figure 7.8 shows the estimated TP loading from the major drainage basins in the Round Lake watershed. The watershed modeling suggests that 45 percent of the watershed load to Round Lake are part of the 06-33-A drainage area.

- The most recent plant surveys in Round Lake indicate that invasive species curlyleaf pondweed, Eurasian watermilfoil and Brittle naiad are present in moderate to low densities (Blue Water Science, 2014).

- The carp population was analyzed in Round Lake in 2011 and 2012 as part of the University of Minnesota's study for Purgatory Creek (Sorensen, et al., 2015). Zero occurrences of carp either adult or young were found in Round Lake.

7.7 Current and Past Management Actions

The following includes a summary of BMPs either implemented or analyzed in the Round Lake watershed:

- Removal of geese from Round Lake park to control TP additions and E. coli beach levels
- Use of barley straw in Bren Lane and RLP stormwater ponds to reduce TP levels. Barley straw additions did not appear to impact TP concentrations in the ponds (Blue Water Science, 2006) (Blue Water Science, 2008).
- Harvesting of 190 tons of invasive and overgrowth plants in 2008 and 2009 (RPBCWD, 2008) (RPBCWD, 2009).
- Ponds M, RLE, and RLP in the Round Lake watershed were dredged and expanded to meet NURP standards in the winter of 2009/2010 by the city of Eden Prairie.
- Liquid calcium nitrate (LCN) was applied to Round Lake as part of a pilot test on June 15, 2010 (Ch2M HILL, 2011). The application of calcium nitrate halted phosphorus release and mercury methylation, but was not able to reverse either
- In-lake alum treatment occurred in 2012 by the City of Eden Prairie. If properly dosed, the treatment within the lake is expected to initially reduce the internal phosphorus loading by approximately 80% (Welch & Cooke, 1999), resulting in a reduction of 46 pounds per year.

- Ponds 07-14-A, 07-14-B, 08-23-A, 08-32-A, 09-13-A, and 08-13-B analyzed in the Round Lake watershed over years 2012 and 2013, were determined to have TP concentrations above 0.250 mg/l and could benefit from remediation measures (RPBCWD, 2014).
- Carp were not found in Round Lake as part of surveys conducted in 2011 and 2012 (Sorensen, et al., 2015).
- Suggested BMP and mitigation measures for Round Lake as part of the "One Water" Water Management Plant (CH2M HILL, 2011) include:
    - control curlyleaf pondweed mechanically and through herbicide treatment,
    - control Eurasian water milfoil mechanically and/or through herbicide treatment,
    - control cyanobacteria through hypolimnetic oxygenation, sediment oxygenation, or chemical inactivation of phosphorus,
    - control phytoplankton through bio-manipulation and fisheries management,
    - fisheries management to develop a sustainable bluegill and northern pike population.

7.8 Evaluation of Water Quality Improvement Options

All of the BMPs identified for Round Lake are listed and described in detail in the following subsections. Table 7.5 provides a list of the potential BMPs and Figure 7.10 shows the identified potential BMP locations in the Round Lake watershed.

7.8.1 New storm water feature in subwatershed Round_Lake, RL_1

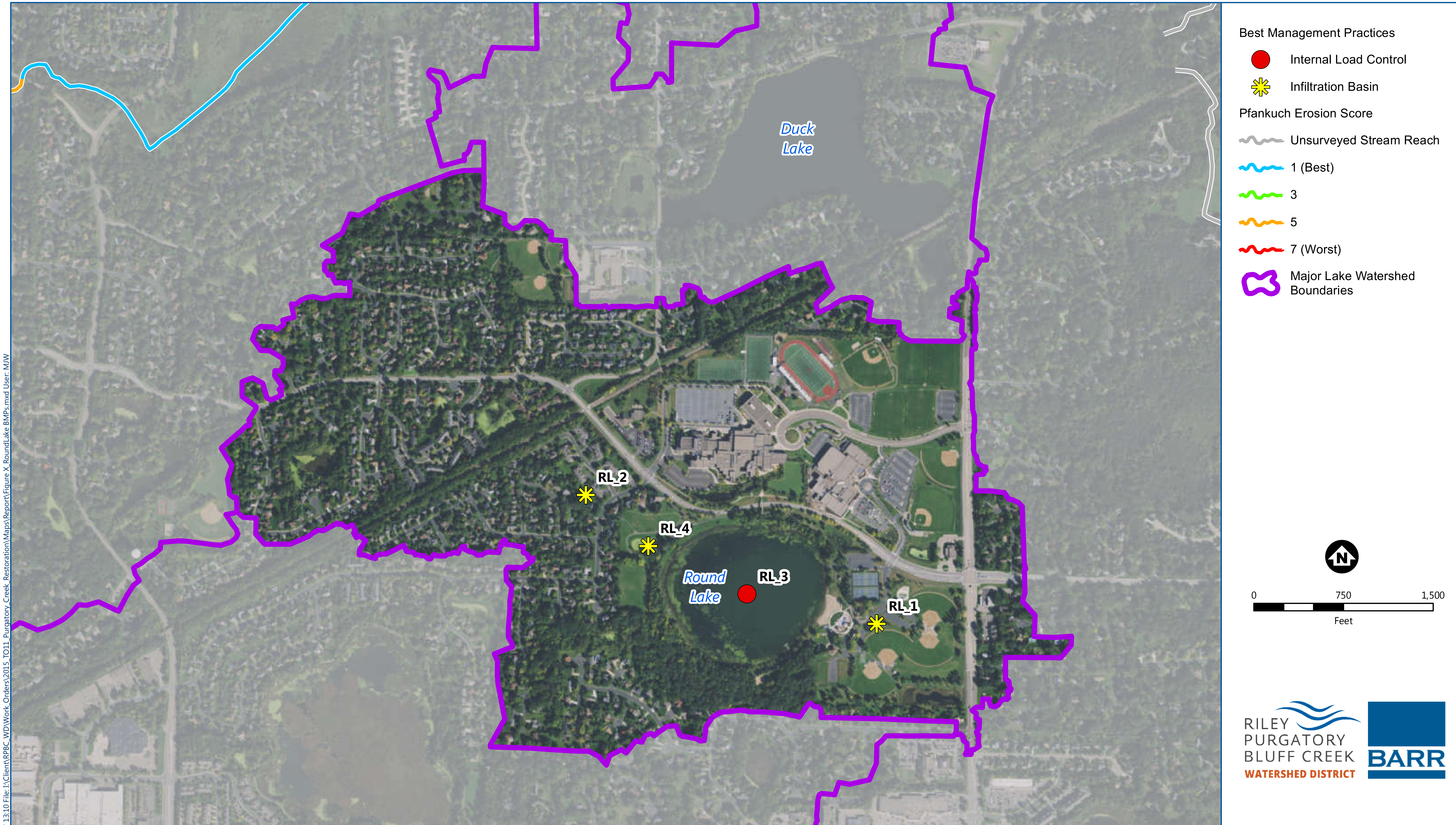
As part of the required treatment to meet the district's storm water management rule for redevelopment, the city of Eden Prairie is constructing a storm water treatment feature (RL_1) in subwatershed Round_Lake around the parking lots of Round Lake Park. This feature did not exist in 2015, the period of model calibration. Therefore, this feature reduces TP loading from the watershed to Round Lake from what was modeled. The cost of this feature, however, has already been incurred.

Table 7.5 - Summary of Round Lake BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
RL_1	Infiltration Basin *- A 0.4 acre, 1-foot deep infiltration basin designed to treat 2.7 acres of impervious area*	6.8	6.8	N/A	$118,300 ($95,000 - $166,000)	$2,400 ($1,900 - $3,300)	$930 ($750 - $1,310)	$930 ($750 - $1,310)
RL_2	Underground Infiltration Basin *- A buried 0.3-acre, 1.5-foot deep chamber intercepting storm sewer, designed to treat 10.9 acres of impervious area*	27.1	24.4	N/A	$245,300 ($196,000 - $343,000)	$4,900 ($3,900 - $6,900)	$480 ($390 - $680)	$540 ($430 - $750)
RL_3	Internal Load Control *- Two treatments of a whole lake alum treatment*	46	46	N/A	$490,000 ($392,000 - $686,000)	$0	$350 ($280 - $490)	$350 ($280 - $490)
RL_4	Infiltration Basin *- Convert the existing 1.4 acre pond to an infiltration basin, designed to treat 13 acres of impervious area*	20.6	20.6	N/A	$361,700 ($289,000 - $506,000)	$7,200 ($5,800 - $10,100)	$930 ($750 - $1,310)	$930 ($750 - $1,310)

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. There is no overall load reduction goal for Round Lake; this lake already meets the goal.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.



ALL IDENTIFIED BMPs, ROUND LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 7.10

7.8.2 Underground infiltration basin in subwatershed RLP-2, RL_2

BMP RL_2 is an underground infiltration structure in subwatershed RLP-2, in the back yards of homes between Hunters Run and Bridlewood Curve, designed to treat 10.9 acres of impervious area. The buried infiltration structure is proposed to be approximately 0.3 acres and about 1.5 feet deep, and could be constructed of pre-cast or cast-in-place concrete, or a pre-molded plastic system. The system would have one inlet from the existing storm sewer that runs through this area, and one 42-inch overflow outlet tied back into the same existing storm sewer system. The system could potentially remove 27.1 pounds of TP per year based on 30-year modeling results. Based on the distance of the BMP to Round Lake and the opportunities for sediment and TP deposition, the estimated reduction of TP load to the lake is about 24.4 pounds of TP per year. The cost-benefit of this BMP is estimated to be about $540 per pound of TP, assuming the BMP functions for 30 years.

7.8.3 Internal load control in Round Lake, RL_3

BMP RL_3 represents the alum treatment to bind mobile phosphorus in the lake sediment which occurred in 2012 by Eden Prairie (Section 7.7). The treatment within the lake is expected to initially reduce the internal phosphorus loading by approximately 80% (Welch & Cooke, 1999), resulting in a reduction of 46 pounds per year. Because the treatment has already occurred the estimated cost of BMP RL_3 is provided for comparison with other BMPs. The cost-benefit of this BMP is estimated to be about $350 per pound of TP, assuming treatment is not needed again for at least another 15 years (Huser, et al., 2015). However, as TP loading from the contributing watershed continues in the future, phosphorus will again build up in the sediment and internal loading may become a significant factor again in the future. Therefore, future treatments may be necessary again in approximately about ten years. The periodic nature of internal load control highlights the importance of treating the contributing watershed load in preference over internal load control.

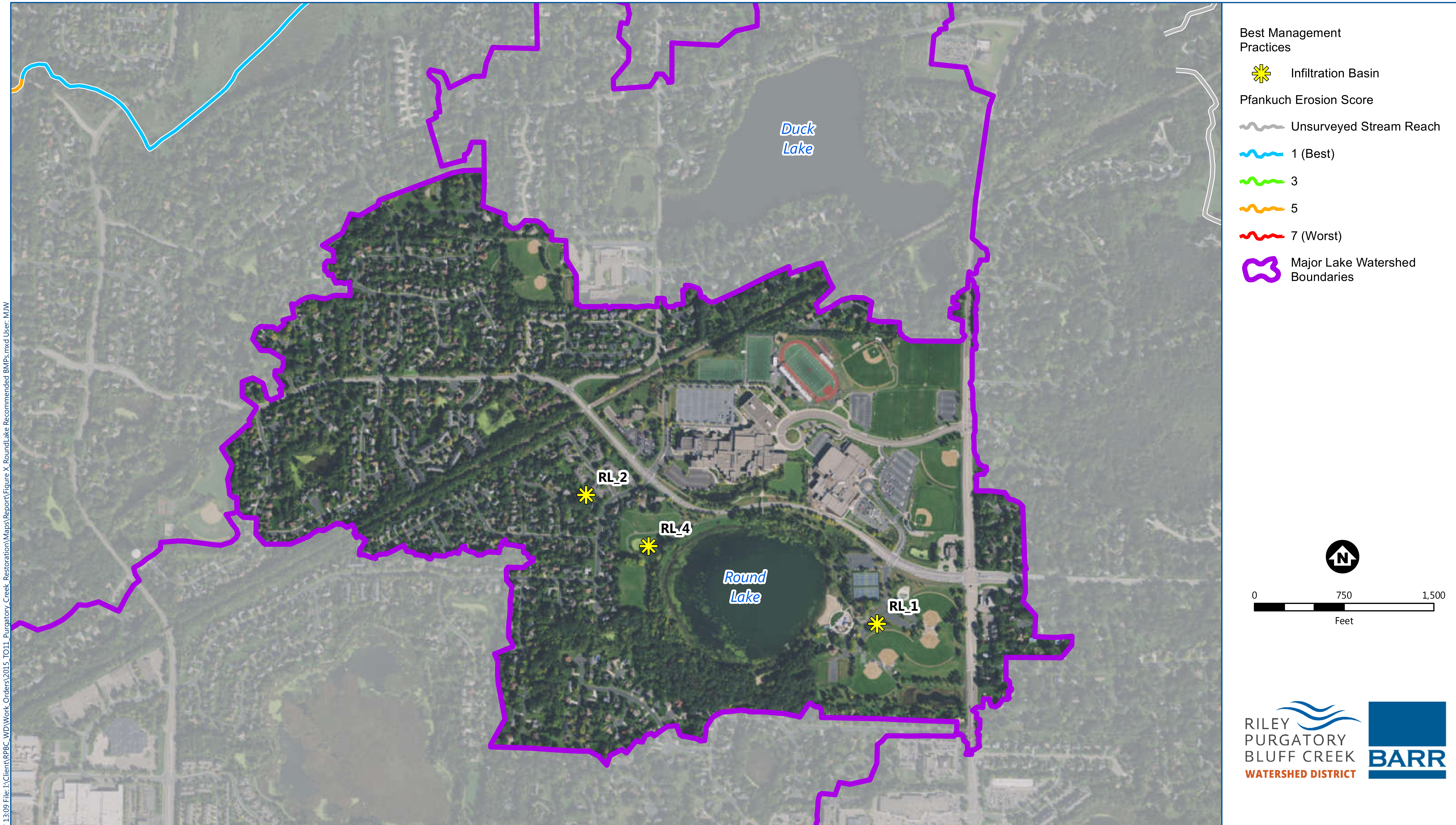
7.8.4 Converted pond to infiltration basin in subwatershed 08-23-A, RL_4

BMP RL_4 is an existing stormwater pond converted to an infiltration basin in subwatershed 08-23-A adjacent to Round Lake east of Hames Way, designed to treat 13 acres of impervious area. The soils in this area are “A” soils, with a high capacity to infiltrate water. This infiltration basin is proposed to be approximately 1.4 acres at the surface and about 1.5 feet deep. The infiltration basin would have two inlets from existing storm sewer, and one 36-inch overflow outlet. The infiltration basin could remove 20.6 pounds of TP per year, in addition to what the existing stormwater pond is already removing. Based on the proximity of the BMP in the watershed relative to Round Lake, the estimated reduction of TP to the lake is also about 20.6 pounds of TP per year. The cost-benefit of this BMP for Round Lake is estimated to be about $930 per pound of TP, assuming the BMP functions for 30 years. However, this area may have trouble infiltrating water because of the proximity to the lake and the elevation of the BMP, despite the “A” soils.

7.9 Recommendations for Water Quality Goal Attainment

There is no overall load reduction goal for Round Lake because this lake is already meeting water quality goals (Section 7.5.3). Even though a load reduction is not necessary, some of the identified BMPs, would be beneficial for Round Lake. Therefore, the recommended BMPs for the Round Lake watershed are in the bullet list below along with the magnitude of the TP load reduction expected. The recommended BMPs, including the recent alum treatment, are also shown in Figure 7.11. The total reduction expected by the recommended BMPs is 51.8 pounds per year from the watershed. The summary below is intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment TP release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. This is consistent with the district's "ONE WATER Watershed Management Approach" (Section 2.3.4 of (RPBCWD, 2011)).

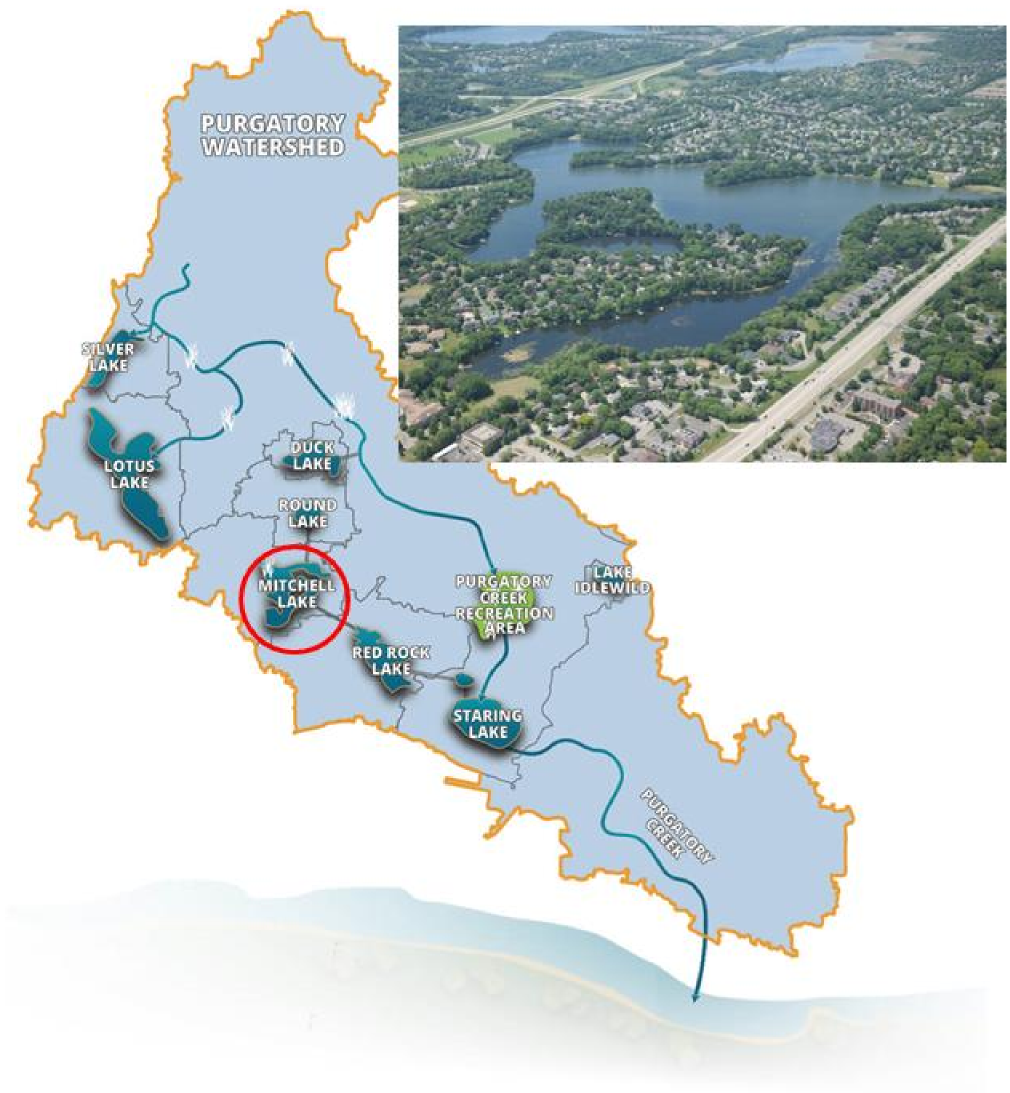
- RL_1, infiltration basin in subwatershed Round_Lake, ~6.8 pounds TP per year
- RL_2, underground infiltration basin in subwatershed RLP-2, ~24.4 pounds TP per year
- RL_4, converted pond to infiltration basin in subwatershed 08-23-A, ~20.6 pounds of TP per year



RECOMMENDED BMPs, ROUND LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 7.11

8.0 Mitchell Lake



8.1 Watershed Characteristics

The Mitchell Lake watershed lies with the boundaries of the Cities of Eden Prairie and Chanhassen. The direct watershed area contributing to Mitchell Lake is 937 acres including the lake surface area of 124 acres (Figure 8.1). Mitchell Lake has one upstream lake. Round Lake with a watershed of 475 acres contributes flow to Mitchell Lake. The flow from Mitchell Lake exits through a control structure into a storm sewer pipe that drains to Red Rock Lake.

8.1.1 Drainage Patterns

The stormwater conveyance system in the Mitchell Lake watershed is comprised of storm sewer networks, constructed stormwater detention ponds, and natural wetlands within the watersheds tributary to the lake (Figure 8.1). Most of the constructed stormwater ponds within the Mitchell Lake watershed are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows.

The Mitchell Lake watershed was divided into subwatersheds based on updated topographical data (MDNR, 2011), storm sewer data, BMP locations, and other information from the cities of Chanhassen and Eden Prairie. The subwatersheds were grouped into 10 major drainage areas within the Mitchell Lake watershed (Figure 8.1). Each major drainage area is named after the terminating watershed in each conveyance network. In addition to the major drainage areas is the lakes direct watershed. The direct watershed includes areas along the shoreline of the lake that contribute flow directly to the lake through surface flow as well as small stormsewered sections that do not receive treatment before discharging into the lake.

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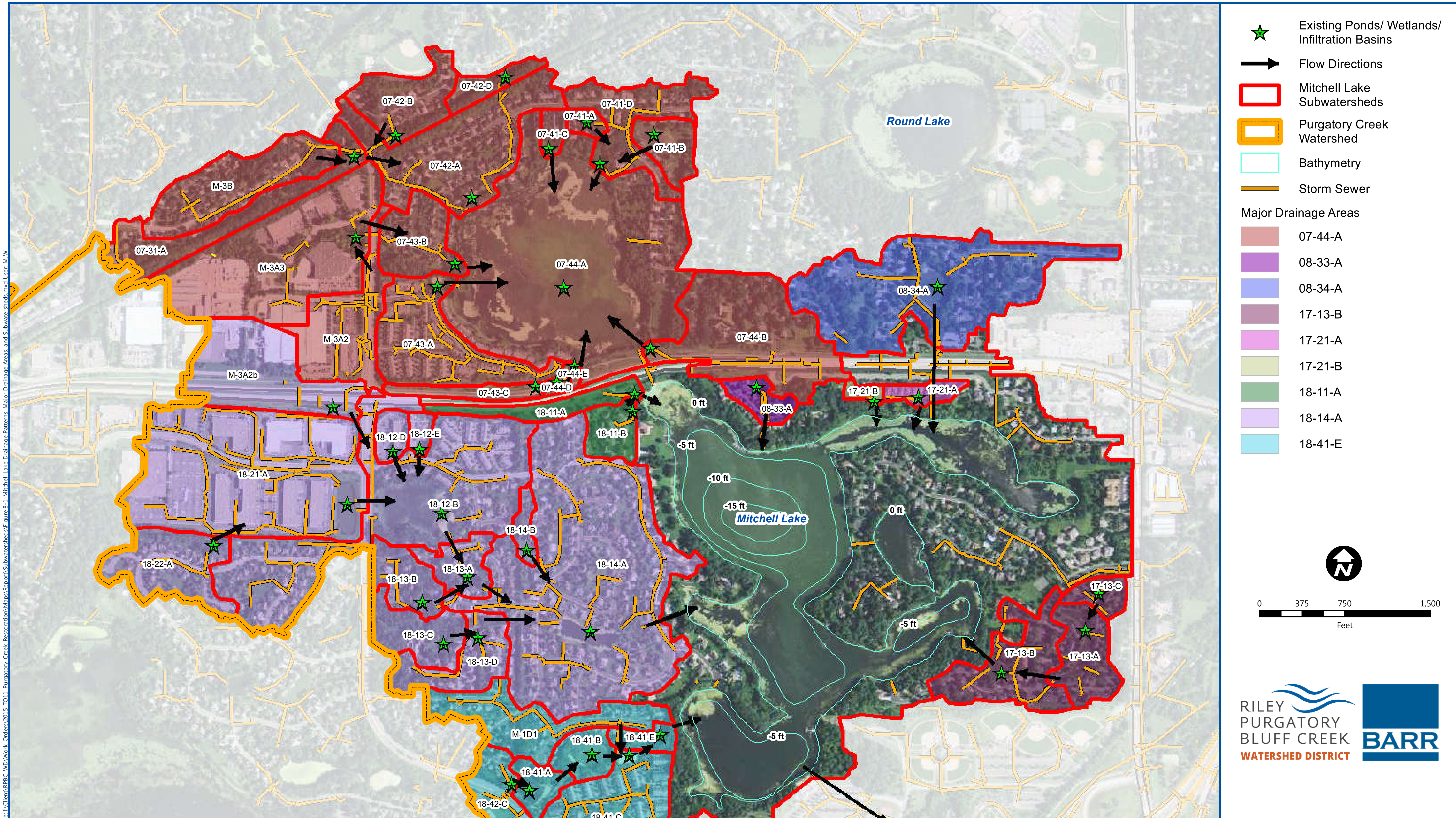


MITCHELL LAKE SUBWATERSHEDS AND STORMSEWER ALIGNMENTS

FIGURE 8.1

8.1.2 Land Use

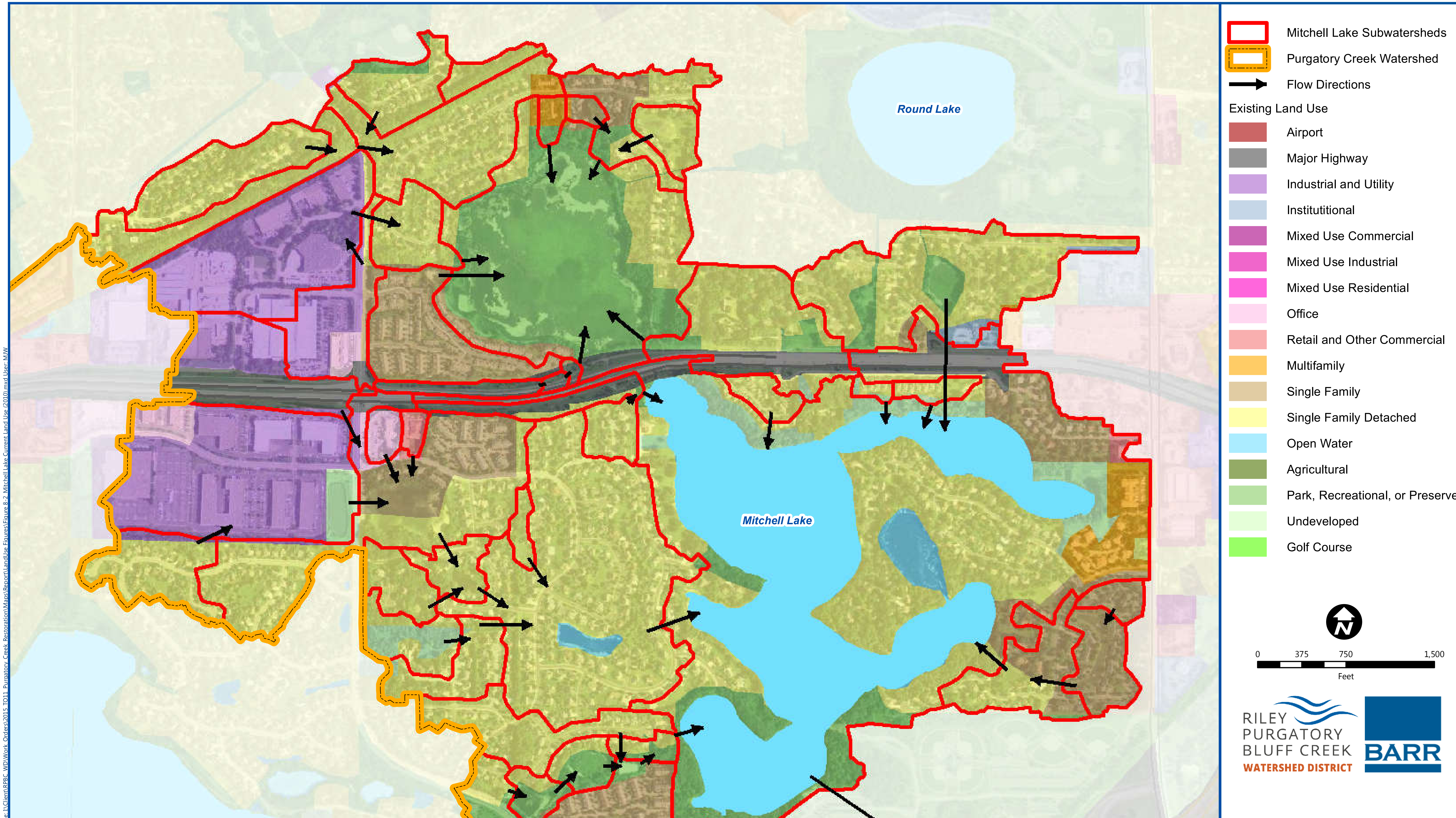
Land use within a lake's watershed can impact the hydrology and water quality of a lake. Varying land uses contribute different quantities of sediments and TP to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

Existing land-use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council. The land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix D.

The majority of the Mitchell Lake watershed is covered by single family residential land use (66%). Other major land uses include park, recreational, or preserve (7%), major highway (6%), industrial and utility (13%), undeveloped (3%) and multifamily (2%). Figure 8.2 shows the exiting land uses present in the Mitchell Lake watershed.

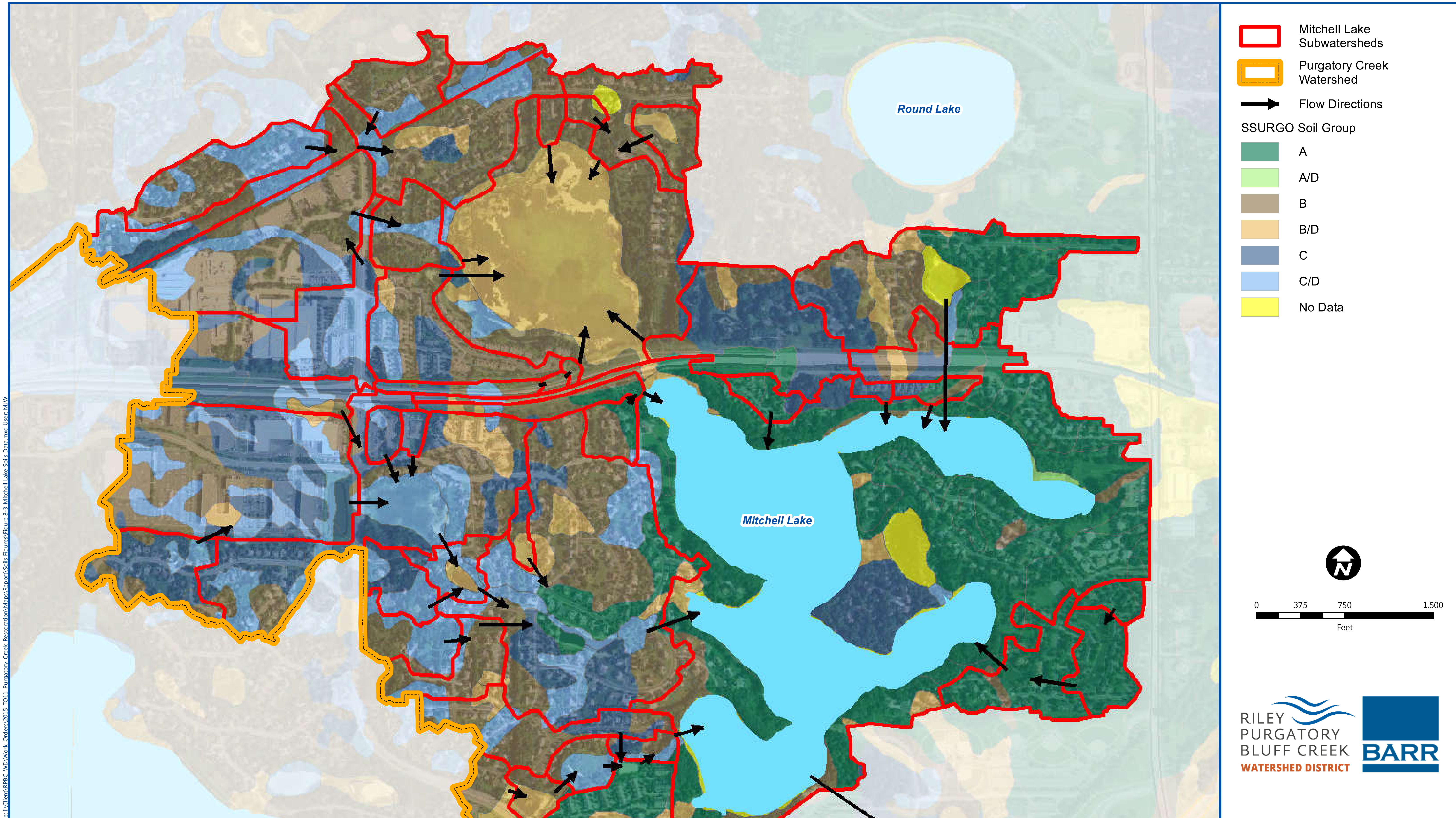
8.1.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database map for Hennepin County, the underlying soils in the Mitchell Lake watershed are predominantly classified as hydrologic soil group (HSG) A with high infiltration rates and B with moderate infiltration rates (Figure 8.3). The Areas surrounding the lake and in the eastern portion of the lakes watershed are covered with A soils. The western part of the lake's watershed is predominately HSG C and C/D soils with low infiltration rates. The north western portion of the watershed is covered in B soils.



MITCHELL LAKE LAND USE CLASSIFICATIONS

FIGURE 8.2



MITCHELL LAKE SOILS CLASSIFICATIONS

FIGURE 8.3

8.2 Lake Characteristics

Table 8.1 provides a summary of the physical characteristics for Mitchell Lake. Mitchell Lake has an open-water surface area of approximately 124 acres. The lake is shallow, with a maximum depth of approximately 19 feet and mean depth of approximately 5.3 feet. The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 874.21 feet MSL (2014) to a low measurement of 865.87 feet MSL (1977). Since 2013 water levels in Mitchell Lake have averaged 871.75 feet MSL. Water elevations were not measured between 2001 and 2012. The outlet of Mitchell Lake is a manmade structure that conveys water to Red Rock Lake. The outlet is at elevation 868.27 feet. At the average water elevation of 871.75 feet the total water volume in Mitchell Lake is 729 acre-ft.

Table 8.1 Mitchell Lake Physical Characteristics

Lake Characteristic	Mitchell Lake
Lake MDNR ID	27-0070-00
MPCA Lake Classification	shallow
Water Level Control Elevation (feet MSL)	868.27
MnDNR Classification	Natural environment
Average Water Elevation (feet MSL)	871.75
Surface Area (acres)	124
Mean Depth (feet)	5.3
Maximum Depth (feet)	19
Littoral Area (acres)	109
Volume (at normal water elevation) (acre-feet)	729
Thermal Stratification Pattern	dimictic
Estimated Residence Time (years) – 2014-2015 climatic Conditions	0.8
Watershed Area Tributary to Upstream Lake	475[2]
Total Watershed Area	1412[2]
Subwatershed Area (acres)	937[2]
Trophic Status Based on 2015 Growing Season Average Water Quality Data	hypereutrophic

1 – Average water elevation 2013-2015.
2 – Watershed area includes surface area of lakes

While Mitchell Lake is relatively shallow, a review of temperature and dissolved oxygen profiles suggest that Mitchell Lake is a dimictic lake. This means that the lake mixes twice a year in the fall and spring as surface water temperature reach the temperature of maximum density (~39^{o} F). During the summer months temperature stratification is strong enough to prevent wind mixing event from fully mixing the lake water column.

The MnDNR classified Mitchell Lake as a natural environment lake. According to the MnDNR the classification is used to determine lot size, setbacks and, to a certain degree, land uses on the adjacent land through shoreland management guidance and typically has little to do with surface water use of boats or motors, hunting and fishing or fish management.

8.3 Water Quality Conditions

Historical water quality data, in terms of growing-season (June – September) average TP concentrations, chlorophyll *a* concentrations, and Secchi disc transparency for Mitchell Lake are presented in Figure 8.4. Also, shown in these figures are the MPCA water quality standards for a shallow lake for each parameter. Historically, TP concentrations were elevated above the shallow lake water quality standard of 60 µg/L. Before 2008, all growing season average concentrations were elevated above the standard. Starting in 2008 all average TP concentrations were below the standard until 2015 when the growing season average TP concentration increased to 70 µg/L. Some of the recent improvement could potentially be the result of less phosphorus loading from Round Lake, which periodically discharges into Mitchell. The degree to which Mitchell Lake was impacted by the Round Lake alum treatment in 2012 is difficult to estimate because actual discharge from Round Lake was not measured. However, simulation of the 2015 water year suggests there was little water flowing out of Round Lake. The lowest average concentration on record was 43 µg/L in 2013. The highest average concentration was 230 µg/L in 1978.

Growing season average chl-a concentrations in Mitchell Lake before 2011 mostly fall above the water quality standard of 20 µg/L for a shallow lake. Over the past 5 years (2011-2015) average concentrations have achieved the standard all years except for 2015 when the average chl-a concentration increased to 31 µg/L. The lowest chl-a average concentration of 11 µg/L occurred in year 2014. The highest growing season average concentration of 140 µg/L occurred in 1978.

Growing season average Secchi depth readings before 1996 alternate between meeting and not meeting the water quality standard of 1.0 meter for a shallow lake. From 1996 – 2007 all average depths did not achieve the standard. After 2007, all average depths achieve the standard, except for 2015. In 2015 the growing season average Secchi depth was 0.9 meters. The lowest (worst) average Secchi depth of 0.4 was measured in 1978. The best average Secchi depth of 1.9 meters was recorded in 1984.

Trends in the water quality data were determined by calculating a Thiel-Sen slope on the annual average growing season values and the significance of the trend was tested using the Mann-Kendall non parametric test at the 95% confidence internal. Significant improving water quality trends were present in all three water parameters from 1999-2015 (Table 8.2).

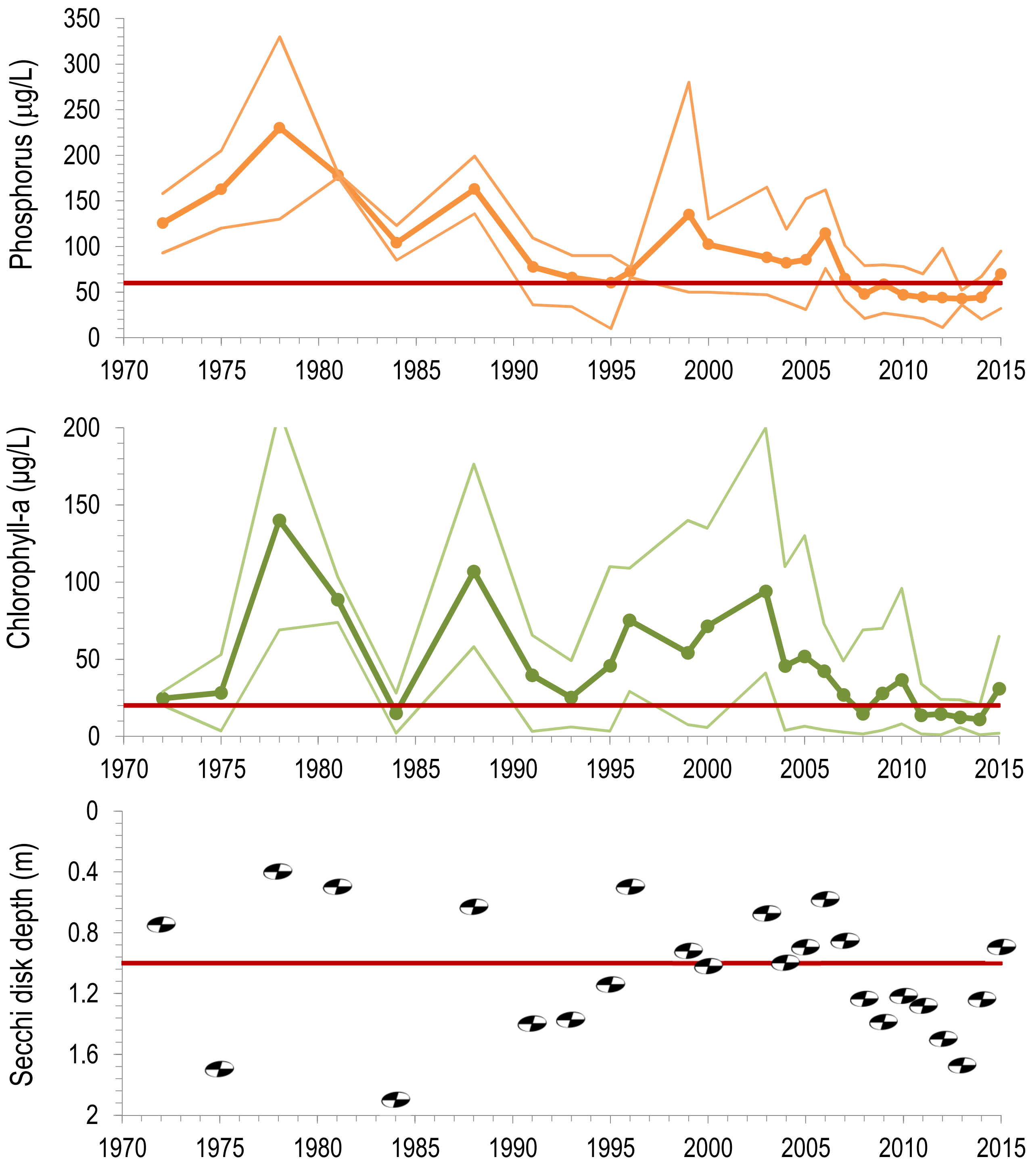


Figure 8.4
Mitchell Lake Water Quality Growing Season (June - September) Average, Min and Max

Table 8.2 Mitchell Lake water quality parameter Thiel-Sen trends

Parameter	1999-2015	Entire Record
TP (µg/L/yr)	-5*	-3
Chl-a (µg/L/yr)	-3.5*	-1.8*
Secchi Depth (m/yr)	0.04*	0.02

* Designates significant trends at the 95% confidence level using Mann-Kendall significance test

8.3.1 Paleolimnology

In 2011 the district contracted with St. Croix Watershed Research Station to use paleolimnological techniques to reconstruct the trophic and sedimentation history of Mitchell Lake (Ramstack & Edlund, 2011). A sediment core was collected from each lake, and lead-210 activity was analyzed to develop a dating model and determine the sediment accumulation rate over the past 150 to 200 years.

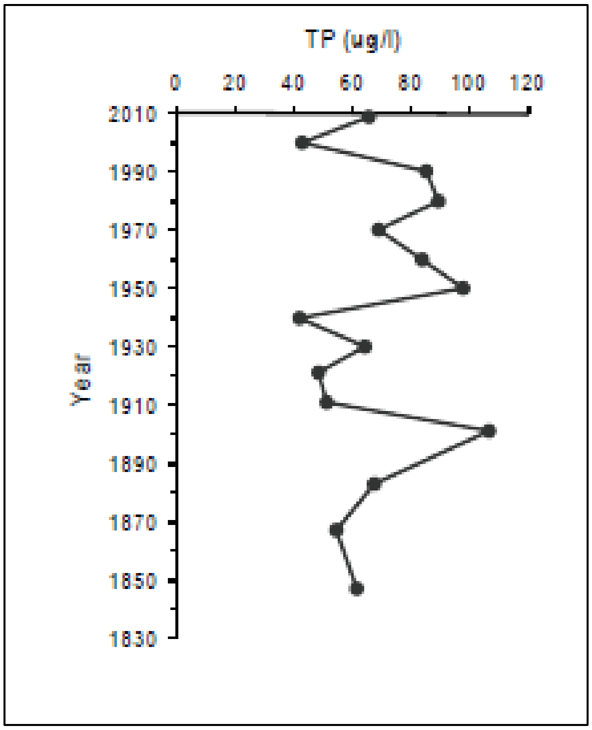


Figure 8.5 Mitchell Lake Diatom-inferred TP reconstruction (Ramstack & Edlund, 2011).

Reconstructed TP concentration in Mitchell Lake have fluctuated between 42 µg/L and 100 µg/L over the period of record. Removing the 1900 value of 100 µg/L shows a range of 40 µg/L to 65 µg/L between years 1850 – 1940 (Figure 8.5). Overall the reconstructed TP values show that the lake has been productive since the mid-1800s (Ramstack & Edlund, 2011). The current measured growing season average TP concentration of 70 µg/L for year 2015 is at the upper end of reconstructed values between years 1850 and 1940 (i.e., current lake water quality is similar to what it was under predevelopment conditions).

8.3.2 Water Quality Relationships

As previously discussed, phosphorus often acts as the limiting nutrient for algal growth (as measured by chlorophyll *a*), which in turn, affects lake water clarity (Secchi depth). This section describes how incremental phosphorus load reductions would be expected to impact perceptible changes in lake water quality. The compiled data for the water quality variables from Mitchell Lake were analyzed to develop relationships between the water quality parameters: TP, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season averages. In addition to developing the water quality relationships based on the observed data, the regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) were also plotted against the lake data.

The relationships between the various water quality parameters for the actual Mitchell Lake data did indicate some correlation between the water quality parameters (Figure 8.6). The MPCA regression equations resulted in similar fit for the chlorophyll *a*, Secchi disc transparency data, and TP. For this reason the MPCA statewide regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Mitchell Lake based on TP concentration.

Figure 8.6 shows the individual water quality data points for Mitchell Lake, along with plots of the MPCA statewide regression equations.

The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla (µg/L) = 1.31 Log10 TP (µg/L) – 0.95
- Log10 Secchi (meters) = -0.59 Log10 Chla (µg/L) + 0.89
- Log10 Secchi (meters)= -0.81 Log10 TP (µg/L) + 1.51

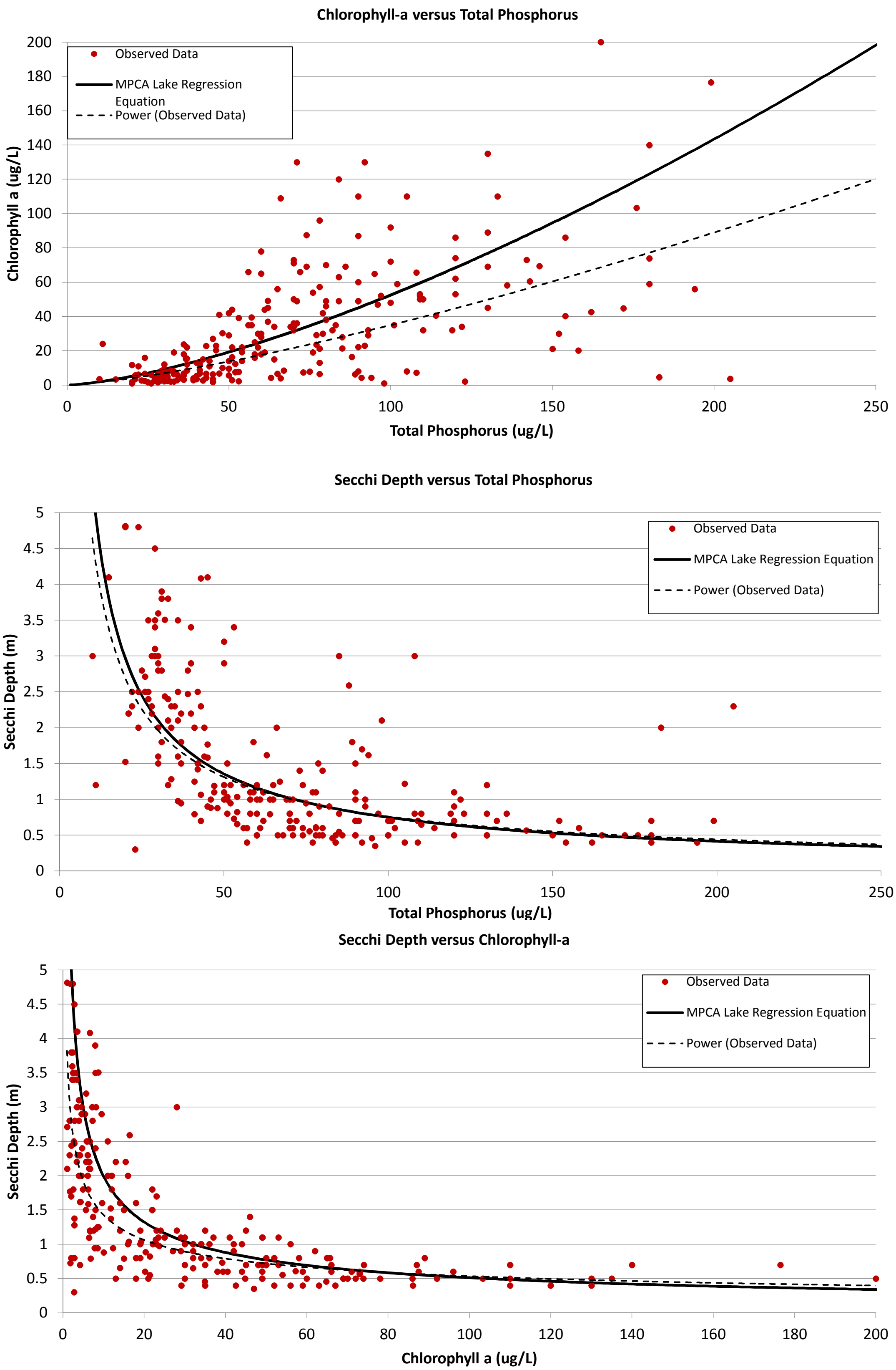


Figure 8.6
Mitchell Lake Individual Samples
Water Quality Parameter
Regression Relationships

8.4 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores)). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

8.4.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess TP loads.

Plankton surveys have been collected on Mitchell Lake for years: 1995, 1996, 1999, 2005, 2007, and 2008. A survey conducted in September of 2008 found 78% of the phytoplankton to be large bodied cyanobacteria that cannot be controlled by the zooplankton population.

While green algae are edible to zooplankton and serve as a valuable food source, cyanobacteria are considered a nuisance type of algae because they:

- Are generally inedible to fish, waterfowl, and most zooplankters
- Float at the lake surface in expansive algal blooms
- May be toxic to animals when occurring in large blooms
- Can disrupt lake recreation because they are most likely to be present during the summer months

8.4.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

Zooplankton were studied in Mitchell Lake throughout the open water period in 2015 by the RPBCWD staff (RPBCWD, 2015). It was found that the three groups of zooplankton (cladocera, copepods, and rotifers) had similar numbers during the 2015 monitoring season. All three species had moderate numbers in the spring with a decline in July and increase for the remainder of the year into the fall. Grazing rates of the algae community were estimated to be between 10% and 41% with peak grazing rated in September when large body cladocera were more abundant (RPBCWD, 2015).

8.4.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

Macrophyte surveys were conducted on Mitchell Lake in 2013, 2014 and 2015 as part of a University of Minnesota study (Dunne & Newman, 2016). It was found that Mitchell Lake had a diverse aquatic macrophyte community with 16 different species observed in the three sampling periods in 2015. The most abundant species was coontail. Curlyleaf pondweed was also abundant in Mitchell Lake with the highest coverage found in April of 2015 (Dunne & Newman, 2016). Other species found in at least 5% of the sites surveyed include star duckweed, white water lily, narrow leaf pondweed, flat-stem pondweed, and northern watermilfoil. Two invasive macrophyte species were found in Mitchell Lake: Eurasian watermilfoil and curlyleaf pondweed. Curlyleaf pondweed was found at nuisance levels in the spring and early summer (Dunne & Newman, 2016). Even though an Endothol herbicide treatment was applied in the spring of 2015, limited effects were observed on the peak curlyleaf pondweed population during the summer. Reductions were observed in the treated area, however increases in untreated areas appeared to offset the reductions. Eurasian watermilfoil was found at low frequencies (Dunne & Newman, 2016).

8.4.4 Fishery

The MDNR developed a classification system for Minnesota lakes relative to the chemical and physical properties of each lake class and the fishery that is supported by each lake (Schupp, 1992). According to its ecological classification, Mitchell Lake is a Class 42 lake. Class 42 lakes are typically shallow and productive lakes with fish assemblages that include white sucker, bluegills, and black bullheads (Schupp, 1992).

Based on a 2011 fish survey from the MDNR northern pike and black crappie are the most abundant species in Mitchell Lake. Other fish found in the survey include bluegills, pumpkinseed, and black bullhead. Past surveys have found hybrid sunfish, largemouth bass, walleye, white crappie, and central mudminnows in addition to the fish found in the most recent 2011 survey. In the past 10 years the MDNR has stocked Mitchell Lake with walleye, largemouth bass, and bluegills. Carp surveys in 2011 and 2012 found zero occurrences of carp in Mitchell Lake (Sorensen, et al., 2015).

8.5 TP Source Assessment

The watershed and in-lake water quality models were developed to assess both the external and internal TP loads in Mitchell Lake for the 2015 water year (October 2014 – September 2015). A detailed discussion of the modeling methods used is presented in Section 2.2.2 and Appendix D. Possible lake external loads of TP include atmospheric depositions, stormwater runoff from the lake watershed, surficial groundwater interactions with the lake waters, internal loads from upstream ponds and wetlands, and load from any upstream lakes that might flow into the waterbody.

External loads that applied to Mitchell Lake are atmospheric deposition, watershed loads, groundwater, and upstream lakes. Internal loading within the ponds and wetlands was not evaluated for this study and no channels with erosion potential contribute the Mitchell Lake. Internal TP loads can come from sediment TP release, curlyleaf pondweed, or benthivorous fish activity.

Figure 8.7 summarizes the 2015 annual water year TP budgets for Mitchell Lake, including the relative contributions of the internal and external TP loads. This budget explains the sources of TP to the lake and helps direct and prioritize implementation strategies. Each of the sources are discussed further in the following section(s).

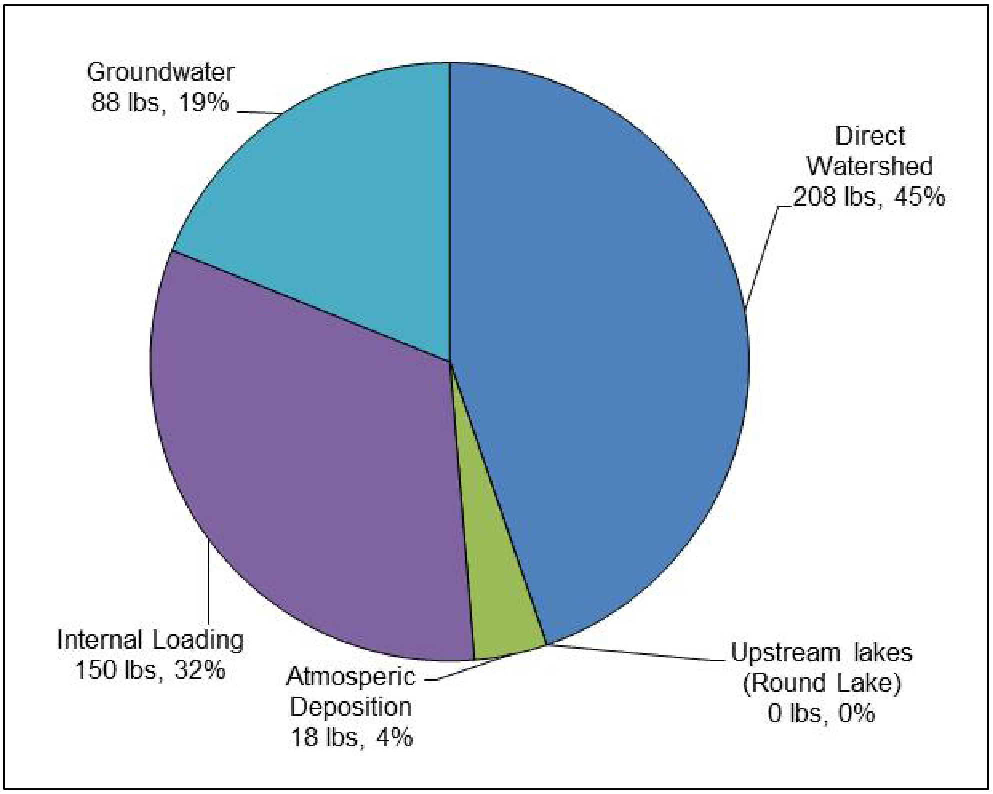


Figure 8.7 Mitchell Lake TP load sources for 2015 water year

8.5.1 External Loads

8.5.1.1 Atmospheric Deposition

Atmospheric deposition of TP onto the lake water surface was calculated by using the estimated statewide TP atmospheric deposition rate of 0.17 kg/ha/year (Barr Engineering, 2004). For Mitchell Lake, this loading rate was applied to the combined open water area. The daily rate was applied to the surface area of the lake based on the modeled lake water elevation from the lake water balance model. The resulting atmospheric deposition TP load for the 2015 water year was 18 pounds which amounted to 4% of the TP load to Mitchell Lake (Figure 8.7).

8.5.1.2 Watershed Loads

The P8 watershed model estimated surface runoff from Mitchell Lake's subwatersheds (not passing through upstream lakes) based on observed climatic data (precipitation and temperature). The total untreated watershed load from the watersheds in Mitchell Lake for the 2015 water year was estimated to be 523 pounds. The watershed load travels through existing stormwater ponds, wetlands, infiltration practices, and other BMPs located throughout the watershed providing treatment which reduces the TP load reaching Mitchell Lake to 208 pounds. This represents an estimated 60% removal by existing treatment practices in the watershed. Watershed sources represent 45% of the total water load to Mitchell Lake (Figure 8.7).

To help evaluate areas that might benefit from additional treatment, watershed loads to the lake were calculated for each of Mitchell Lake's individual subwatersheds. The load to the lake is defined as the amount of TP load from that watershed reaching the lake without being removed by an existing BMP within the subwatershed or downstream from the subwatershed. The P8 results were used to calculate the total annual average untreated watershed TP loads from each subwatershed. Next, the watershed load to the lake was calculated. This was accomplished by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each subwatershed that reached the lake without being removed by an existing BMP. The watershed load to the lake for each subwatershed is shown in Figure 8.8.

8.5.1.3 Surficial Groundwater

Based on the 2015 calibration of the water balance modeling for Mitchell Lake, there appears to be a significant surficial groundwater source in Mitchell Lake. The groundwater flow into Mitchell Lake ranges between 1 and 1.5 cfs throughout the year. To calculate the load to the lake from groundwater a TP concentration of 35 µg/L was applied. This estimation resulted in 88 pounds of TP entering Mitchell Lake through surficial groundwater or 19% of the total TP load (Figure 8.7).

8.5.1.4 Upstream Lakes

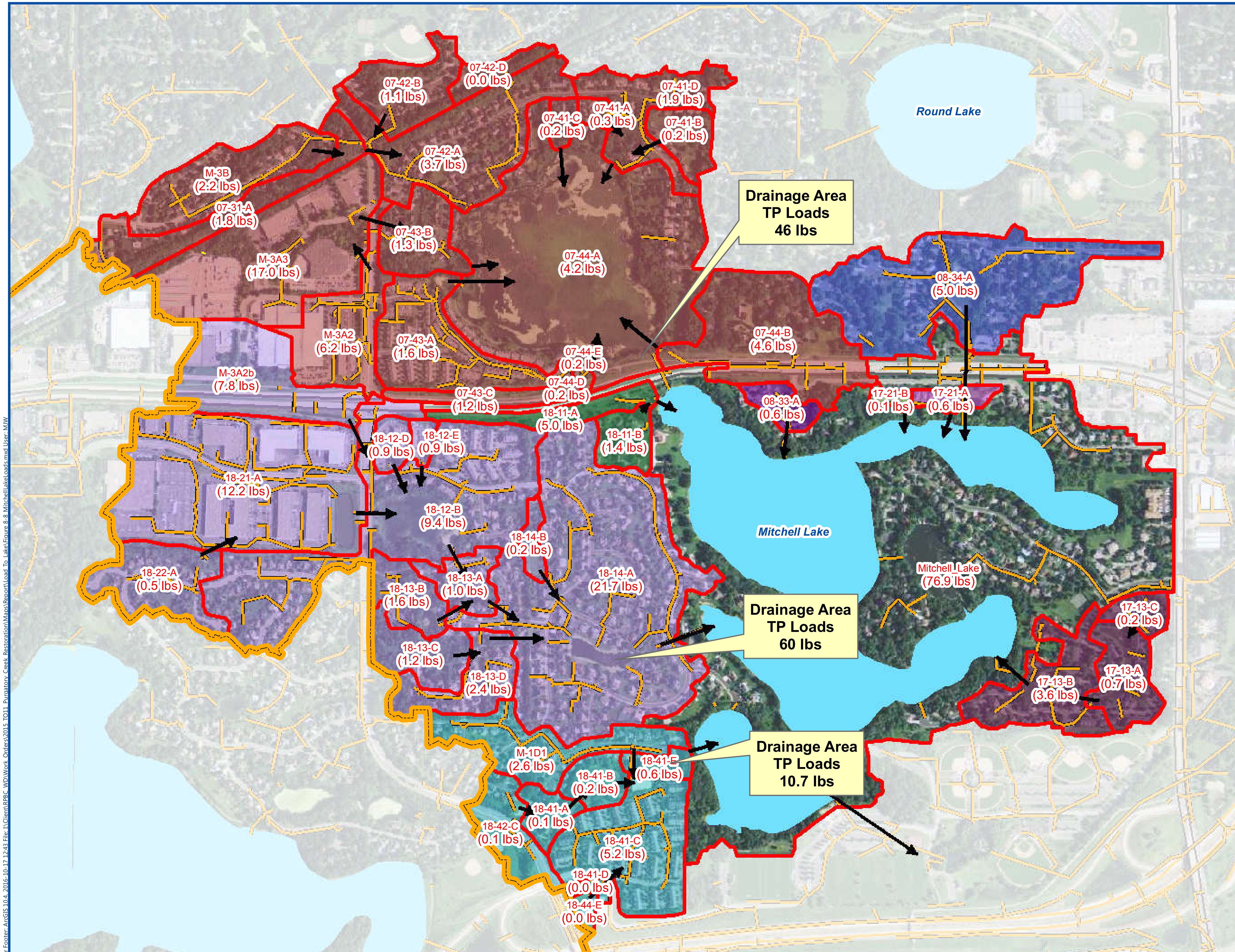
Mitchell Lake is part of the Eden Prairie chain of lakes. The outflow from Round Lake enters Mitchell Lake. In the 2015 water year flow from Round Lake was limited. Only about 0.5 acre-ft. of water left Round Lake during the 2015 water year. Flow and TP concentration from Round Lake were estimated using the Round Lake in-lake model. The resulting load to Mitchell Lake from Round Lake was negligible.

8.5.2 Internal Loads

Internal loading in Mitchell Lakes represented 32% (150 pounds) of the TP loads in the 2015 water year (Figure 8.8). The internal loading sources to Mitchell Lake appear to be primarily from curlyleaf pondweed die back and sediment phosphorus release.

8.5.2.1 Curlyleaf Pondweed

Because of the relatively high occurrence in Mitchell Lake, TP loading from curlyleaf pondweed may be significant during part of the summer was not explicitly modeled to quantify its potential impact for this study. The internal loading calibration parameter was used to simulate this release along with other sources of internal loading.



MITCHELL LAKE SUBWATERSHED TP LOADS TO THE LAKE

FIGURE 8.8

8.5.2.2 Benthivorous Fish Activity

In fish surveys of Mitchell Lake in 2011 and 2012 by the University of Minnesota no adult or young carp were found (Sorensen, et al., 2015). As a result, this analysis exclude the activities of carp and other benthivorous fish as a significant source of TP in Mitchell Lake and were not quantified as part of the in-lake water quality modeling in 2015.

8.5.2.3 Sediment Release

Internal loading through sediment release occurs during anoxic conditions. A review of dissolved oxygen profiles in Mitchell Lake showed anoxic conditions reaching a depth of 10 feet from the lake's water surface during the middle summer months. Persistent stratification in Mitchell Lakes occurs throughout the summer with complete mixing event only happening in the late fall and early spring. The stratification and subsequent anoxic conditions in the hypolimnion allow for the release of phosphorus throughout the growing season months. Elevated TP concentrations have been recorded in the lake hypolimnion corresponding to anoxic conditions. TP concentrations in the hypolimnion have reached as high as 300 µg/L in 2015 with concentrations typically seen between 100 and 300 µg/L from July through September. As the lake mixes through wind mixing events and turnover in the fall from temperature changes this TP load is distributed throughout the water column impacting surface water TP concentrations.

8.5.3 TP Load Reductions

The in-lake model was used to estimate TP load reductions needed to meet the water quality goal for Mitchell Lake during 2015. Table 8.3 shows the measured and modeled growing season average (June – September) concentration, the TP load to the lake under existing conditions, the water quality goal, the TP loading capacity for meeting the water quality standard and the required percent reduction needed to meet the water quality goal. Under existing (2015) conditions Mitchell Lake is not meeting the water quality goal for a shallow lake of 60 µg/L. Modeled and measured growing season average TP concentrations in the lake surfaces waters for the 2015 water year was 70 µg/L. Mitchell Lake was modeled as a completely mixed lake with modeled concentration representing the volumetric average concentrations in the water column. The TP load under existing conditions was 464 pounds for the 2015 water year. To meet the water quality goal, the load to Mitchell Lake would need to be reduced to 405 pounds resulting in a 13% TP load reduction.

Table 8.3 Mitchell Lake estimated load reductions required to meet TP water quality goal for 2015 water year

Measured growing season average TP concentration (µg/L)	Modeled growing season average TP concentration (µg/L)	Estimate 2015 TP loading rate (lbs/yr)	TP concentration goal (µg/L)	Estimated Loading Capacity to meet WQ goal (lbs/yr)	Percent reduction needed to achieve goal (%)
70	70	464	60	405	13%

The calibrated in-lake model was used to determine in lake water quality based on the amount of TP load to the lake (Figure 8.9). TP concentrations were calculated from the in-lake model. Chl-a and Secchi depth concentrations were determined based on the water quality relationships discussed in section 8.3.2. The figure shows how incremental load reductions would impact the water quality in Mitchell Lake. For example, if the load to Mitchell Lake was reduced by 20 pounds the lake TP concentration would be projected to be 67 µg/L, the Chl-a concentration would be 28 µg/L, and the Secchi depth would be 1.1 meter. If the load was reduced by 70 pounds the resulting TP is projected to 58 µg/L, the Chl-a concentration would be 23 µg/L and the Secchi depth would be 1.2 meters.

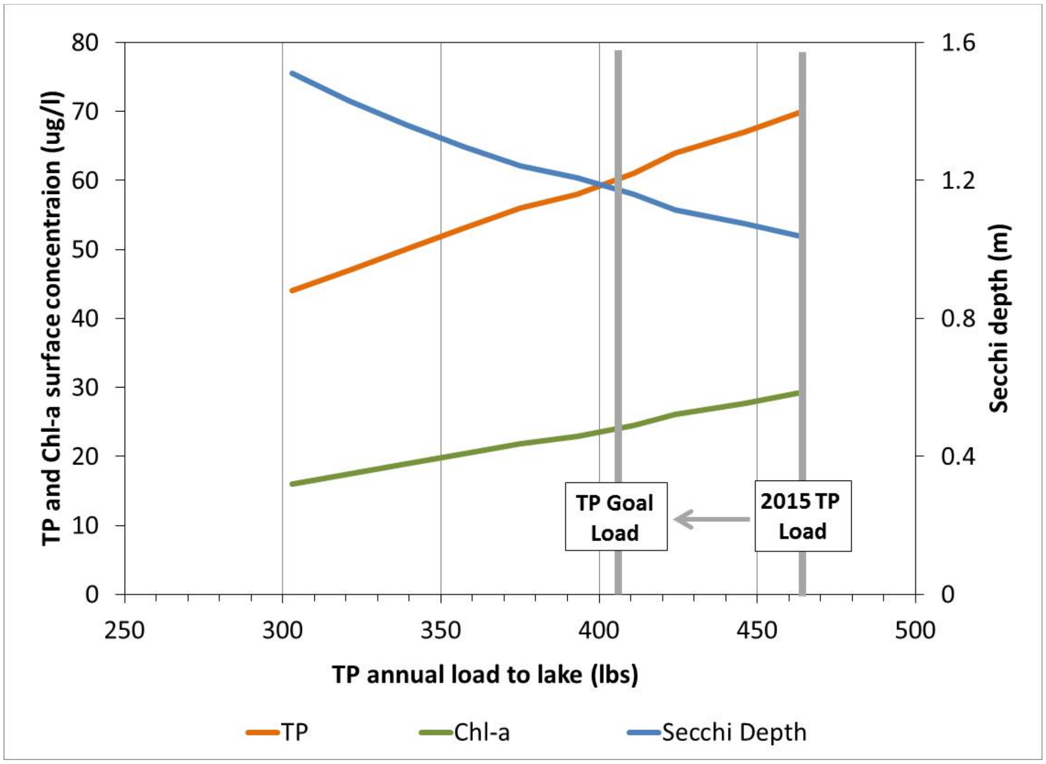


Figure 8.9 Mitchell Lake TP load relationship with lake water quality (TP, Chl-a and clarity)

8.6 Summary of Diagnostic Findings

Table 8.4 provides a summary of the key water-quality findings for Mitchell Lake.

Table 8.4 Diagnostic Findings for Mitchell Lake

Topic	Mitchell Lake
Water Quality Standards and Goals	- Did not meet the MPCA water quality standard for a shallow lake for TP, Chl-a, Secchi depth in year 2015. - Between 2011 and 2014 all three water quality parameters met the water quality standard. - Does not meet the RPBCWD long term vision for Secchi depth of 2 meters.
Baseline Water Quality	- Current TP concentrations are consistent with sediment core reconstructed values.
Water Quality Trends	- Significant improving trends were detected in TP, Chl-a, and Secchi depth for years 1999-2015.
Watershed Runoff	- Represents approximately 45% of the annual TP load. - Watershed load is reduced by an estimated 60% by existing BMPs, ponds, and wetlands located throughout the watershed. - Round lake contributes 0% of the load to Mitchell Lake.
Macrophyte Status	- Curlyleaf pondweed was found at nuisance levels in the spring and early summer of 2015. - Eurasian watermilfoil is present at low densities
Fishery Status	- No carp found in recent survey by U of M
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer
Internal Loading from sediments	- Internal loading from sediment estimated to be 32% of annual TP load
Methylmercury in Fish Tissues	- Not currently listed as impaired - No consumption advisories

Additional discussion of the diagnostic findings in relation to the sources of TP and water quality of the lake based on the data analyses, watershed and in-lake modeling, and review of recent studies and information is included. These conclusions influenced the implementation strategies evaluated for the management of Mitchell Lake water quality (see Section 8.8).

- In 2015 Mitchell Lake did not meet the MPCA shallow lake water quality standards for all TP, Chl-a and Secchi depth. In previous years from 2011-2014 all three parameters did meet the water quality goals. Significant trends were present in all three parameters for the time periods 1999-2015.

- Approximately 85 percent of the watershed runoff receives treatment prior to entering Mitchell Lake due to the number of stormwater ponds and other waterbodies within the watershed. As stormwater runoff passes through the many constructed stormwater ponds and natural wetlands in the watershed, significant removal of TP associated with particulates in the runoff occurs due to particle settling and infiltration. Modeling suggests that approximately 60% of the watershed load in removed in existing BMPs before reaching Mitchell Lake. As a result, the watershed modeling suggests that a significant portion of the TP in the watershed runoff reaching the lake is in a soluble form or associated with very small particles that are difficult to settle. Therefore, treatment practices the can remove dissolved phosphorus such as infiltration and enhanced filtration practices should be examined in addition to practices in currently untreated areas.

- The watershed phosphorous load to Mitchell Lake represented an estimated 45 percent of the total annual TP budget to the lake during the 2015 water year; internal loading represented another estimated 32 percent of the total annual TP budget.

- Round Lake contributes flow to Mitchell Lake. During the 2015 water year flow from Round Lake was minimal contributing a negligible amount of TP to Mitchell Lake.

- Figure 8.8 shows the estimated TP loading from the major drainage basins in the Mitchell Lake watershed. The watershed modeling suggests that 37 percent of the watershed load to Mitchell Lake is coming from the lake's direct watershed. Another 29 percent is coming from the drainage area contributing to 16-14-A and 22 percent from the drainage area contributing to 07-44-A.

- The most recent plant surveys in Mitchell Lake indicate that invasive species curlyleaf pondweed is present in nuisance levels. Treatment of Endothol was provided in 2015 with limiting effects on the overall levels of curlyleaf pondweed (Dunne & Newman, 2016). Eurasian watermilfoil was also found in Mitchell Lake but at low levels with not management needed.

- The carp population was analyzed in Mitchell Lake in 2011 and 2012 as part of the University of Minnesota's study for Purgatory Creek (Sorensen, et al., 2015). Zero occurrences of carp either adult or young were found in Mitchell Lake.

8.7 Current and Past Management Actions

The following includes a summary of BMPs either implemented or analyzed in the Mitchell Lake watershed:

- An investigation was implemented to use SolarBees for treatment of high cyanobacteria levels in 2008. The pilot program was determined to be inconclusive (RPBCWD, 2008).
- A pilot program was implemented in 2009 to test the use of a DynamOx pure oxygen injection system to inject oxygen into the hypolimnion of one of the basins in Mitchell Lake. This test achieved its overall goal of suppressing phosphorus release from the sediments but experienced significant fouling due to iron buildup (CH2M HILL, 2010).
- A second pilot program was implemented in 2009 to test the use of a slow release calcium peroxide dose applied to a second basin in Mitchell Lake. The dose was not enough to elevate the oxidation reduction potential (ORP) at the sediment water interface and therefore did not impact

the release of phosphorus from the sediments. Further testing was recommended (CH2M HILL, 2010) but not conducted.

- Mechanical plant harvesting has been implemented in Mitchell Lake attempting to control plant growth and non-native plant species in 2008, 2009, 2010, 2011, 2012.
- Mitchell Lake aquatic management plan recommended Aquathol K and mechanical harvesting to control curlyleaf pondweed in Mitchell Lake (Wenck Associates, Inc., 2014). The District took the lead on herbicide treatment for curlyleaf pondweed and the City of Eden Prairie took the lead on harvesting. Herbicide treatments have been conducted in 2014, 2015, and 2016.
- Weevils were used to control Eurasian water milfoil growth.
- Ponds 07-43-A, 07,44-A, 18-13-A, 18-13-B, 18-41-B, and 08-34-A were analyzed in the Mitchell Lake watershed during 2012 and 2013. They were determined to have TP concentrations above 0.250 mg/l and could benefit from remediation measures (RPBCWD, 2014).
- Other BMP and mitigation measures suggested for Mitchell Lake as part of the "One Water" Water Management Plant (CH2M HILL, 2011) include:
    - control purple loosestrife with beetles,
    - control cyanobacteria through hypolimnetic oxygenation, sediment oxygenation.
    - control phytoplankton through bio-manipulation and fisheries management.
- Carp were not found in Mitchell Lake as part of surveys conducted in 2011 and 2012 (Sorensen, et al., 2015).

8.8 Evaluation of Water Quality Improvement Options

All of the BMPs identified for Mitchell Lake are listed and described in detail in the following subsections. Table 8.5 provides a list of the potential BMPs and Figure 8.10 shows the identified potential BMP locations in the Mitchell Lake watershed.

8.8.1 New wet pond in subwatershed M-3A3, ML_1

BMP ML_1 is a new wet pond in subwatershed M-3A3 north of Exlar Corporation, just west of Dell Road, designed to treat 23.2 acres of impervious area. This pond is proposed in an existing, low-lying area, and is approximately 0.9 acres at the surface with an average depth of about 3 feet. The pond could potentially remove 29.5 pounds of TP per year based on 30-year modeling results. However, based on the location of the BMP in the watershed relative to Mitchell Lake, and the wetland complex downstream of this proposed BMP, the TP reduction to the lake is only estimated to be 7.5 pounds of TP per year. The cost-benefit of this BMP for Mitchell Lake is estimated to be about $950 per pound of TP, assuming the BMP functions for 30 years.

8.8.2 Internal load control in Mitchell Lake, ML_2

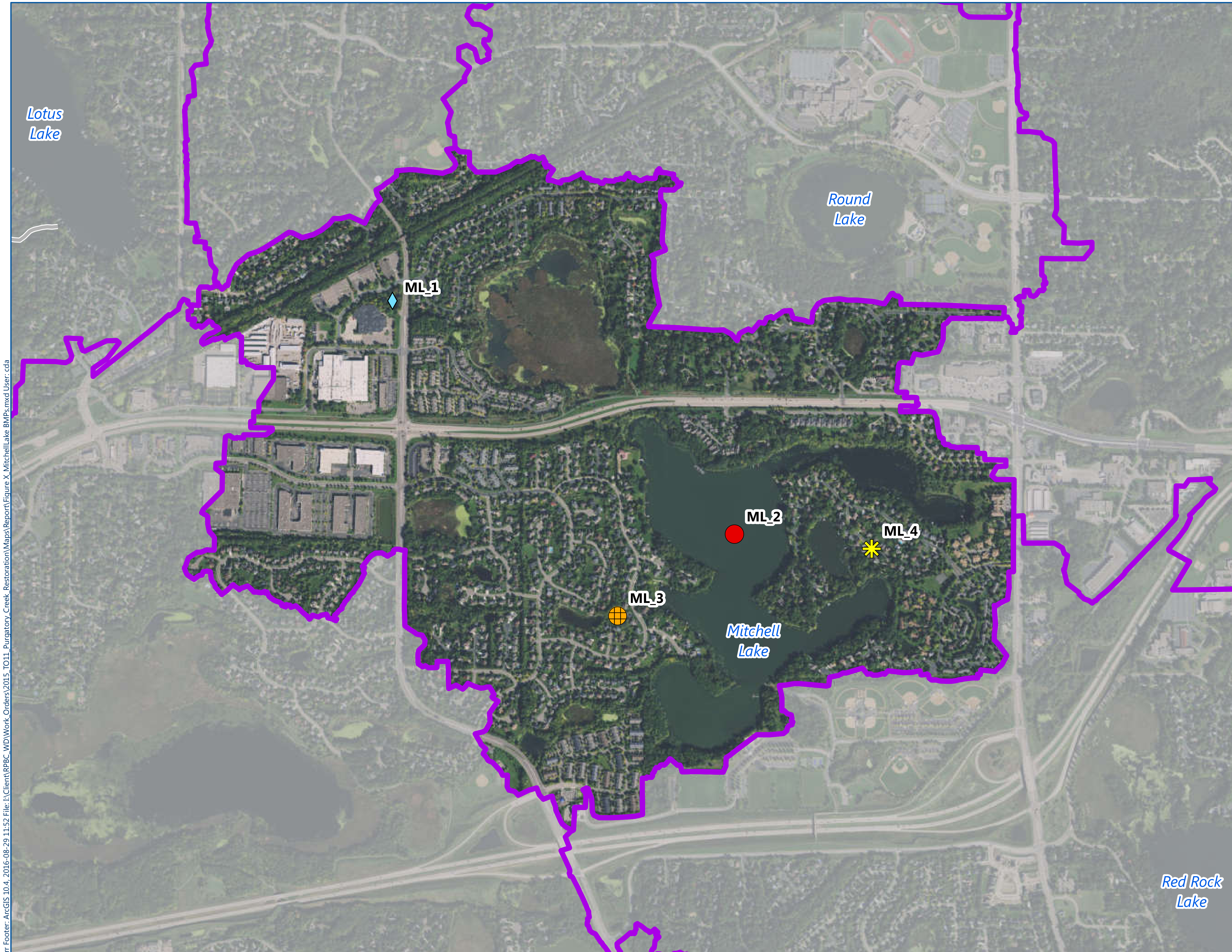
BMP ML_2 is a method for reducing the internal loading within the lake, likely with an alum treatment to bind mobile phosphorus in the lake sediment. The treatment within the lake is expected to initially reduce the internal phosphorus loading by approximately 80% (Welch & Cooke, 1999), resulting in a reduction of 102 pounds per year. The dose needed to achieve this reduction is estimated to be approximately 1,200 gallons per acre, based on 2005 samples of mobile phosphorus in the sediment cores of Mitchell Lake (Barr Engineering, 2005). The cost-benefit of this BMP is estimated to be about $140 per pound of TP, assuming treatment is not needed again for at least another 15 years (Huser, et al., 2015). Two treatments will likely be needed over 30 years and the total cost of both treatments is estimated to be $518,000 (Table 8.5). Because of the significant load reduction and the low cost, BMP ML_2 is recommended for the lake after external loads are controlled in order to maximize the design life of the application. Because Mitchell Lake is a natural environment lake, it is important to note that while MPCA is expected to permit an alum treatment (similar to what occurred with Round Lake), MN Rule 6280.0250 Subp. 4(E) prohibits the use of pesticides to control aquatic plants. As a result, improved water transparency following an alum treatment could contribute to propagation of unwanted plant growth that would have greater limitations on control.

Table 8.5 - Summary of Mitchell Lake BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
ML_1	New Wet Pond *- A 0.9 acre, 3-foot deep wet pond designed to treat 23.2 acres of impervious area north of Duck Lake Trail*	29.5	7.5	13%	$132,900 ($106,000 - $186,000)	$2,700 ($2,100 - $3,700)	$240 ($190 - $340)	$950 ($760 - $1,330)
ML_2	Internal Load Control *- Two treatments of a whole lake alum treatment*	120	120	203%	$518,000 ($414,000 - $725,000)	$0	$140 ($120 - $200)	$140 ($120 - $200)
ML_3	Iron Enhanced Sand Filter *- A 0.3 acre iron enhanced sand filter designed to treat 14.6 acres of impervious area*	32.7	21.1	36%	$578,800 ($463,000 - $810,000)	$11,600 ($9,300 - $16,200)	$940 ($760 - $1,320)	$1,460 ($1,170 - $2,050)
ML_4	Underground Infiltration *- Infiltration vault under S Bay Curve, treating 4.4 acres of impervious area*	7.7	7.7	13%	$314,500 ($252,000 - $440,000)	$6,300 ($5,000 - $8,800)	$2,180 ($1,740 - $3,050)	$2,180 ($1,740 - $3,050)

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. Overall load reduction goal for Mitchell Lake is 59 pounds of phosphorus per year.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.



Best Management Practices

- Internal Load Control
- Infiltration Basin
- Iron Enhanced Filter
- New Wet Pond
- Major Lake Watershed Boundaries

0 1,000 2,000
Feet

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

BARR

ALL IDENTIFIED BMPs, MITCHELL LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 8.10

8.8.3 Iron enhanced sand filter in subwatershed 18-14-A, ML_3

BMP ML_3 is an iron enhanced sand filter in subwatershed 18-14-A in an existing low-lying area behind homes along George Moran Drive. This BMP could be designed to treat 14.6 acres of impervious area. This iron enhanced sand filter is proposed to be approximately 0.3 acres at the surface and about 1.5 feet deep. An existing wet pond immediately upstream of this location would be used for pre-settling, with the outlet from the wet pond connected to this iron enhanced sand filter. The iron enhanced sand filter could potentially remove 32.7 pounds of TP per year based on 30-year modeling results. Based on the location of the BMP relative to Mitchell Lake, the estimated reduction of TP reaching the lake is approximately 21.1 pounds of TP per year. The cost-benefit of this BMP is estimated to be about $1,460 per pound of TP, assuming the BMP functions for 30 years.

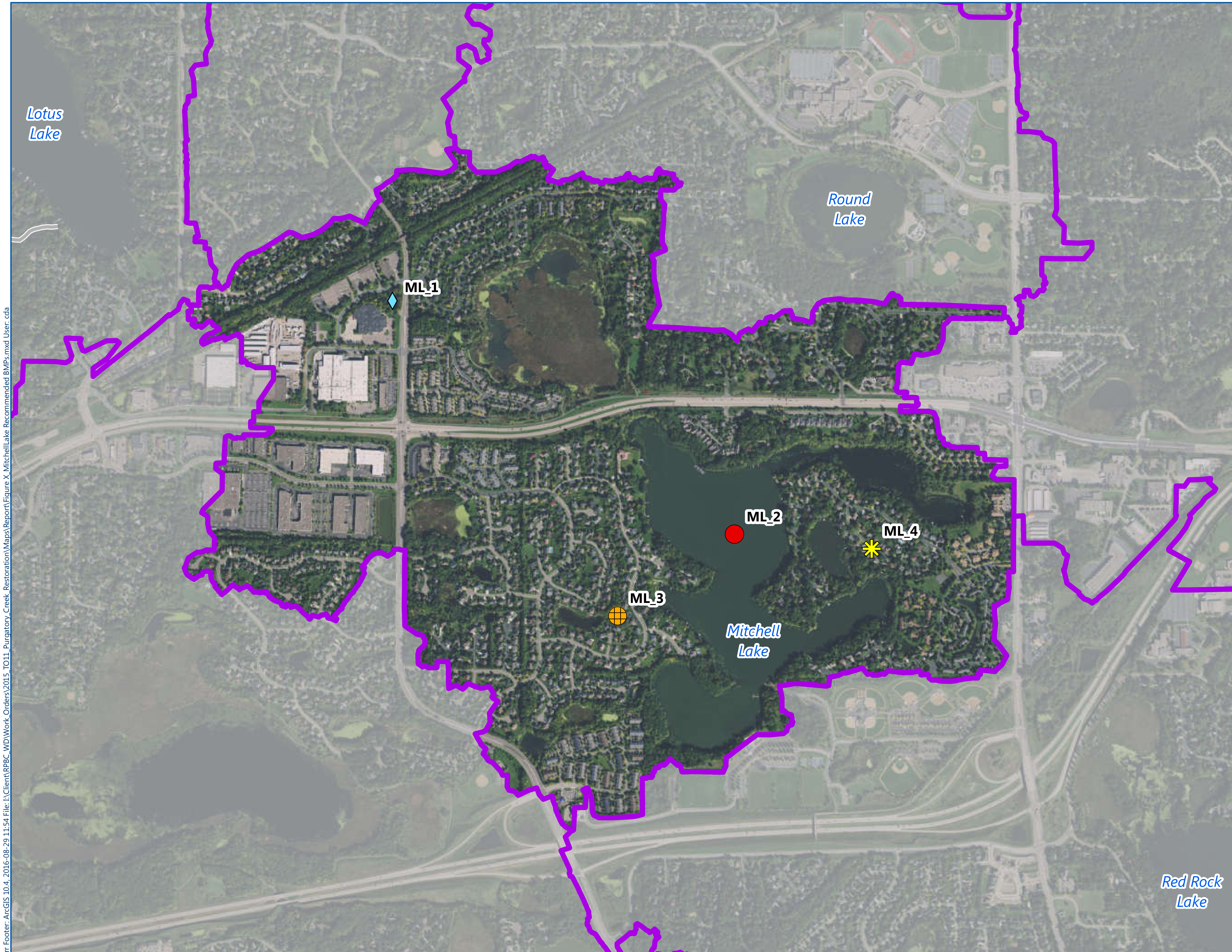
8.8.4 Underground infiltration in subwatershed Mitchell_Lake, ML_4

BMP ML_4 is an underground infiltration vault in subwatershed Mitchell_Lake, collinear with existing storm sewer under South Bay Curve, designed to treat about 4.4 acres of impervious area. The buried infiltration vault is proposed to be approximately 200 feet long and about the width of the residential road, and could be constructed of a pre-molded plastic system. The storage system would have one inlet from the existing storm sewer that runs through this area, and one 24-inch overflow outlet tied back into the same existing storm sewer system. There is some concern about the possibility of saturating the ground near homes adjacent to South Bay Curve, and the effect this may have on basements. The system could reduce the annual TP load to the lake by 7.7 pounds of TP per year. The cost-benefit of this BMP is estimated to be about $2,180 per pound of TP, assuming the BMP functions for 30 years. This BMP provides the added benefits of reducing runoff volume.

8.9 Recommendations for Water Quality Goal Attainment

The overall load reduction for Mitchell Lake is recommended to be 59 pounds of TP per year to reach the water quality goal (Section 8.5.3). The recommended BMPs for the Mitchell Lake watershed are in the bullet list below along with the percent of the overall load reduction goal that each individual BMP provides. The recommended BMPs are also shown in Figure 8.11. The TP reduction expected by the recommended watershed BMPs is 36.3 pounds per year and 120 pounds per year internally. The summary below is intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment TP release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. This is consistent with the district's "ONE WATER Watershed Management Approach" (Section 2.3.4 of (RPBCWD, 2011)).

- ML_1, new wet pond in subwatershed M-3A3, ~13% of the total load reduction goal
- ML_2, internal load control in Mitchell Lake, ~203% of the total load reduction goal
- ML_3, iron enhanced sand filter in subwatershed 18-14-A, ~36% of the total load reduction goal
- ML_4, underground infiltration in subwatershed Mitchell_Lake, ~13% of the total load reduction goal



Best Management Practices
- Internal Load Control
- Infiltration Basin
- Iron Enhanced Filter
- New Wet Pond
- Major Lake Watershed Boundaries

N

0 1,000 2,000
Feet

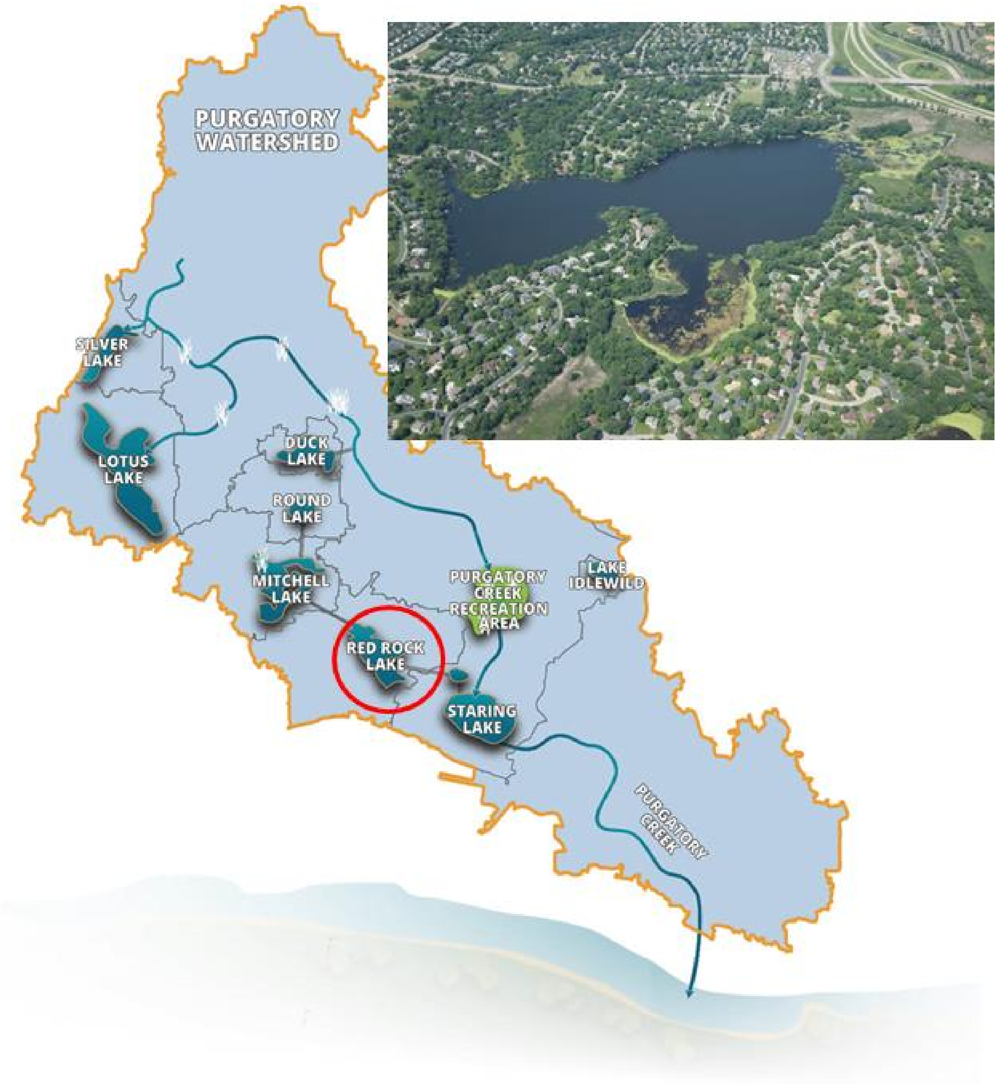
RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

BARR

RECOMMENDED BMPs, MITCHELL LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 8.11

9.0 Red Rock Lake



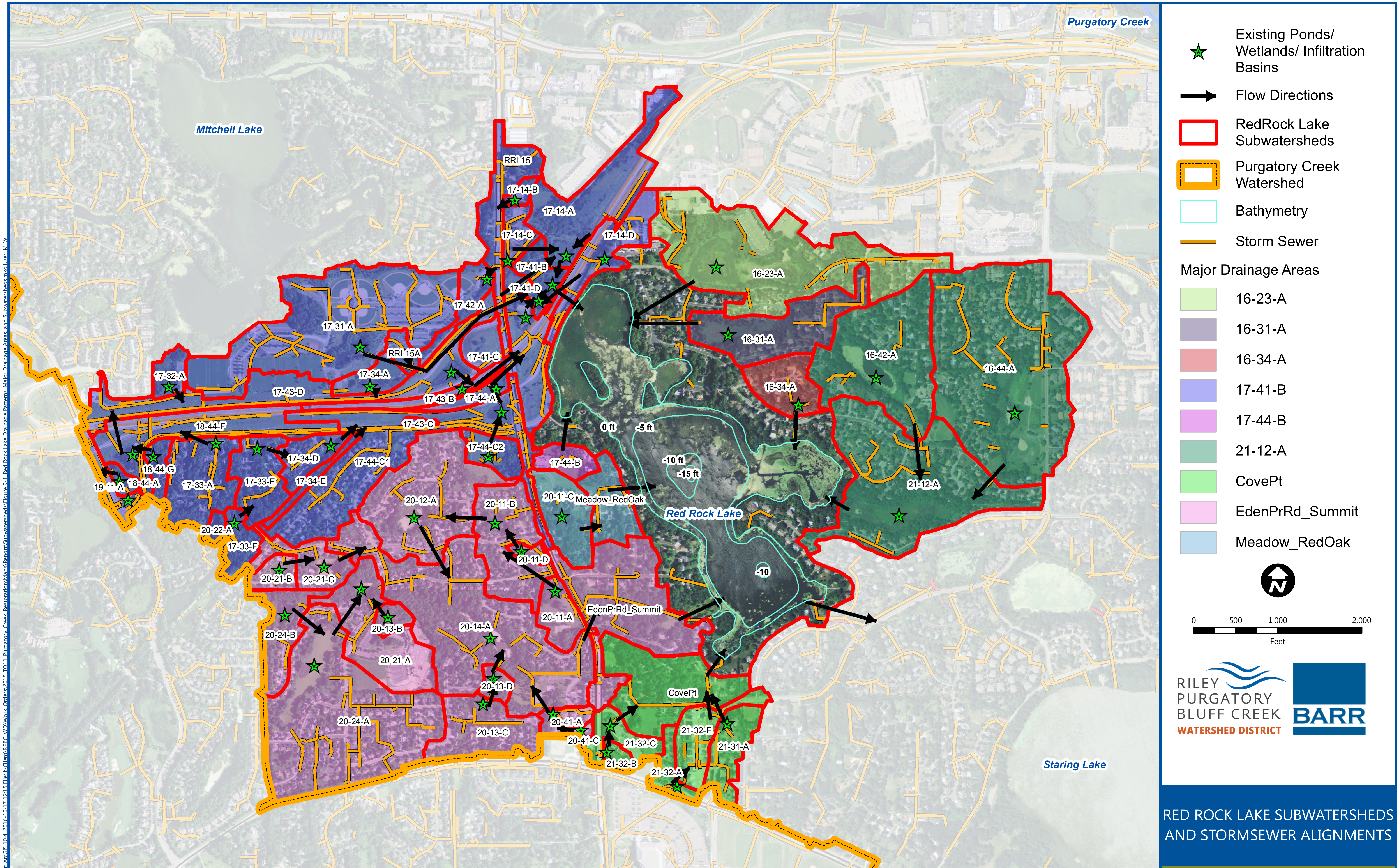
9.1 Watershed Characteristics

Red Rock Lake lies with the boundaries of the city of Eden Prairie. The direct watershed area contributing to Red Rock Lake is 1286 acres including the lake surface area of 121 acres (Figure 9.1). Red Rock Lake has two upstream lakes. Round Lake with a watershed of 475 acres contributes flow to Mitchell Lake and Mitchell Lake with a watershed area of 937 acres contributes flow directly to Red Rock Lakes. Combined the watershed area from the two upstream lakes is 1412 acres. The total watershed area of Red Rock Lake including the areas from the upstream lakes is 2698 acres. The flow from Red Rock Lake exits through a control structure into a storm sewer pipe that drains through a series of ponds and Lake McCoy and finally into Staring Lake.

9.1.1 Drainage Patterns

The stormwater conveyance system in the Red Rock Lake watershed is comprised of storm sewer networks, constructed stormwater detention ponds, and natural wetlands within the watersheds tributary to the lake (Figure 9.1). Most of the constructed stormwater ponds within the Red Rock Lake watershed are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows.

The Red Rock Lake watershed was divided into subwatersheds based on updated topographical data (MDNR, 2011), storm sewer data, BMP locations, and other information from the city of Eden Prairie. The subwatersheds were grouped into 9 major drainage areas within the Red Rock Lake watershed (Figure 9.1). Each major drainage area is named after the terminating watershed in each conveyance network. In addition to the major drainage areas is the lakes direct watershed. The direct watershed includes areas along the shoreline of the lake that contribute flow directly to the lake through surface flow as well as small stormsewered sections that do not receive treatment before discharging into the lake.



RED ROCK LAKE SUBWATERSHEDS AND STORMSEWER ALIGNMENTS

FIGURE 9.1

9.1.2 Land Use

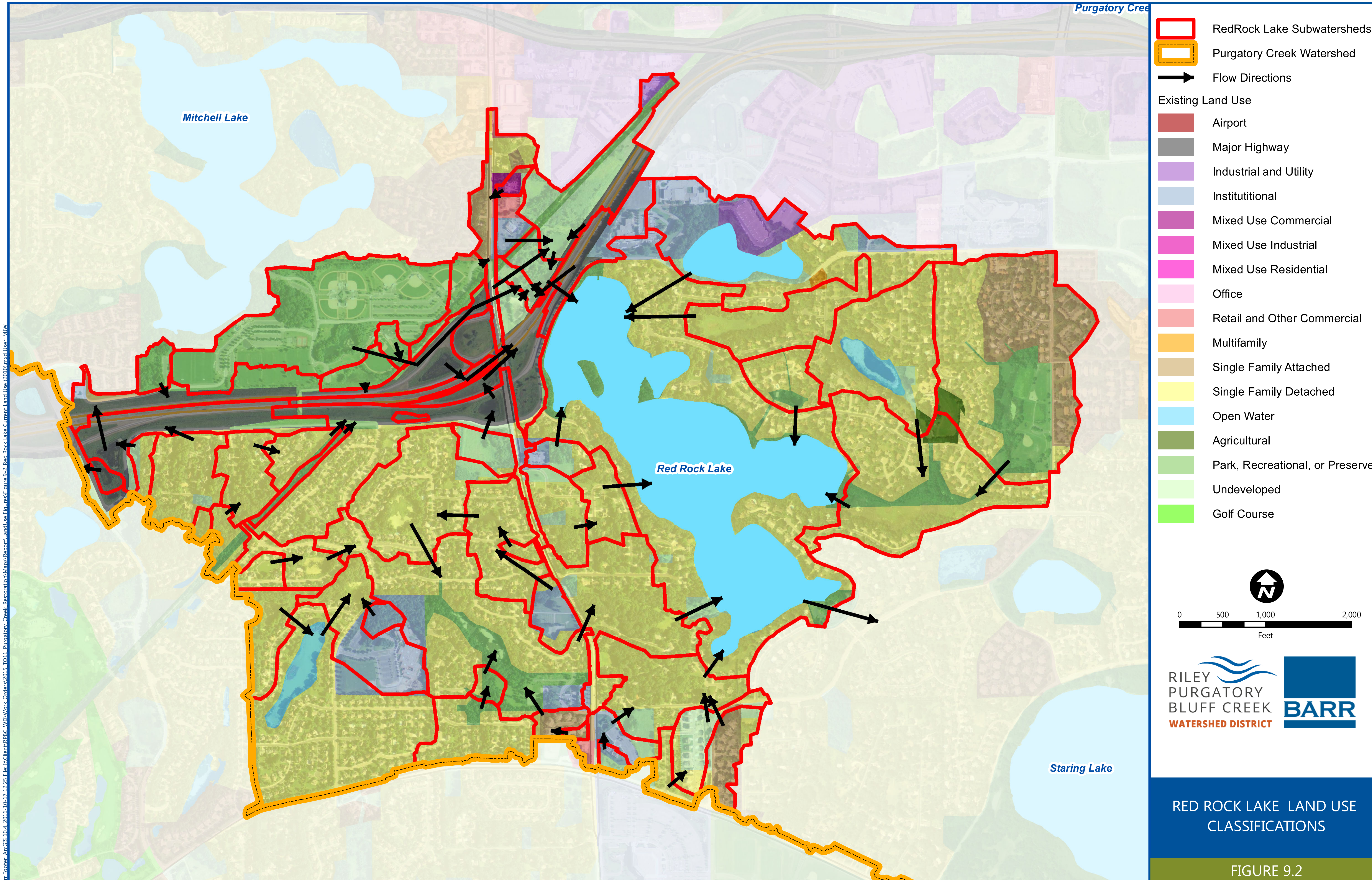
Land use within a lake's watershed can impact the hydrology and water quality of a lake. Varying land uses contribute different quantities of sediments and TP to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

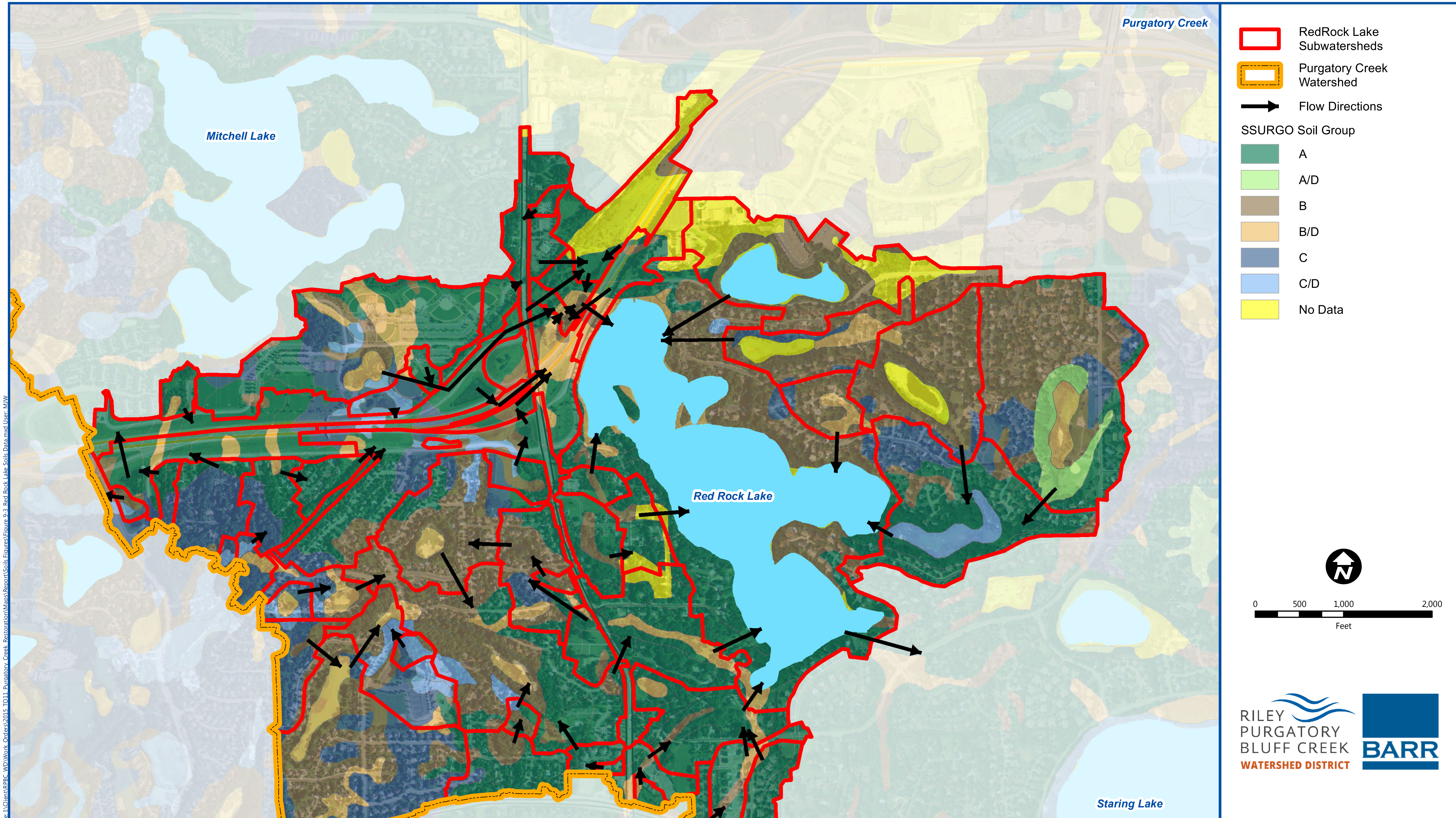
Existing land-use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council. The land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix D.

The majority of the Red Rock watershed is covered by single family residential land use (61%). Figure 9.2 shows the exiting land uses present in the Red Rock Lake watershed.

9.1.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database map for Hennepin County, the underlying soils in the Red Rock Lake watershed are predominantly classified as hydrologic soil group (HSG) A with high infiltration rates and B with moderate infiltration rates (Figure 9.3). The rest of the areas are predominately covered by HSG C soils with low infiltration rates.


Purgatory Cree
Mitchell Lake
Red Rock Lake
Staring Lake
RedRock Lake Subwatersheds
Purgatory Creek Watershed
Flow Directions
Existing Land Use
Airport
Major Highway
Industrial and Utility
Institutional
Mixed Use Commercial
Mixed Use Industrial
Mixed Use Residential
Office
Retail and Other Commercial
Multifamily
Single Family Attached
Single Family Detached
Open Water
Agricultural
Park, Recreational, or Preserve
Undeveloped
Golf Course
0 500 1,000 2,000
Feet
RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT
BARR
RED ROCK LAKE LAND USE CLASSIFICATIONS
FIGURE 9.2



RED ROCK LAKE SOILS CLASSIFICATIONS

FIGURE 9.3

9.2 Lake Characteristics

Table 9.1 provides a summary of the physical characteristics for Red Rock Lake. Red Rock Lake has an open-water surface area of approximately 121 acres. The lake is shallow, with a maximum depth of approximately 19 feet and mean depth of approximately 4.7 feet. The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 842.69 feet MSL (2014) to a low measurement of 835.69 feet MSL (1970). Since 2011 water levels in Red Rock Lake have averaged 840.45 feet MSL. Water elevations were not measured between 2001 and 2010. The outlet of Red Rock Lake is a manmade structure that conveys water to Staring Lake through a series of stormwater ponds as well as Lake McCoy. The outlet is an elevation of 837.77 feet. At the average water elevation of 840.45 feet the total water volume in Red Rock Lake is 615 acre-ft.

Table 9.1 Red Rock Lake Physical Characteristics

Lake Characteristic	Red Rock Lake
Lake MDNR ID	27-0076-00
MPCA Lake Classification	shallow
Water Level Control Elevation (feet MSL)	837.77
Average Water Elevation (feet MSL)	840.45
Surface Area (acres)	121
Mean Depth (feet)	4.7
Maximum Depth (feet)	19
Littoral Area (acres)	119
Volume (at normal water elevation) (acre-feet)	615
Thermal Stratification Pattern	polymictic
Estimated Residence Time (years) – 2014-2015 climatic Conditions	0.2
Watershed Area Tributary to Upstream Lake	1412[2]
Total Watershed Area	2698[2]
Subwatershed Area (acres)	1286[2]
Trophic Status Based on 2015 Growing Season Average Water Quality Data	eutrophic

1 – Average water elevation 2011-2015.
2 – Watershed area includes surface area of lakes

Given the depth of Red Rock Lake and the review of temperature and dissolved oxygen profiles suggest that Red Rock Lake is a polymictic lake. This means that the lake mixes multiple times throughout the year from wind mixing events. The temperature profile in the water column suggests that the lake does stratify resulting in anoxic conditions near the lake sediments; however wind mixing events during the summer can be strong enough to completely mix the lake water column providing oxygen to the sediments and mixing TP throughout the water column.

9.3 Water Quality Conditions

Historical water quality data, in terms of growing-season (June – September) average TP concentrations, chlorophyll *a* concentrations, and Secchi disc transparency for Red Rock Lake are presented in Figure 9.4. Also shown in these figures are the MPCA water quality standards for a shallow lake for each parameter. Growing season average TP concentration before 1985 hover above or below the water quality standard for a shallow lake of 60 µg/L. Between 1988 and 2006 average concentrations are all above the standard except for two years. From 2008 to 2015, five of the eight average TP concentrations are below the standard. In 2015, the growing season average concentration was 48 µg/L. The lowest recorded average concentration of 34 µg/L was recorded in 2012. The highest average concentration of 113 µg/L was recorded in 1988.

Growing season average chl-a concentrations between 1988 and 2010 were all above the water quality standard of 20 µg/L for a shallow lake. Between 2011 and 2015 four of the five growing season average chl-a concentrations achieve the water quality standard. In 2015 the average chl-a concentration was 15 µg/L. The lowest average concentration of record of 5 µg/L was collected in 2012. The highest growing season average concentration of 108 µg/L was collected in 1988.

Growing season average Secchi depth before 1988 all met the water quality standard for a shallow lake of 1 meter. Between 1988 and 2007 only four years met the standard. After 2007 to present, all average depths met the standard. The most recent average Secchi depth in 2015 was 1.2 meters. The highest (best) average Secchi depth of 2.5 meters was collected in 2011. The lowest (worst) average Secchi depth of 0.3 meters was in 1989.

Trends in the water quality data were determined by calculating a Thiel-Sen slope on the annual average growing season values and the significance of the trend was tested using the Mann-Kendall non parametric test at the 95% confidence internal. Significant improving water quality trends were present in all three water parameters from 1999-2015 (Table 9.2).

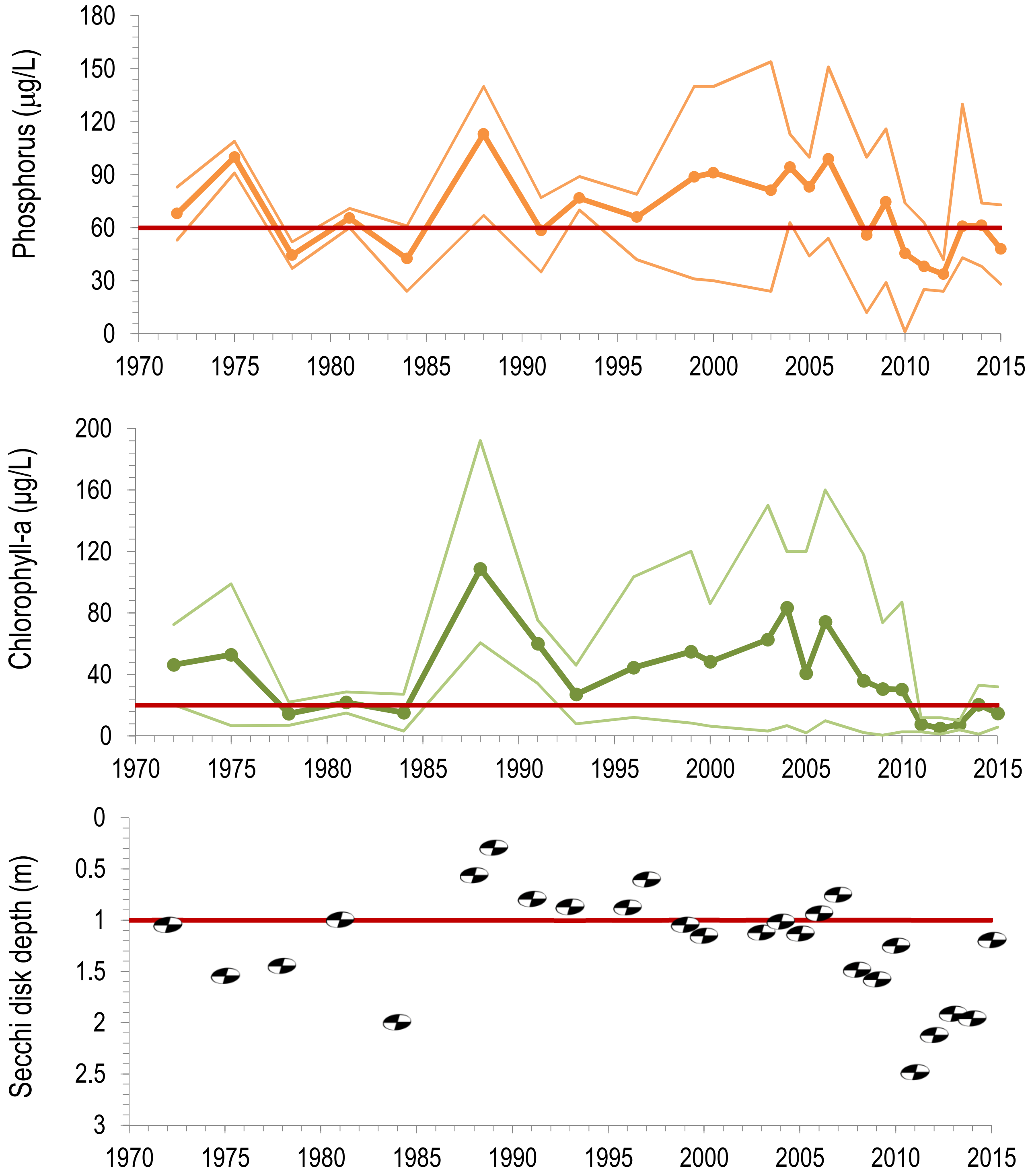


Figure 9.4
Red Rock Lake Water Quality
Growing Season (June - September) Average, Min and Max

Table 9.2 Red Rock Lake water quality parameter Thiel-Sen trends for year 1999-2015

Parameter	1999-2015	Entire Record
TP (µg/L/yr)	-3*	0
Chl-a (µg/L/yr)	-3.6*	-0.7
Secchi Depth (m/yr)	0.06*	0.03*

Notes:
* Designates significant trends at the 95% confidence level using Mann-Kendall significance test

9.3.1 Water Quality Relationships

As previously discussed, phosphorus often acts as the limiting nutrient for algal growth (as measured by chlorophyll *a*), which in turn, affects lake water clarity (Secchi depth). This section describes how incremental phosphorus load reductions would be expected to impact perceptible changes in lake water quality. The compiled data for the water quality variables from Red Rock Lake were analyzed to develop relationships between the water quality parameters: TP, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season averages. In addition to developing the water quality relationships based on the observed data, the regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) were also plotted against the lake data.

The relationships between the various water quality parameters for the actual Red Rock Lake data did indicate some correlation between the water quality parameters (Figure 9.5). The MPCA regression equations resulted in similar fit for the chlorophyll *a*, Secchi disc transparency data, and TP. For this reason the MPCA statewide regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Red Rock Lake based on TP concentration.

Figure 9.5 shows the individual water quality data points for Red Rock Lake, along with plots of the MPCA statewide regression equations.

The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla (µg/L) = 1.31 Log10 TP (µg/L) – 0.95
- Log10 Secchi (meters) = -0.59 Log10 Chla (µg/L) + 0.89
- Log10 Secchi (meters)= -0.81 Log10 TP (µg/L) + 1.51

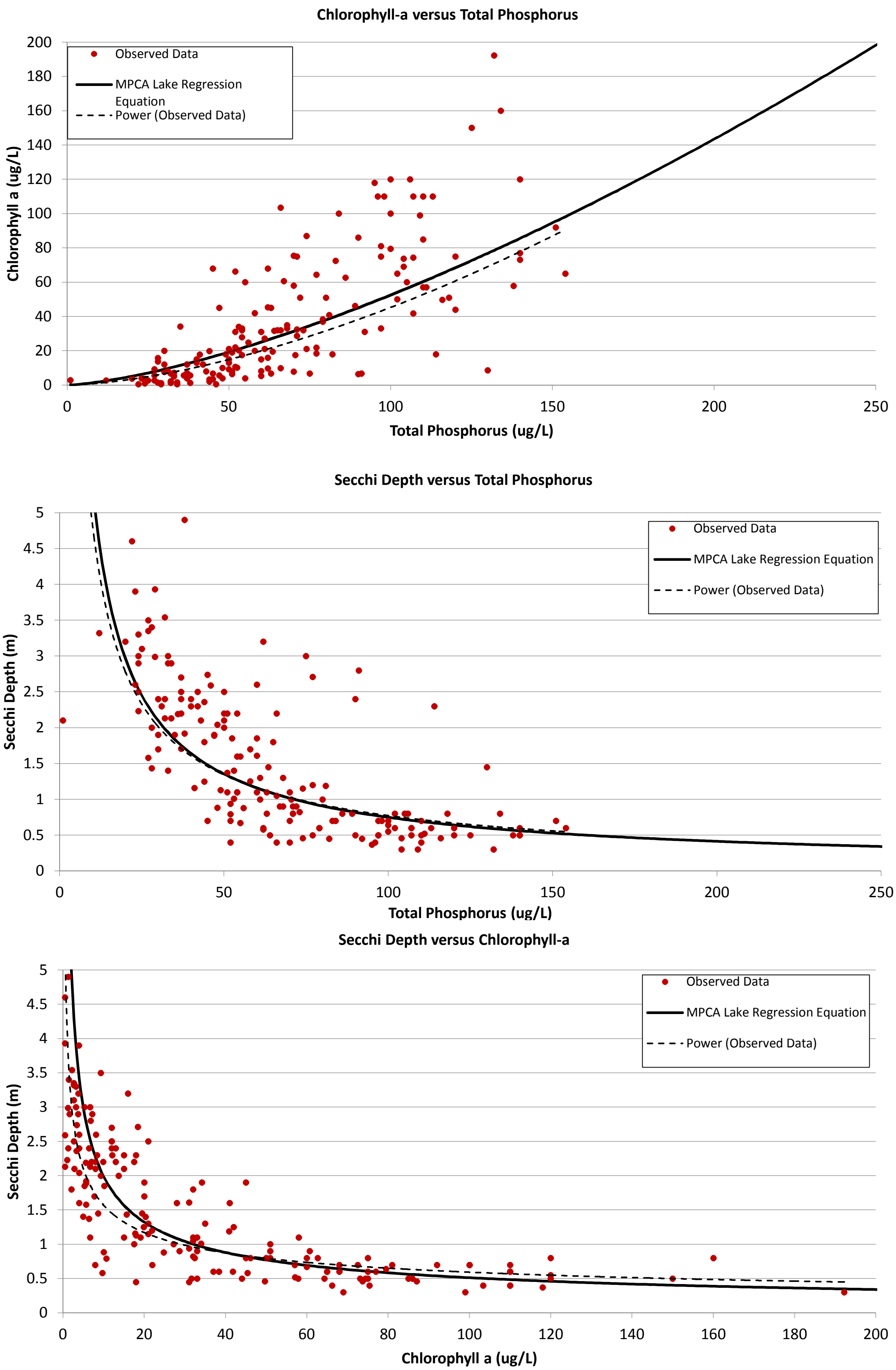


Figure 9.5
Red Rock Lake Individual Samples
Water Quality Parameter
Regression Relationships

9.4 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores)). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

9.4.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess TP loads.

Plankton surveys have been collected on Red Rock for years: 1999 and 2011. The most recent survey conducted in 2011 found that the phytoplankton community is dominated by small bodied phytoplankton throughout the monitoring season (April – September). Large bodied cyanobacteria peak in July representing only 11% of the phytoplankton population.

While green algae are edible to zooplankton and serve as a valuable food source, cyanobacteria are considered a nuisance type of algae because they:

- Are generally inedible to fish, waterfowl, and most zooplankters
- Float at the lake surface in expansive algal blooms
- May be toxic to animals when occurring in large blooms
- Can disrupt lake recreation because they are most likely to be present during the summer months

9.4.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

The zooplankton community was analyzed in Red Rock Lake during the monitoring season in year 2015 (RPBCWD, 2015). It was found that rotifiers were the most abundant zooplankton species in Red Rock Lake throughout the sampling season except in June when copepods outnumber rotifiers. Grazing rates from large cladocera consuming algae were estimated to be between 8% and 30% between May and August. In September grazing rates jumped to 94% of the epilimnion grazed per day. This spike is due to the number of Daphnia galeata mendotaes increasing substantially during this time (RPBCWD, 2015).

9.4.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

A plant survey was conducted on Red Rock Lake in year 2013. The survey was conducted in early June and August. The survey found curlyleaf pondweed and coontail to be the most abundant species of macrophytes in the lake with coontail found in ~60% of the sites sampled during both sampling periods and curlyleaf pondweed found in 43% of the sites in June and only 5% of the sites in August. The abundance of coontail helps reduce the TP available for algae growth because coontail absorbs nutrients directly from the water column. Other plant species found at greater than 10% of the sites include whitewater lily, star duckweed, flatstem pondweed, spatterdock and stringy pondweed. Eurasian watermilfoil was also found in Red Rock Lake but only in 1% of the sites sampled in June.

In 2014 curlyleaf pondweed and coontail were delineated in Red Rock Lake during the month of June (Blue Water Science, 2015). The initial delineation found widespread curlyleaf pondweed with 6 areas having the potential for moderate to high density growth. In mid-June a total of 15 acres of curlyleaf pondweed, coontail and filamentous algae were removed through mechanical harvesting. A subsequent analysis in late June found curlyleaf growth to be light to moderate. In the following year, 2015, herbicide treatment for curlyleaf pondweed was implemented to control the growth and spread of the invasive species (Blue Water Science, 2015).

9.4.4 Fishery

The MDNR developed a classification system for Minnesota lakes relative to the chemical and physical properties of each lake class and the fishery that is supported by each lake (Schupp, 1992). According to its ecological classification, Red Rock Lake is a Class 42 lake. Class 42 lakes are typically shallow and productive lakes with fish assemblages that include white sucker, yellow perch, bluegills, pumpkinseeds, black crappie, black bullhead, and northern pike (Schupp, 1992). Class 42 lakes are considered marginal fish lakes because they may winterkill frequently.

The MDNR conducted a fish survey on Red Rock Lake in 2011. The 2011 survey found northern pike level lower than previous surveys. Largemouth bass were not found in 2011. It was suggested that this absence of the largemouth bass were due to a winter fish kill caused by aeration system failures during the winter months. Six species of panfish have been found in Red Rock Lake including black crappies in very low abundance, bluegills at lower levels than similar lakes in the state, yellow perch at higher abundance than similar lakes in the state, pumpkinseeds and hybrid sunfish were also sampled. Roughfish were found at very low levels with two species present: black bullhead and white suckers. Since 2011 Red Rock Lake has been routinely stocked by the MDNR with bluegills and largemouth bass. Fish surveys in 2011 and 2012 by the University of Minnesota found zero occurrences of carp in Red Rock Lake (Sorensen, et al., 2015).

9.5 TP Source Assessment

The watershed and in-lake water quality models were developed to assess both the external and internal TP loads in Red Rock Lake for the 2015 water year (October 2014 – September 2015). A detailed discussion of the modeling methods used is presented in Section 2.2.2 and Appendix D. Possible lake external loads of TP include atmospheric depositions, stormwater runoff from the lake watershed, surficial groundwater interactions with the lake waters, internal loads from upstream ponds and wetlands, and load from any upstream lakes that might flow into the waterbody.

External loads that applied to Red Rock Lake are atmospheric deposition, watershed loads, and upstream lakes. Internal loading within the ponds and wetlands was not evaluated for this study, no channels with erosion potential contribute the Red Rock Lake, and no significant load from groundwater sources were found meaning the inflow of groundwater likely equals the outflow. Internal TP loads can come from sediment TP release, curlyleaf pondweed, or benthivorous fish activity.

Figure 9.6 summarizes the 2015 annual water year TP budgets for Red Rock Lake, including the relative contributions of the external and internal TP loads. This budget explains the sources of TP to the lake and helps direct and prioritize implementation strategies. Each of the sources are discussed further in the following section(s).

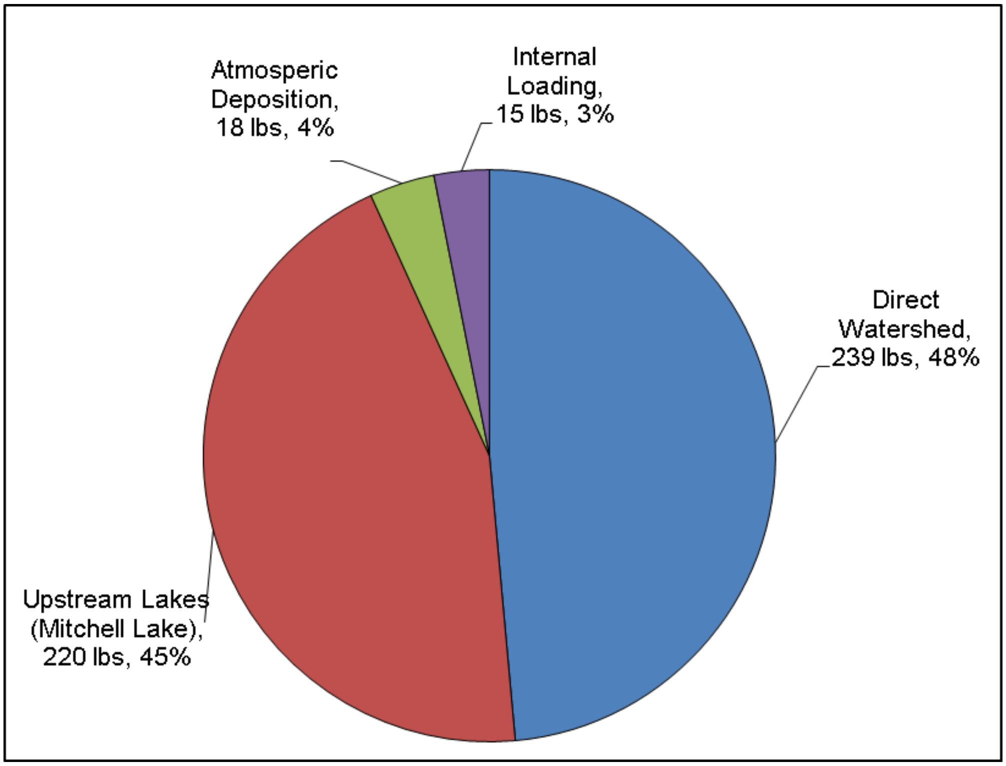


Figure 9.6 Red Rock Lake TP load sources for 2015 water year

9.5.1 External Loads

9.5.1.1 Atmospheric Deposition

Atmospheric deposition of TP onto the lake water surface was calculated by using the estimated statewide TP atmospheric deposition rate of 0.17 kg/ha/year (Barr Engineering, 2004). For Red Rock Lake, this loading rate was applied to the combined open water area. The daily rate was applied to the surface area of the lake based on the modeled lake water elevation from the lake water balance model. The resulting atmospheric deposition TP load for the 2015 water year was 18 pounds which amounts to 4% of the TP load to Red Rock Lake (Figure 9.6).

9.5.1.2 Watershed Loads

The P8 watershed model estimated surface runoff from Red Rock Lake's subwatersheds (not passing through upstream lakes) based on observed climatic data (precipitation and temperature). The total untreated watershed load from the watersheds in Red Rock Lake for the 2015 water year was modeled to be 564 pounds. The watershed load travels through existing stormwater ponds, wetlands, infiltration practices, and other BMPs located throughout the watershed providing treatment resulting in a load of only 239 pounds reaching the lake. This represents a 58% removal being provided by existing treatment practices in the watershed. Watershed sources represent 48% of the total water load to Red Rock Lake (Figure 9.6).

To help evaluate areas that might benefit from additional treatment, watershed loads to the lake were calculated for each of Red Rock Lake's individual subwatersheds. The load to the lake is defined as the amount of TP load from that watershed reaching the lake without being removed by an existing BMP within the subwatershed or downstream from the subwatershed. The P8 results were used to calculate the total annual average untreated watershed TP loads from each subwatershed. Next, the watershed load to the lake was calculated. This was accomplished by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each subwatershed that reached the lake without being removed by an existing BMP. The watershed load to the lake for each subwatershed is shown in Figure 9.7.

9.5.1.3 Upstream Lakes

Red Rock Lake is part of the Eden Prairie Chain of Lakes. The outflow from Mitchell Lake enters Red Rock Lake contributing a TP load to the lake. The Mitchell Lake in-lake model was used to determine flow and TP concentration entering Red Rock Lake. Modeled surface concentrations in Mitchell Lake were used as the estimated inflow concentrations into Red Rock Lake. Flow entered Red Rock Lake at an average flow rate for the 2015 water year of 1.81 cfs. The average concentration of the water entering Red Rock Lake from Mitchell Lake was 55 µg/L. This resulted in a TP load from Mitchell Lake to Red Rock Lake of 220 pounds which represents 45% of the TP load to the lake (Figure 9.6).

9.5.2 Internal Loads

Internal loading in Red Rock Lakes represented only 3% (15 pounds) of the TP loads in the 2015 water year (Figure 9.6). The internal loading sources to Red Rock Lake include curlyleaf pondweed and sediment P release.

9.5.2.1 Curlyleaf Pondweed

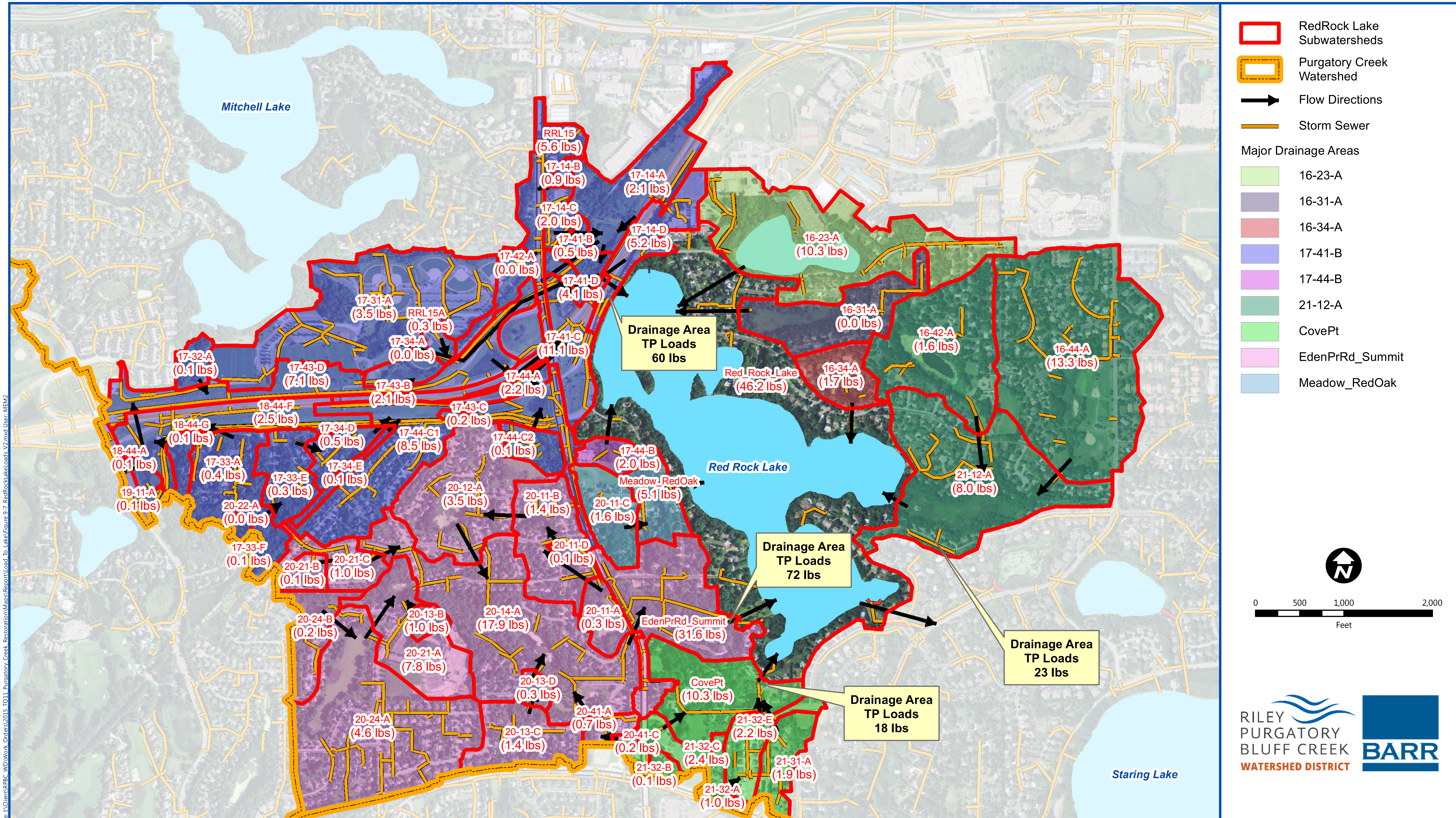
Treatment measures were implemented in Red Rock Lake for curlyleaf pondweed in 2014 and 2015. In 2015 an Endothol treatment was implemented to limit the early growth of curlyleaf pondweed. Due to these implementation procedures it is assumed that for the 2015 water year curlyleaf pondweed influences in internal loading were minimal. Continued management will be needed to limit the impact of curlyleaf pondweed on TP concentrations and water quality. If levels are degraded to moderate/ high density levels then impacts on water quality would be expected. In this analysis it was assumed that curlyleaf pondweed was a minor source of TP to Red Rock Lake due to current management efforts by RPDCWD and the city of Eden Prairie.

9.5.2.2 Benthivorous Fish Activity

In fish surveys of Red Rock Lake in 2011 and 2012 by the University of Minnesota no adult or young carp were found (Sorensen, et al., 2015). As a result, this analysis assumes that the activities of carp and other benthivorous fish are not a significant source of TP in Red Rock Lake and were not quantified as part of the in-lake water quality modeling in 2015.

9.5.2.3 Sediment Release

Internal loading through sediment release occurs during anoxic conditions. A review of dissolved oxygen profiles in Red Rock Lake showed anoxic conditions reaching a depth of 10 feet from the lakes water surface during the middle summer months. However at this depth the surface area of is only ~4 acres representing 3% of the total surface area of Red Rock Lake. The internal loading rate is only applied to sediment areas that are anoxic. Therefore, loading from internal sediment sources is limited based on the geometry of the lake. Wind mixing events are also capable of reoxygenating the sediments while only the sediments in the deeper pool become deoxygenated and provide an opportunity for phosphorus to be released back into the water column.



RED ROCK LAKE SUBWATERSHED TP LOADS TO THE LAKE

FIGURE 9.7

9.5.3 TP Load Reductions

The in-lake model was used to determine TP load reductions needed to meet the water quality goal for the lake. Table 9.3 shows the measured and modeled growing season average (June – September) concentration, the TP load to the lake under existing conditions, the water quality goal, the TP loading capacity for meeting the water quality standard and the required percent reduction needed to meet the water quality goal. Under existing conditions Red Rock Lake is meeting the water quality goal for a shallow lake of 60 µg/L. Modeled and measured growing season average concentrations in the lake surfaces waters for the 2015 water year were 49 µg/L and 48 µg/L respectively. The TP load under existing conditions was 493 pounds for the 2015 water year. No reductions are needed in Red Rock Lake to meet the TP goal for the analyzed time period. While load reduction are not required in Red Rock Lake to meet the water quality standard for the 2015 water year BMPs to further reduce the TP concentrations in the lake could be implemented to protect and enhance the health of the lake.

Table 9.3 Red Rock Lake estimated load reductions required to meet TP water quality goal for 2015 water year

Measured growing season average TP concentration (µg/L)	Modeled growing season average TP concentration (µg/L)	Estimate 2015 TP loading rate (lbs/yr)	TP concentration goal (µg/L)	Estimated Loading Capacity to meet WQ goal (lbs/yr)	Percent reduction needed to achieve goal (%)
48	49	493	60	Meets goal	0

Figure 9.8 shows how lake concentrations react to lake load reductions. The calibrated in-lake TP model was used to determine in lake water quality based on the amount of TP load to the lake. Chl-a and Secchi depth concentrations were determined based on the water quality relationships discussed in Section 9.3.1. The figure shows how incremental load reductions would impact the water quality in Red Rock Lake. A TP load reduction of 45 pounds would reduce the lake TP concentration to 43 µg/L. A TP load reduction of 90 pounds could reduce the lake concentration to 38 µg/L.

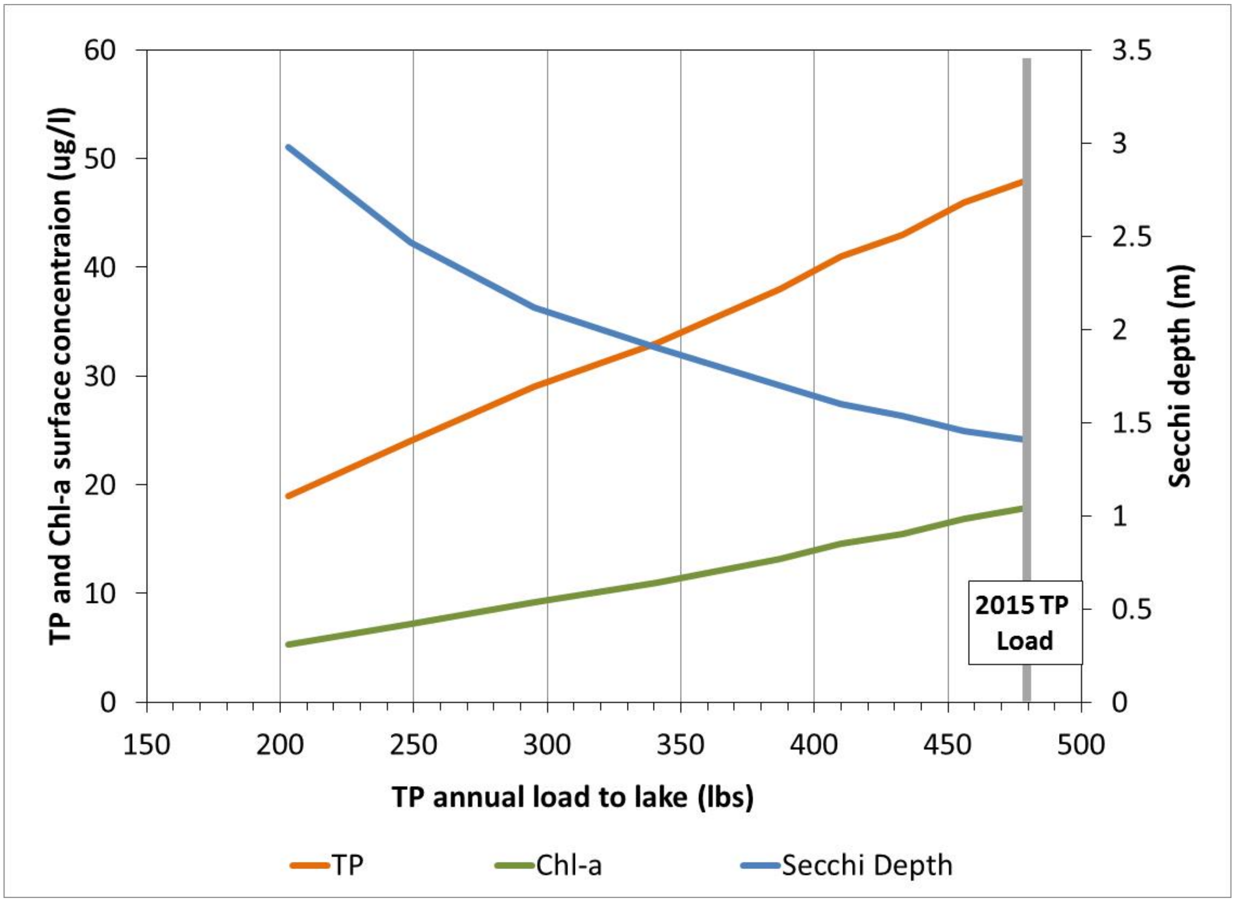


Figure 9.8 **Red Rock Lake TP load relationship with lake water quality (TP, Chl-a and clarity)**

9.6 Summary of Diagnostic Findings

Table 9.4 provides a summary of the key water-quality findings for Red Rock Lake.

Table 9.4 Diagnostic Findings for Red Rock Lake

Topic	Red Rock Lake
Water Quality Standards and Goals	- Water quality standards for TP, Chl-a and secchi depth all met the standard for a shallow lake in 2015. - Does not meet the RPBCWD long term vision for secchi depth of 2 meters.
Baseline Water Quality	- Sediment reconstruction was not conducted
Water Quality Trends	- Significant improving trends were present in TP, Chl-a, and secchi depth from 1999-2015.
Watershed Runoff	- Represents approximately 48% of the annual TP load. - Watershed load is reduced by an estimated 58% by existing BMPs, ponds, and wetlands located throughout the watershed. - Mitchell Lake contributes 45% of the load to Red Rock Lake.
Macrophyte Status	- Current management of curlyleaf pondweed have limited curlyleaf to low densities
Fishery Status	- No carp found in recent survey by U of M
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer
Internal Loading from sediments	- Internal loading from sediment estimated to be 15% of annual TP load
Methylmercury in Fish Tissues	- Listed as impaired for aquatic consumption due to mercury in fish tissue in 2002 - A TMDL plan was approved in 2008 by the MPCA.

Additional discussion of the diagnostic findings in relation to the sources of TP and water quality of the lake based on the data analyses, watershed and in-lake modeling, and review of recent studies and information is included. These conclusions influenced the implementation strategies evaluated for the management of Mitchell Lake water quality (see Section 9.8).

- In 2015 Red Rock Lake met the MPCA shallow lake water quality standards for all TP, Chl-a and secchi depth. Significant improving trends are present in all three parameters from 1999-2015.

- Approximately 86 percent of the watershed runoff receives treatment prior to entering Red Rock Lake due to the number of stormwater ponds and other waterbodies within the watershed. As stormwater runoff passes through the many constructed stormwater ponds and natural wetlands in the watershed, significant removal of TP associated with particulates in the runoff occurs due to particle settling and infiltration. Modeling suggests that approximately 58% of the watershed load is removed in existing BMPs before reaching Red Rock Lake. As a result, the watershed modeling suggests that a significant portion of the TP in the watershed runoff reaching the lake is in a soluble form or associated with very small particles that are difficult to settle. Therefore, treatment practices the can remove dissolved phosphorus such as infiltration and enhanced filtration practices should be examined in addition to practices in currently untreated areas.

- The watershed phosphorous load to Red Rock Lake represented an estimated 48 percent of the total annual TP budget to the lake during the 2015 water year; internal loading represented another estimated 15 percent of the total annual TP budget.

- Mitchell Lake contributes flow Red Rock Lake. During the 2015 water year flow from Mitchell Lake contributed 45% of the TP load to Red Rock Lake. Reducing concentrations in Mitchell Lake could have an impact on the water quality in Red Rock Lake.

- Figure 9.8 shows the estimated 2015 water year TP loading from the major drainage basins in the Red Rock Lake watershed. The watershed modeling suggests that 19 percent of the watershed load to Red Rock Lake is coming from the lake's direct watershed. Another 25 percent is coming from the drainage area contributing to 17-41-B and 30 percent from the drainage area contributing to EdenPrRd_Summit.

- Mechanical harvesting and herbicide treatment of curlyleaf pondweed have been conducted in Red rock Lake in 2014 and 2015. The management actions have limited the growth of curlyleaf pondweed with current levels and low densities. Continued management will prevent curly leaf pondweed from impacting the water quality of Red Rock Lake.

- The carp population was analyzed in Red Rock Lake in 2011 and 2012 as part of the University of Minnesota's study for Purgatory Creek (Sorensen, et al., 2015). Zero occurrences of carp either adult or young were found in Mitchell Lake.

9.7 Current and Past Management Actions

The following includes a summary of BMPs either implemented or analyzed in the Red Rock Lake watershed:

- An aeration system was installed in 1991.
- Mechanical plant harvesting was implemented in Red Rock Lake to control plant growth and non-native plant species in 2012 and 2013.
- Plant management plan includes mechanical harvesting of curlyleaf pondweed and treatment with Aquathol K on a maximum 10 acres area (Wenck Associates Inc., 2015).
- A stormwater basin inventory and analysis identified 7 stormwater ponds out of 74 basins in the Red Rock Lake and Duck Lake watersheds as high priority basins that should be routinely inspected and maintained (Wenck Associates, Inc., March 2014).

- Ponds 16-42-A and 21-12-A, analyzed in the Red Rock Lake watershed during 2012 and 2013, were determined to have TP concentrations above 250 µg/l and could benefit from remediation measures (RPBCWD, 2014).
- Other potential BMP and mitigation measures suggested for Red Rock Lake as part of the "One Water" Water Management Plant (CH2M HILL, 2011) include:
    - control purple loosestrife with beetles.
- Carp were not found in Red Rock Lake as part of surveys conducted in 2011 and 2012 (Sorensen, et al., 2015).

9.8 Evaluation of Water Quality Improvement Options

All of the BMPs identified for Red Rock Lake are listed and described in detail in the following subsections. Table 9.5 provides a list of the potential BMPs and Figure 9.9 shows the identified potential BMP locations in the Red Rock Lake watershed.

9.8.1 New wet pond in subwatershed 16-44-A, RRL_1

BMP RRL_1 would be a new wet pond in subwatershed 16-44-A on the vacant land near Pheasant Woods Park west of Mitchell Road. The BMP would receive runoff from 17.8 acres of untreated impervious area. This pond is proposed to be approximately 1.5 acres at the surface with an average depth of about 3 feet. The pond could remove 22.7 pounds of TP per year. Based on the location of the BMP in the watershed relative to Red Rock Lake, the reduction of TP load to the lake is estimated to be 9.5 pounds of TP per year. The cost-benefit of this BMP for Red Rock Lake is estimated to be about $1,720 per pound of TP, assuming the BMP functions for 30 years.

9.8.2 Infiltration basin in subwatershed 17-44-B, RRL_2

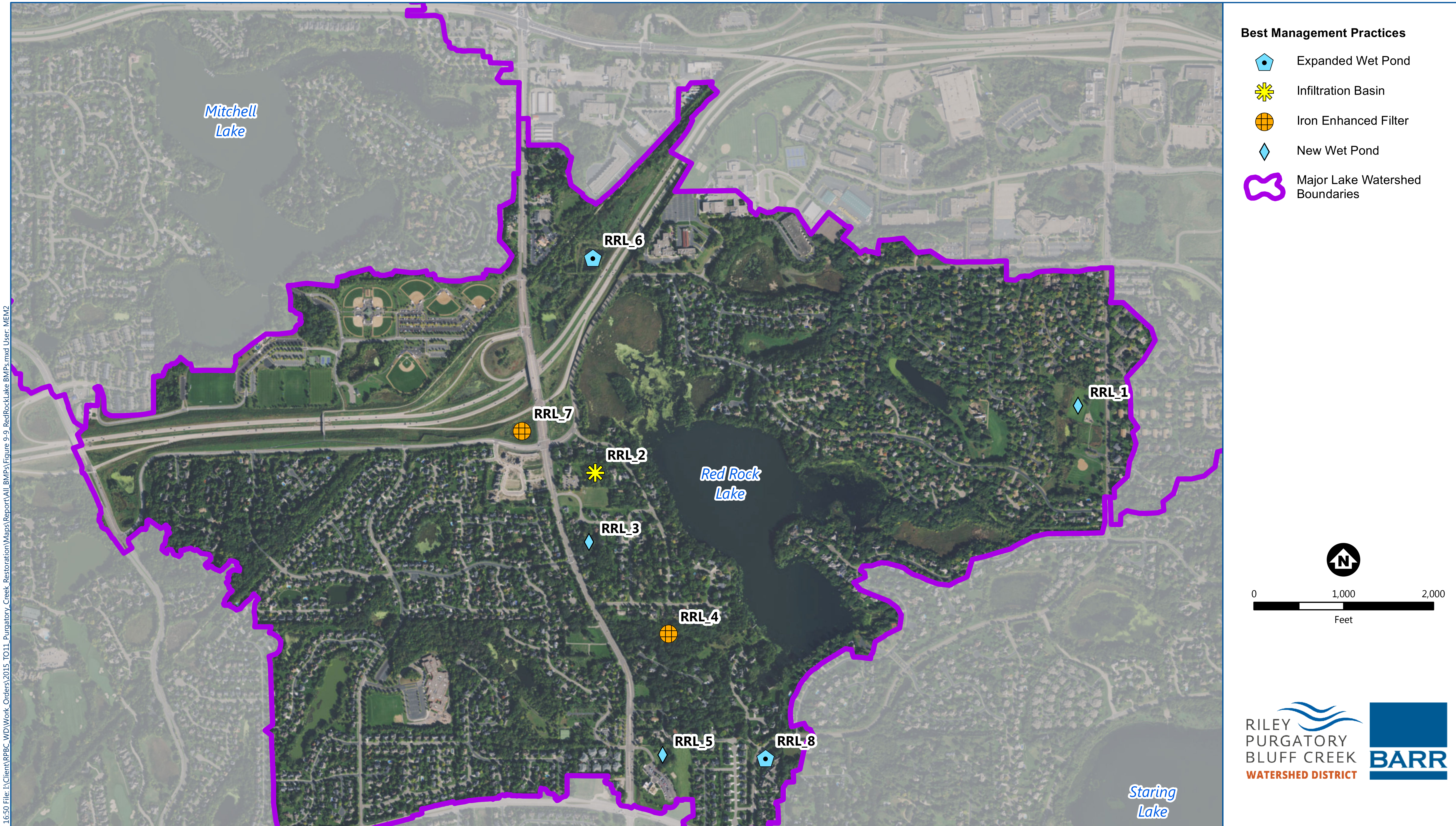
BMP RRL_2 is a new infiltration basin in subwatershed 17-44-B in the low-lying area behind Victory Lutheran Church and would receive runoff from0.9 acres of untreated impervious area. According to the NRCS SSURGO data, the soils in this area are "A" and "B" soils, indicating soils with a good capacity to infiltrate water. This infiltration basin is proposed to be approximately 0.3 acres at the surface and about 1.5 feet deep. The infiltration basin could remove 2.0 pounds of TP per year of watershed loading to Red Rock Lake. The cost-benefit of this BMP for Red Rock Lake is estimated to be about $2,400 per pound of TP, assuming the BMP functions for 30 years.

Table 9.5 - Summary of Red Rock Lake BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
RRL_1	New Wet Pond *- A 1.5 acre, 3-foot deep wet pond designed to treat 17.8 acres of impervious area*	22.7	9.5	N/A	$305,900 ($245,000 - $428,000)	$6,100 ($4,900 - $8,600)	$720 ($570 - $1,010)	$1,720 ($1,370 - $2,400)
RRL_2	Infiltration Basin *- A 0.15 acre, 1.5-foot deep infiltration basin designed to treat 0.9 acres of impervious area*	2	2	N/A	$89,700 ($72,000 - $126,000)	$1,800 ($1,400 - $2,500)	$2,400 ($1,920 - $3,350)	$2,400 ($1,920 - $3,350)
RRL_3	New Wet Pond *- A 1.0 acre, 3-foot deep wet pond designed to treat 2.2 acres of impervious area*	0.3	0.3	N/A	$112,200 ($90,000 - $157,000)	$2,200 ($1,800 - $3,100)	$19,800 ($15,840 - $27,720)	$19,800 ($15,840 - $27,720)
RRL_4	Iron Enhanced Sand Filter Trench *- A 2.5 acre, 1.5-foot deep iron enhanced sand filter designed to treat 6.5 acres of impervious area*	24.5	24.5	N/A	$979,800 ($784,000 - $1,372,000)	$19,600 ($15,700 - $27,400)	$2,130 ($1,710 - $2,990)	$2,130 ($1,710 - $2,990)
RRL_5	New Wet Pond *- A 0.5 acre, 1.5-foot deep wet pond designed to treat 0.8 acres of impervious area*	1.7	1.7	N/A	$164,600 ($132,000 - $230,000)	$3,300 ($2,600 - $4,600)	$5,170 ($4,130 - $7,240)	$5,170 ($4,130 - $7,240)
RRL_6	Expanded Wet Pond *- A 1.0 acre, 3-foot deep wet pond designed to treat 1.8 acres of impervious area*	2.9	2.9	N/A	$194,000 ($155,000 - $272,000)	$3,900 ($3,100 - $5,400)	$3,570 ($2,860 - $5,000)	$3,570 ($2,860 - $5,000)
RRL_7	Iron Enhanced Sand Filter Benches *- A 1.0 acre iron enhanced sand filter around an existing wet pond, designed to treat 12.3 acres of impervious area*	17.5	10	N/A	$440,500 ($352,000 - $617,000)	$8,800 ($7,000 - $12,300)	$1,340 ($1,070 - $1,880)	$2,350 ($1,880 - $3,290)
RRL_8	Expanded Wet Pond *- A 0.8 acre, 4-foot deep wet pond designed to treat 2.4 acres of impervious area*	2.1	2.1	N/A	$651,700 ($521,000 - $912,000)	$13,000 ($10,400 - $18,200)	$16,530 ($13,230 - $23,150)	$16,530 ($13,230 - $23,150)
RRL_9	Assume Mitchell Lake meets load and quality goals	37	37	N/A	See Table 12.1 for the cost for Mitchell Lake BMPs			

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. There is no overall load reduction goal for Red Rock Lake; this lake already meets the goal.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.



ALL IDENTIFIED BMPs,
RED ROCK LAKE WATERSHED
WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 9.9

9.8.3 New wet pond in subwatershed 20-11-C, RRL_3

BMP RRL_3 would be a new wet pond in an existing low-lying area in subwatershed 20-11-C, east of the intersection of Eden Prairie Road and Candlewood Parkway. The pond would receive runoff from 2.2 acres of untreated impervious area. This pond is proposed to be approximately 1.0 acre at the surface and about 3 feet deep. The pond is estimated to remove only 0.3 pounds of TP per year, in addition to what is already removed in this area. Based on the proximity of the BMP in the watershed relative to Red Rock Lake, the removal of TP from the lake is also expected to be 0.3 pounds of TP per year. Because of the low removal rate, the cost-benefit of this BMP for Red Rock Lake is estimated to be about $19,800 per pound of TP, assuming the BMP functions for 30 years.

9.8.4 Iron enhanced sand filter chamber in subwatershed EdenPrRd_Summit, RRL_4

BMP RRL_4 is an iron enhanced sand filtration (IESF) chamber in subwatershed EdenPrRd_Summit, collinear with existing storm sewer south of Summit Drive. This chamber would treat runoff from 6.5 acres of untreated impervious area as well as polishing runoff treated by existing upstream BMPs. The buried chamber is proposed to be approximately 100 feet long and about 50 feet wide, with a solid concrete floor, walls and cap. The chamber would have one inlet from the existing storm sewer that runs through this area, and one 48-inch outlet tied back into the same existing storm sewer system. The IESF could potentially remove 24.5 pounds of TP per year based on 30-year modeling results. Because the outlet would be routed directly to Red Rock Lake via the existing storm sewer, the TP reduction at the lake is also expected to be 24.5 lbs. The cost-benefit of this BMP is estimated to be about $2,130 per pound of TP, assuming the BMP functions for 30 years.

9.8.5 New wet pond in subwatershed CovePt, RRL_5

BMP RRL_5 would receive runoff from 0.8 acres of untreated impervious area and is conceptually designed as a new wet pond in subwatershed CovePt on the vacant land northeast of Prairie Community Church. This pond is proposed to be approximately 0.5 acres at the surface and about 1.5 feet deep and would be immediately downstream of an existing stormwater pond. With some rerouting of storm sewer and a moderately more complex outlet structure, the permanent pool of the pond could be increased to 4 or 5 feet to make it more efficient. The pond could remove 1.7pounds of TP per year. Because the outlet would be routed directly to Red Rock Lake via existing storm sewer, the reduction of TP to the lake is also expected to be 1.7pounds of TP per year. The cost-benefit of this BMP for Red Rock Lake is estimated to be about $5,170 per pound of TP, assuming the BMP functions for 30 years.

9.8.6 Expanded wet pond in subwatershed 17-14-A, RRL_6

BMP RRL_6 is the expansion of an existing wet pond in subwatershed 17-14-A between Highway 212 and Eden Prairie Road. The pond would receive runoff from roughly 15.5 acres of untreated impervious area. The existing pond is currently undersized (according to the NURP ratio) and is inefficient with regards to removing TP (Wenck Associates, Inc., March 2014). This expanded pond is proposed to be approximately 1.0 acres at the surface with an average depth of about 3.0 feet. The pond is estimated to remove 4.8 pounds of TP per year based on the 30-year modeling simulation. Based on the location of the BMP in the watershed relative to Red Rock Lake, the TP reduction to the lake is simulated to be less, about 2.9 pounds of TP per year. The cost-benefit of this BMP for Red Rock Lake is estimated to be about $3,570 per pound of TP, assuming the BMP functions for 30 years.

9.8.7 Iron enhanced sand filter benches in subwatershed 17-44-C1, RRL_7

BMP RRL_7 is the addition of iron enhanced sand filter benches around an existing stormwater pond in subwatershed 17-44-C1 along Highway 212 (Wenck Associates, Inc., March 2014). This BMP could treat 12.4 acres of untreated impervious area. These iron enhanced sand filter benches are proposed to total approximately 1.0 acre at the surface. The iron enhanced sand filter benches could potentially remove 17.5 pounds of TP per year based on 30-year modeling results. Based on the location of the BMP relative to Red Rock Lake, the estimated reduction of TP reaching the lake is approximately 10.0 pounds of TP per year. The cost-benefit of this BMP is estimated to be about $2,350 per pound of TP, assuming the BMP functions for 30 years.

9.8.8 Expanded wet pond in subwatershed 21-31-A, RRL_8

BMP RRL_8 is the expansion of an existing wet pond in subwatershed 21-31-A at the intersection of Mitchell Road and Cove Pointe Road designed to treat roughly 2.4 acres of impervious area. The existing pond is currently undersized (according to the NURP ratio) and is inefficient with regards to removing TP (Wenck Associates, Inc., March 2014). This expanded pond is proposed to be approximately 0.8 acres at the surface with an average depth of about 3.0 feet. However, to expand the pond, the neighboring private property would need to be acquired, and the excavation and hauling quantities would be significant, potentially lowering the feasibility. The pond is estimated to remove 2.1 pounds of TP per year based on the 30-year modeling simulation. Because the outlet would be routed directly to Red Rock Lake via the existing storm sewer, the TP reduction at the lake is also expected to be 2.1 lbs. The cost-benefit of this BMP for Red Rock Lake is estimated to be about $16,530 per pound of TP, assuming the BMP functions for 30 years.

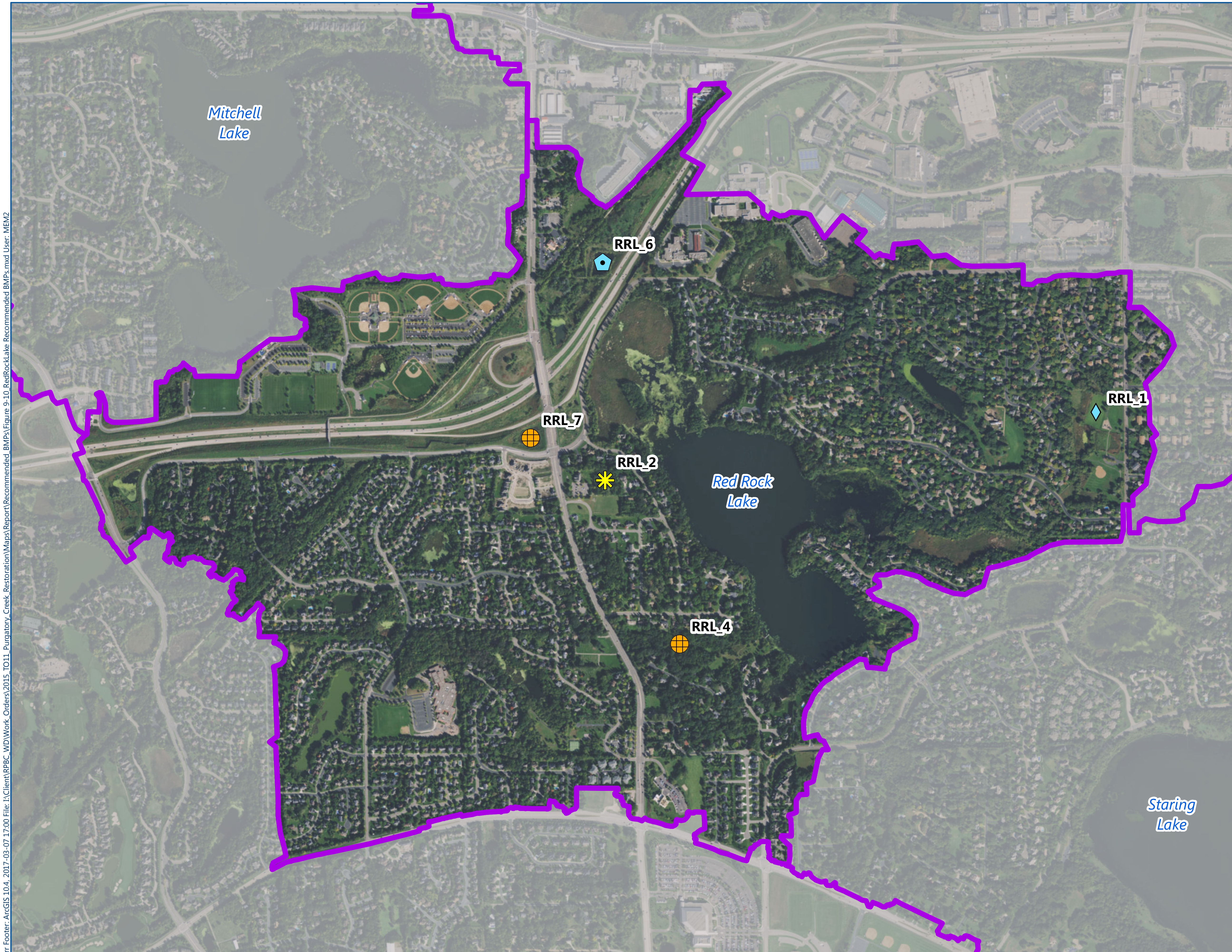
9.8.9 Improve Mitchell Lake water quality, RRL_9

A potential BMP for Red Rock Lake is treating Mitchell Lake to the MPCA's shallow lake standard of 60 µg/L (Section 8.5.3) and that future development of the Red Rock Lake watershed would be regulated for conformance with the RPBCWD stormwater management rules (RPBCWD, 2011). The recommended BMPs for achieving this goal are listed in Section 7.9. The costs associated with implementing each of the recommended BMPs in Mitchell Lake is just over $1,500,000 (the sum of the costs of the recommended Mitchell Lake BMPs). Managing Mitchell Lake to achieve the MPCA's shallow lake standard would not only protect the health and quality of Mitchell Lake, it would also reduce the annual TP loading to Red Rock Lake by 37 pounds. The cost-benefit of improving Mitchell Lake water quality for Red Rock Lake is estimated to be about $40,540 per pound of TP.

9.9 Recommendations for Water Quality Goal Attainment

There is no overall load reduction goal for Red Rock Lake because this lake is already meeting water quality goals (Section 9.5.3). Even though a load reduction is not necessary, some of the identified BMPs would be beneficial for Red Rock Lake to protect and enhance the health of the lake. Therefore, the recommended BMPs for the Red Rock Lake watershed are in the bullet list below along with the magnitude of the TP load reduction expected. The recommended BMPs are also shown in Figure 9.10. The total reduction expected by the recommended BMPs is 85.9 pounds per year from the watershed.

- RRL_1, new wet pond in subwatershed 16-44-A, ~9.5 pounds TP per year
- RRL_2, infiltration basin in subwatershed 17-44-B, ~2.0 pounds TP per year
- RRL_4, sand filter trench in subwatershed EdenPrRd_Summit, ~24.5 pounds TP per year
- RRL_6, expanded wet pond in subwatershed 17-14-A, ~2.9 pounds TP per year
- RRL_7, added iron enhanced sand filter benches to an existing wet pond in subwatershed 17-44-C1, ~10.0 pounds TP per year
- RRL_9, improve Mitchell Lake water quality, ~37 pounds TP per year



Best Management Practices

- Expanded Wet Pond
- Infiltration Basin
- Iron Enhanced Filter
- New Wet Pond
- Major Lake Watershed Boundaries

0 1,000 2,000
Feet

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

BARR

RECOMMENDED BMPs, RED ROCK LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 9.10

10.0 Lake Idlewild

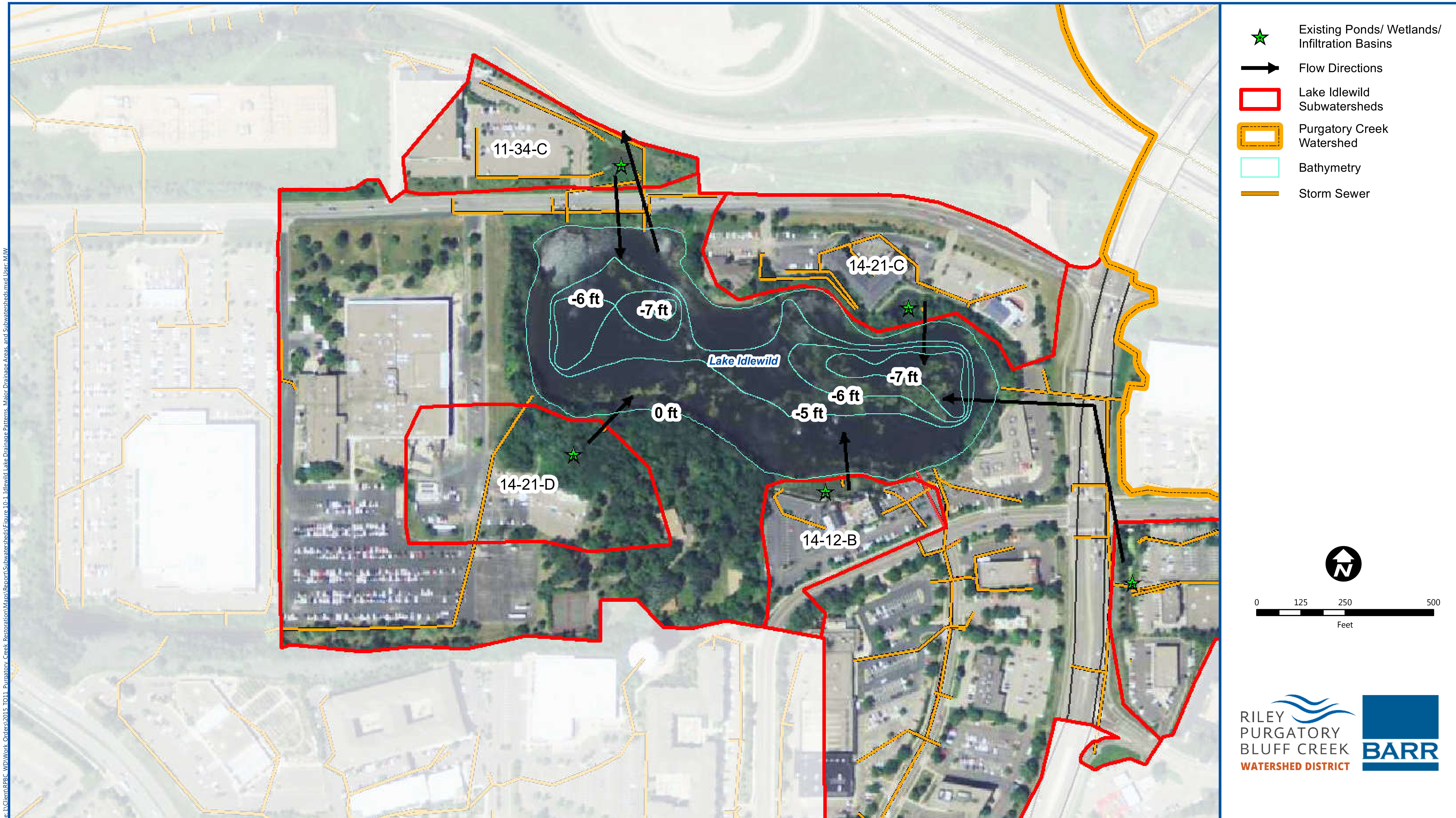
10.1 Watershed Characteristics

Lake Idlewild lies completely within the boundaries of the city of Eden Prairie. The watershed area contributing to Lake Idlewild is 89 acres including the lake surface area of 12 acres (Figure 10.1). Lake Idlewild does not have any upstream lakes contributing flow. The flow from Lake Idlewild exits through a control structure into a storm sewer pipe that drains through a series of ponds and wetlands before entering the Recreation Area and finally into Staring Lake.

10.1.1 Drainage Patterns

The stormwater conveyance system in the Lake Idlewild watershed is comprised of storm sewer networks and constructed stormwater detention ponds within the watersheds tributary to the lake (Figure 10.1). Most of the constructed stormwater ponds within the Lake Idlewild watershed are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows.

The Lake Idlewild watershed was divided into subwatersheds based on updated topographical data (MDNR, 2011), storm sewer data, BMP locations, and other information from the city of Eden Prairie. The subwatersheds include the lakes direct watershed. The direct watershed includes areas along the shoreline of the lake that contribute flow directly to the lake through surface flow as well as small stormsewered sections that do not receive treatment before discharging into the lake.



LAKE IDLEWILD SUBWATERSHEDS AND STORMSEWER ALIGNMENTS

FIGURE 10.1

10.1.2 Land Use

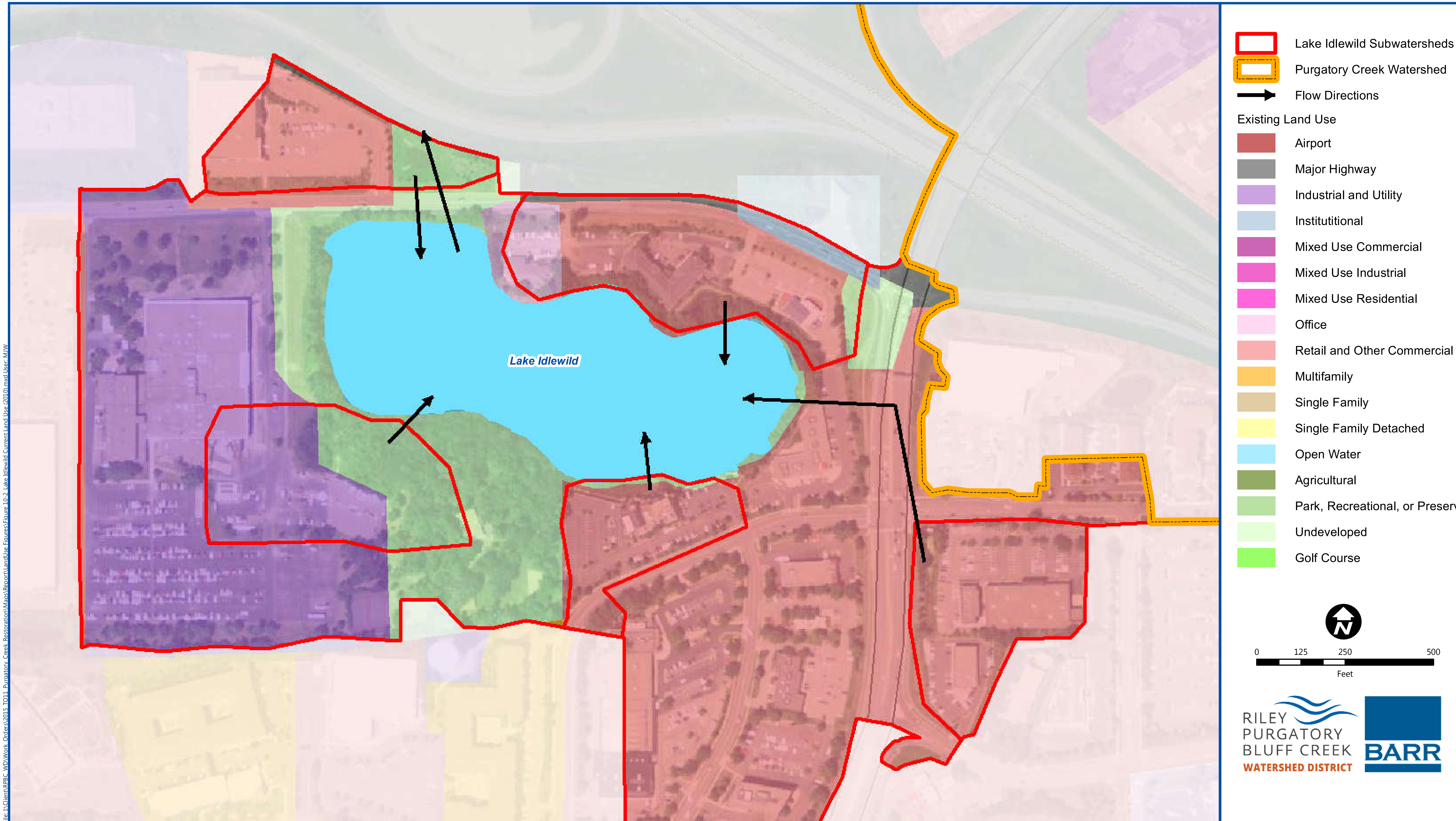
Land use within a lake's watershed can impact the hydrology and water quality of a lake. Varying land uses contribute different quantities of sediments and TP to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

Existing land-use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council. The land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix D.

Much of the Lake Idlewild watershed is covered by office, retail and other commercial land use (47%). The other major land uses include undeveloped (14%), industrial and utility (22%) and open water (15%). Figure 10.2 shows the existing land uses present in the Lake Idlewild watershed.

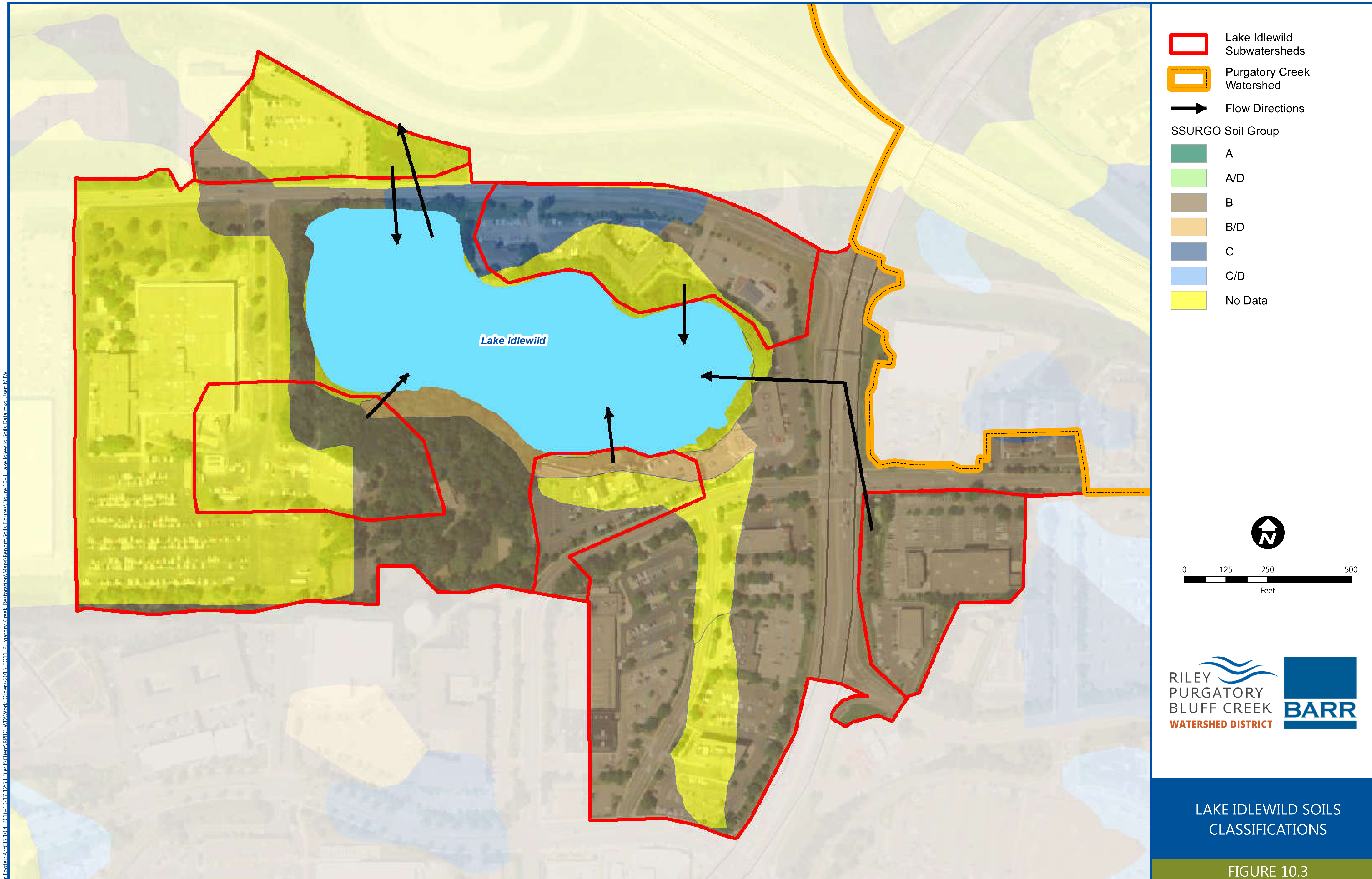
10.1.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database map for Hennepin County, the underlying soils in the Lake Idlewild watershed are predominantly classified as hydrologic soil group (HSG) B with moderate infiltration rates (Figure 10.3).



LAKE IDLEWILD LAND USE CLASSIFICATIONS

FIGURE 10.2



LAKE IDLEWILD SOILS CLASSIFICATIONS

FIGURE 10.3

10.2 Lake Characteristics

Table 10.1 provides a summary of the physical characteristics for Lake Idlewild. Lake Idlewild has an open-water surface area of approximately 12 acres. The lake is shallow, with a maximum depth of approximately 8 feet and mean depth of approximately 4 feet. Elevation data has only been collected in Lake Idlewild for year 2015. The average lake elevation for that year was 853.7 feet MSL. The outlet of Lake Idlewild is a manmade structure that conveys water to Staring Lake through a series of stormwater ponds. The outlet is an elevation of 853.5 feet. At the average water elevation of 853.7 feet the total water volume in Lake Idlewild is 51 acre-ft.

Table 10.1 Lake Idlewild Physical Characteristics

Lake Characteristic	Lake Idlewild
Lake MDNR ID	--
MPCA Lake Classification	Not Classified
Water Level Control Elevation (feet MSL)	853.5
Average Water Elevation (feet MSL)	853.7
Surface Area (acres)	12
Mean Depth (feet)	4
Maximum Depth (feet)	8.2
Littoral Area (acres)	12
Volume (at normal water elevation) (acre-feet)	51
Thermal Stratification Pattern	polymictic
Estimated Residence Time (years) – 2014-2015 climatic Conditions	0.3
Watershed Area Tributary to Upstream Lake	0
Total Watershed Area	89[2]
Subwatershed Area (acres)	89[2]
Trophic Status Based on 2015 Growing Season Average Water Quality Data	hypereutrophic

1 – Average water elevation 2015.
2 – Watershed area includes surface area of lakes

Given the depth of Lake Idlewild and the review of temperature and dissolved oxygen profiles suggest that Lake Idlewild is a polymictic lake. This means that the lake mixes multiple times throughout the year from wind mixing events. Temperature stratification does form resulting in anoxic conditions near the lake sediments; however wind mixing events during the summer can be strong enough to completely mix the lake water column providing oxygen to the sediments and mixing TP throughout the water column.

10.3 Water Quality Conditions

Water quality in Lake Idlewild has only been collected in year 2015. The growing season average (June – September) concentrations and depth are displayed in Table 10.2. The TP growing season average concentration was 71 µg/L. The Chl-a average concentration was 16 µg/L. The average Secchi depth was 1.7 meters. Lake Idlewild is not classified as a lake by the MPCA and therefore is not subject the MPCA water quality goals. Lake Idlewild is classified as a wetland and therefore follows the non-degradation standards by the MPCA.

Table 10.2 Lake Idlewild 2015 growing season average water quality

Parameter	2015 growing season average	2015 max value	2015 min value
TP (µg/L)	71	102	36
Chl-a (µg/L)	16	28	4
Secchi Depth (m)	1.7	2.3	1.1

10.3.1 Water Quality Relationships

As previously discussed, phosphorus often acts as the limiting nutrient for algal growth (as measured by chlorophyll *a*), which in turn, affects lake water clarity (Secchi depth). This section describes how incremental phosphorus load reductions would be expected to impact perceptible changes in lake water quality. However, only one year of data is available for Lake Idlewild. This is not enough information to determine relationships between water quality parameters. State wide regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) can be used for relationships between water quality parameters.

The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla (µg/L) = 1.31 Log10 TP (µg/L) – 0.95
- Log10 Secchi (meters) = -0.59 Log10 Chla (µg/L) + 0.89
- Log10 Secchi (meters)= -0.81 Log10 TP (µg/L) + 1.51

10.4 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores)). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

10.4.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess TP loads. Phytoplankton surveys have not been conducted on Lake Idlewild.

10.4.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

A zooplankton analysis has not been conducted on Lake Idlewild.

10.4.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

A plant survey was conducted in Lake Idlewild for the City of Eden Prairie (Blue Water Science, 2015). The analysis found 2 macrophyte species in an early summer survey and 3 in the late summer representing a low plant diversity. Invasive species were not found in Lake Idlewild.

10.4.4 Fishery

No fish survey have been conducted on Lake Idlewild. Lake Idlewild was used as a walleye rearing pond by the MnDNR in the past.

10.5 TP Source Assessment

The watershed and in-lake water quality models were developed to assess both the external and internal TP loads in Lake Idlewild for the 2015 water year (October 2014 – September 2015). A detailed discussion of the modeling methods used is presented in Section 2.2.2 and Appendix D. Possible lake external loads of TP include atmospheric depositions, stormwater runoff from the lake watershed, surficial groundwater interactions with the lake waters, internal loads from upstream ponds and wetlands, and load from any upstream lakes that might flow into the waterbody.

External loads that applied to Lake Idlewild are atmospheric deposition, watershed loads, and upstream lakes. Internal loading within the ponds and wetlands was not evaluated for this study, no channels with erosion potential contribute the Lake Idlewild, Lake Idlewild does not have any upstream lakes, and no significant load from groundwater sources were found meaning the inflow of groundwater likely equals the outflow. Internal TP loads can come from sediment TP release, curlyleaf pondweed, or benthivorous fish activity.

Figure 10.4 summarizes the 2015 annual water year TP budgets for Lake Idlewild, including the relative contributions of the external and internal TP loads. This budget explains the sources of TP to the lake and helps direct and prioritize implementation strategies. Each of the sources are discussed further in the following section(s).

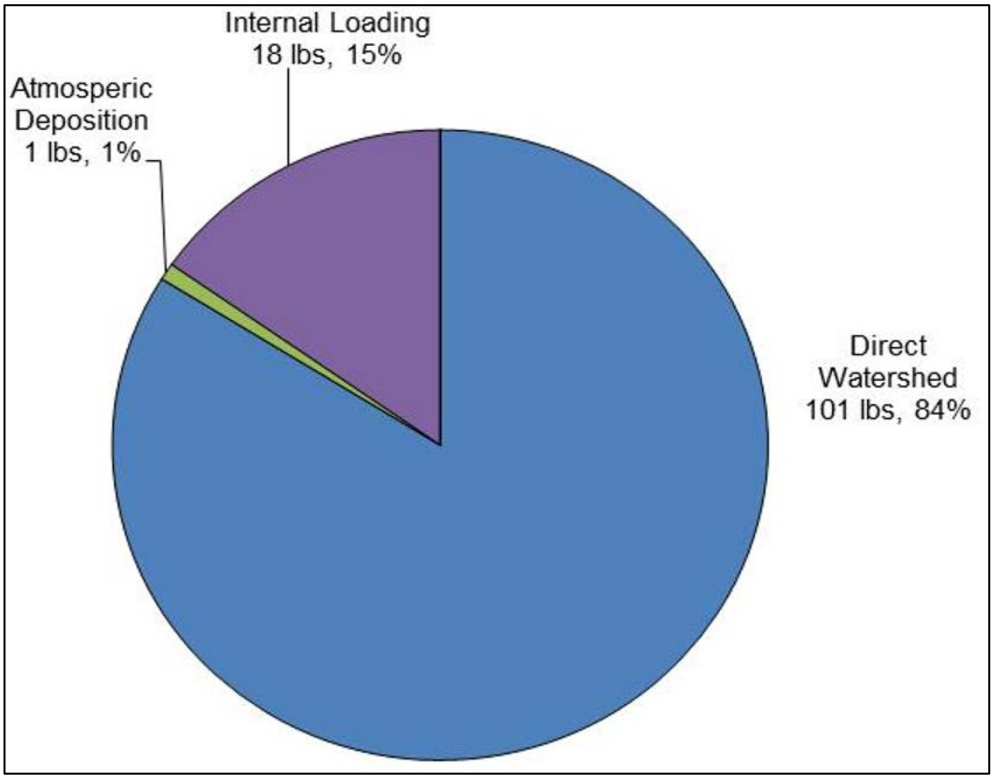


Figure 10.4 Lake Idlewild TP load sources for 2015 water year

10.5.1 External Loads

10.5.1.1 Atmospheric Deposition

Atmospheric deposition of TP onto the lake water surface was calculated by using the estimated statewide TP atmospheric deposition rate of 0.17 kg/ha/year (Barr Engineering, 2004). For Lake Idlewild, this loading rate was applied to the combined open water area. The daily rate was applied to the surface area of the lake based on the modeled lake water elevation from the lake water balance model. The resulting atmospheric deposition TP load for the 2015 water year was 1 pound which amounts to 1% of the TP load to Lake Idlewild (Figure 10.4).

10.5.1.2 Watershed Loads

The P8 watershed model estimated surface runoff from Lake Idlewild's subwatersheds based on observed climatic data (precipitation and temperature). The total untreated watershed load from the watersheds in Lake Idlewild for the 2015 water year was modeled to be 118 pounds. The watershed load travels through existing stormwater ponds, wetlands, infiltration practices, and other BMPs located throughout the watershed providing treatment resulting in a load of 101 pounds reaching the lake. This represents a 12% removal being provided by existing treatment practices in the watershed. Watershed sources represent 84% of the total water load to Lake Idlewild (Figure 10.4).

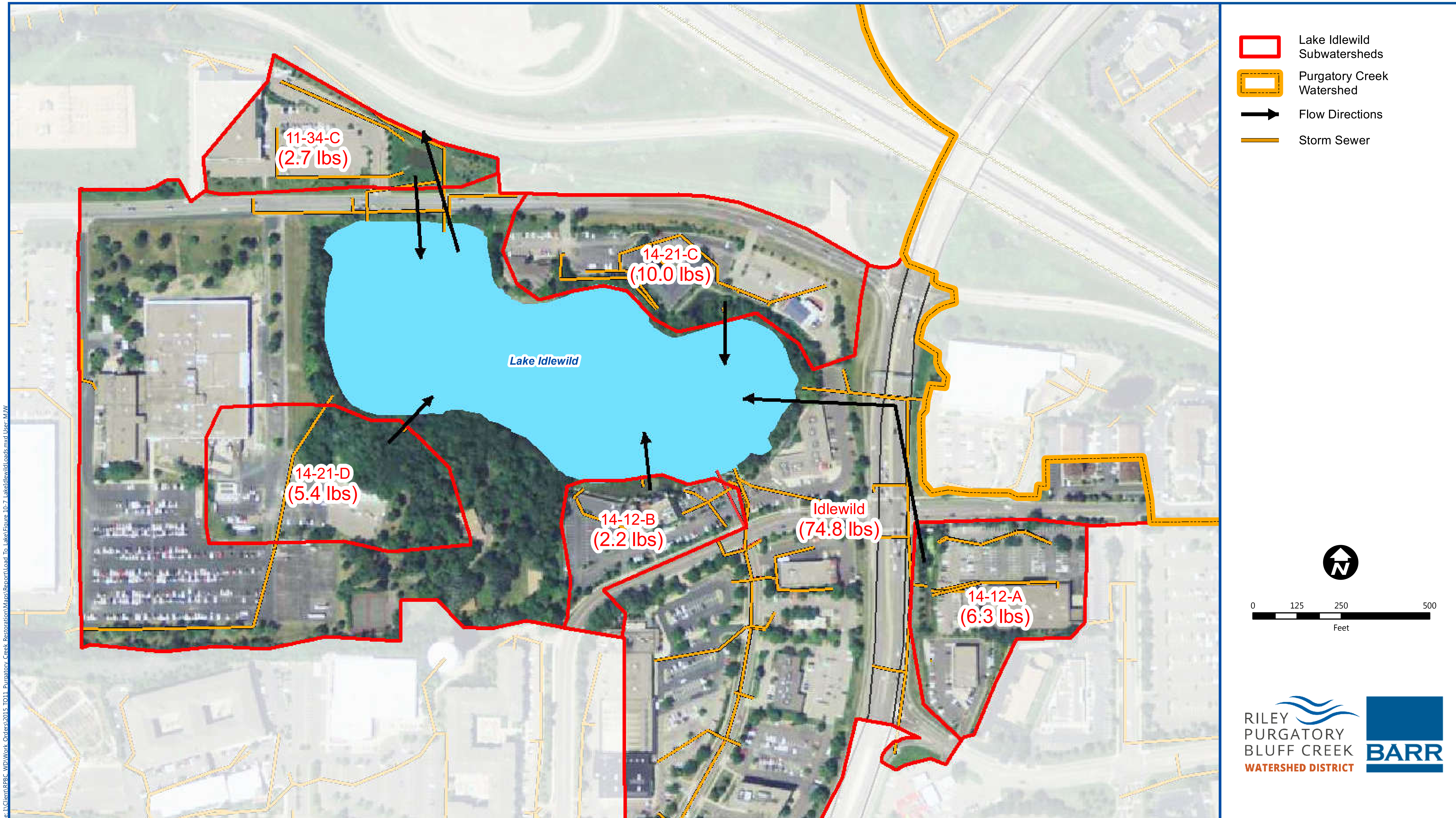
To help evaluate areas that might benefit from additional treatment watershed loads to the lake were calculated for each of Lake Idlewild's individual subwatersheds. The load to the lake is defined as the amount of TP load from that watershed reaching the lake without being removed by an existing BMP within the subwatershed or downstream from the subwatershed. The P8 results were used to calculate the total annual average untreated watershed TP loads from each subwatershed. Next the watershed load to the lake was calculated. This was accomplished by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each subwatershed that reached the lake without being removed by an existing BMP. The watershed load to the lake for each subwatershed is shown in Figure 10.5

10.5.2 Internal Loads

Internal loading in Lake Idlewild represented only 15% (18 pounds) of the TP loads in the 2015 water year (Figure 10.4). The internal loading sources to Lake Idlewild are from sediment TP release only. Neither curlyleaf pondweed nor benthivorous fish such as carp have been found in Lake Idlewild.

10.5.2.1 Sediment Release

Internal loading through sediment release occurs during anoxic conditions. A review of dissolved oxygen profiles in Lake Idlewild showed anoxic in the lakes sediments during the middle summer months. The internal loading rate is only applied to sediment areas that are anoxic, but wind mixing regularly occurs re-oxygenating the lakes sediments and distributing any internal load of TP throughout the water column.



LAKE IDLEWILD SUBWATERSHED TP LOADS TO THE LAKE

FIGURE 10.5

10.5.3 TP Load Reductions

The in-lake model was used to determine TP load reductions needed to meet the water quality goal for the lake. Lake Idlewild does not have a required TP load reduction based on being classifies as a wetland and not a Lake. While load reduction are not required in Lake Idlewild to meet the water quality standard for the 2015 water year BMPs to further reduce the TP concentrations in the lake could be implemented to protect and enhance the health of the lake. Table 10.3 shows the measured and modeled growing season average (June – September) concentration, the TP load to the lake under existing conditions, the water quality goal, the TP loading capacity for meeting the water quality standard and the required percent reduction needed to meet the water quality goal. Under existing conditions Lake Idlewild has an average concentration of 71 µg/L. Under existing conditions the load to the lake was 123 lbs.

Table 10.3 Lake Idlewild estimated load reductions required to meet TP water quality goal for 2015 water year

Measured growing season average TP concentration (µg/L)	Modeled growing season average TP concentration (µg/L)	Estimate 2015 TP loading rate (lbs/yr)	TP concentration goal (µg/L)	Estimated Loading Capacity to meet WQ goal (lbs/yr)	Percent reduction needed to achieve goal (%)
71	70	123	Non-degradation	--	--

Figure 10.6 shows how lake concentrations react to lake load reductions. The calibrated in-lake TP model was used to determine in lake water quality based on the amount of TP load to the lake. Chl-a and Secchi depth concentrations were determined based on the water quality relationships discussed in Section 10.3.1. The figure shows how incremental load reductions would impact the water quality in Lake Idlewild. A TP load reduction of 20 pounds would reduce the lake TP concentration to 60 µg/L. A TP load reduction of 40 pounds could reduce the lake concentration to 48 µg/L.

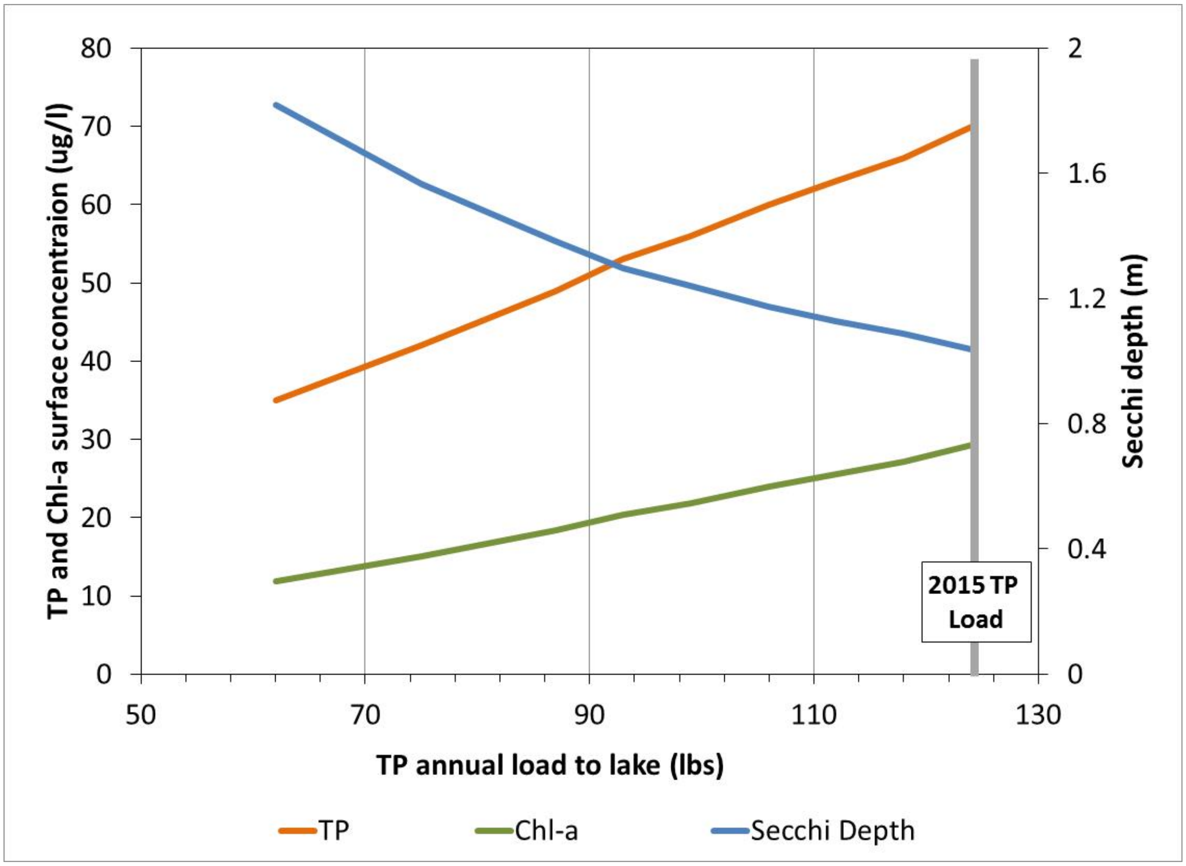


Figure 10.6 Lake Idlewild TP load relationship with lake water quality (TP, Chl-a and clarity)

10.6 Summary of Diagnostic Findings

Table 10.4 provides a summary of the key water-quality findings for Lake Idlewild.

Table 10.4 Diagnostic Findings for Lake Idlewild

Topic	Lake Idlewild
Water Quality Standards and Goals	- Lake Idlewild is not classified as a Lake and only has a nondegredation goal for water quality
Baseline Water Quality	Sediment reconstruction was not conducted
Water Quality Trends	- Water quality data is only available for year 2015
Watershed Runoff	- Represents approximately 84% of the annual TP load. - Watershed load is reduced by an estimated 12% by existing BMPs, ponds, and wetlands located throughout the watershed - Approximately 35 percent of the watershed runoff is treated before entering Lake Idlewild.
Macrophyte Status	- No invasive macrophyte species were found in most recent plant surveys
Fishery Status	- No analysis has been conducted
Cyanobacteria (blue green algae)	- Phytoplankton data not available
Internal Loading from sediments	- Internal loading from sediment estimated to be 15% of annual TP load
Methylmercury in Fish Tissues	- No analysis has been conducted

10.7 Current and Past Management Actions

Past studies listing management actions that have been conducted as well have management actions that should be considered in Lake Idlewild are not available.

10.8 Evaluation of Water Quality Improvement Options

All of the BMPs identified for Lake Idlewild are listed and described in detail in the following subsections. The BMPs identified in this section were initially identified in the Town Center Report (Wenck Associates, Inc., December 2014). Table 10.5 provides a list of the potential BMPs and Figure 10.7 shows the identified potential BMP locations in the Lake Idlewild watershed.

10.8.1 Stormwater planters in subwatershed Idlewild, LI_1

BMP LI_1 is a set of stormwater planters in subwatershed Idlewild along the north side of Eden Road, designed to treat road runoff and provide an aesthetically pleasing appeal to pedestrian walkways (Wenck Associates, Inc., December 2014). The planters will cover approximately 850 square feet. The planters could remove 0.8 pounds of TP per year based on 30-year modeling results. Because of the proximity to the lake and the nature of the planters to infiltrate, the TP reduction to the lake is also expected to be 0.8

pounds of TP per year. The cost-benefit of this BMP for Lake Idlewild is estimated to be about $2,600 per pound of TP, assuming the BMP functions for 30 years.

10.8.2 Infiltration in subwatersheds Idlewild & Idlewild_TC08, LI_2a & LI_2b

BMP LI_2a and LI_2b consists of two new infiltration basins in subwatersheds Idlewild (in the landscaped area between the Champps parking lot and Eden Road) and Idlewild_TC08 (long narrow feature, along the toe of the slope on the west side of Flying Cloud Drive) designed to treat road and parking lot runoff (Wenck Associates, Inc., December 2014). The soils in this area are "B" soils, with a good capacity to infiltrate water. Together, these infiltration basins would cover approximately 0.5 acres. Existing storm sewer along these roads could be diverted into these infiltration basins. The infiltration basins could reduce the loading to the lake by 20 pounds of TP per year based on 30-year modeling results. The cost-benefit of this BMP for Lake Idlewild is estimated to be about $1,780 per pound of TP, assuming the BMP functions for 30 years.

10.8.3 Tree trenches in subwatershed Idlewild_TC-06, LI_3

BMP LI_3 is tree trenches in subwatershed Idlewild_TC-06 along the current entrance to Emerson Process Management with the expectation that the city plans to construct "Main Street" between Technology Drive and Singletree Lane (Wenck Associates, Inc., December 2014). These tree trenches are designed to treat road runoff. The tree trenches will cover approximately 1.3 acres. The tree trenches could potentially remove 15.5 pounds of TP per year. Because of the proximity to the lake and the nature of the tree trenches to store and transpire water, the TP load reduction to the lake is also estimated to be 15.5 pounds of TP per year. The cost-benefit of this BMP for Lake Idlewild is estimated to be about $9,460 per pound of TP, assuming the BMP functions for 30 years.

10.8.4 Underground infiltration in subwatershed 14-21-C, LI_4

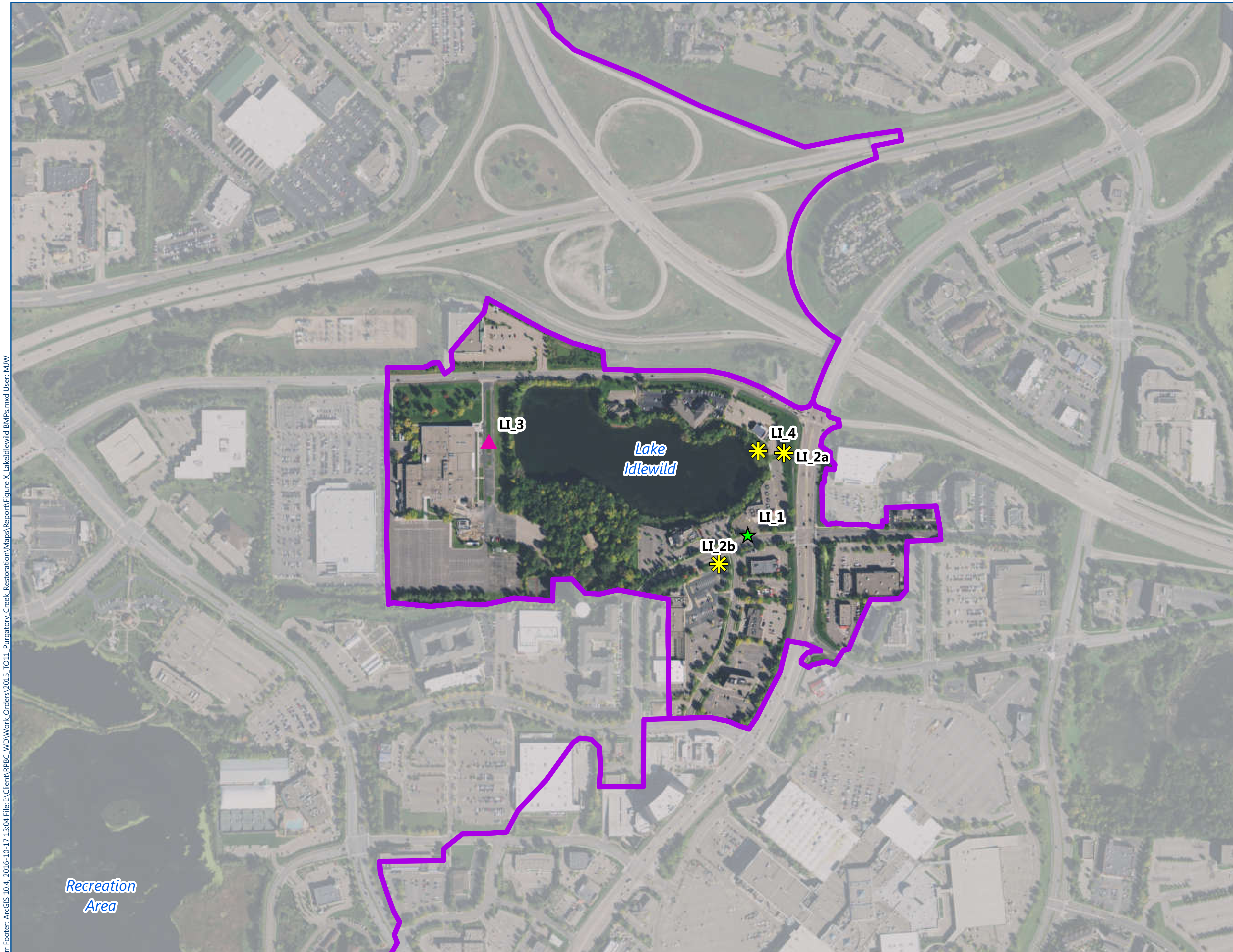
The permitted redevelopment at the intersection of Flying Cloud Drive and Technology Drive (subwatershed 14-21-C) to convert the IHOP site to a Hampton Inn includes an underground infiltration system and permeable pavement. The impervious area of the watershed contributing to this BMP is approximately 1.2 acre (Appendix H of the Proposed Hampton Inn Storm Water Management Plan, 2016). The soils are a clayey sand with low infiltration rates. However, the clayey sand will be over-excavated to reach the silty sand layer below with a preferable infiltration rate. Based on the analysis for the permit review, this underground infiltration feature will remove nearly 88% of the incoming TP load, reducing the load to Lake Idlewild by 2.5 pounds per year (Appendix H of the Proposed Hampton Inn Storm Water Management Plan, 2016).

Table 10.5 - Summary of Lake Idlewild BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
LI_1	Stormwater Planters *- A 850 sq. ft. area of stormwater planters along Eden Road (Town Center Report)*	0.8	0.8	N/A	$38,300 ($31,000 - $54,000)[8]	$800 ($600 - $1,100)	$2,600 ($2,080 - $3,630)	$2,600 ($2,080 - $3,630)
LI_2a & LI_2b	Infiltration *- 0.5 acres of infiltration along Flying Cloud Drive and Eden Road (Town Center Report)*	20	20	N/A	$667,300 ($534,000 - $934,000)[8]	$13,300 ($10,700 - $18,700)	$1,780 ($1,420 - $2,490)	$1,780 ($1,420 - $2,490)
LI_3	Tree Trenches *- A 1.3 acre area of tree trenches between Emerson and Idlewild Lake (Town Center Report)*	15.5	15.5	N/A	$2,750,000 ($2,200,000 - $3,850,000)[8]	$55,000 ($44,000 - $77,000)	$9,460 ($7,570 - $13,250)	$9,460 ($7,570 - $13,250)
LI_4	Infiltration *- Underground infiltration and pervious pavement, treating 1.2 acres of impervious area (already approved, Hampton Inn permit)*	2.5	2.5	N/A	$0	$0	$0	$0

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. There is no overall load reduction goal for Lake Idlewild; the wetland goal is nondegradation.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.
8. Cost estimated by others in the Town Center Report (Wenck Associates, Inc., December 2014).



Best Management Practices

- Infiltration Basin
- Stormwater Planter
- Tree Trenches
- Major Lake Watershed Boundaries

N

500 0 500

Feet

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

BARR

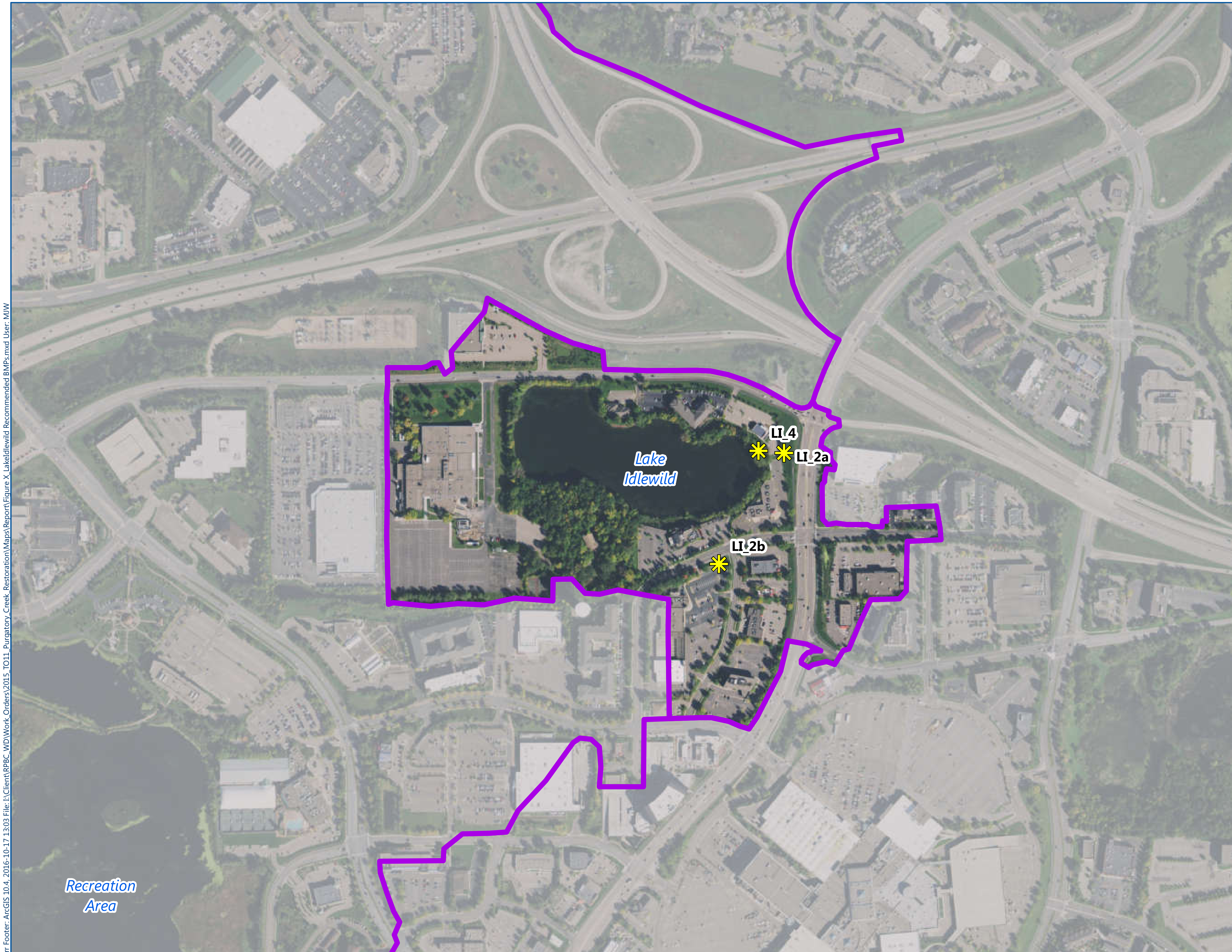
ALL IDENTIFIED BMPs, LAKE IDLEWILD WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 10.7

10.9 Recommendations for Water Quality Goal Attainment

There is no overall load reduction goal for Lake Idlewild because this lake is already meeting water quality goals (Section 10.5.3). Even though a load reduction is not necessary, some of the identified BMPs would protect and enhance the health of Lake Idlewild. Therefore, the recommended BMPs for the Lake Idlewild watershed are in the bullet list below along with the magnitude of the TP load reduction expected. The recommended BMPs are also shown in Figure 10.8. The total reduction expected by the recommended BMPs is 22.5 pounds per year from the watershed, which is expected to reduce the average in-lake phosphorus concentration below 60 µg/L.

- LI_2a & LI_2b, two infiltration basins in subwatersheds Idlewild and Idlewild_TC08, ~20 pounds TP per year
- LI_4, underground infiltration and permeable pavement in subwatershed 14-21-C, ~2.5 pounds TP per year



Best Management Practices

- Infiltration Basin
- Major Lake Watershed Boundaries

500 0 500
Feet

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

BARR

RECOMMENDED BMPs, LAKE IDLEWILD WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 10.8

11.0 Staring Lake

11.1 Watershed Characteristics

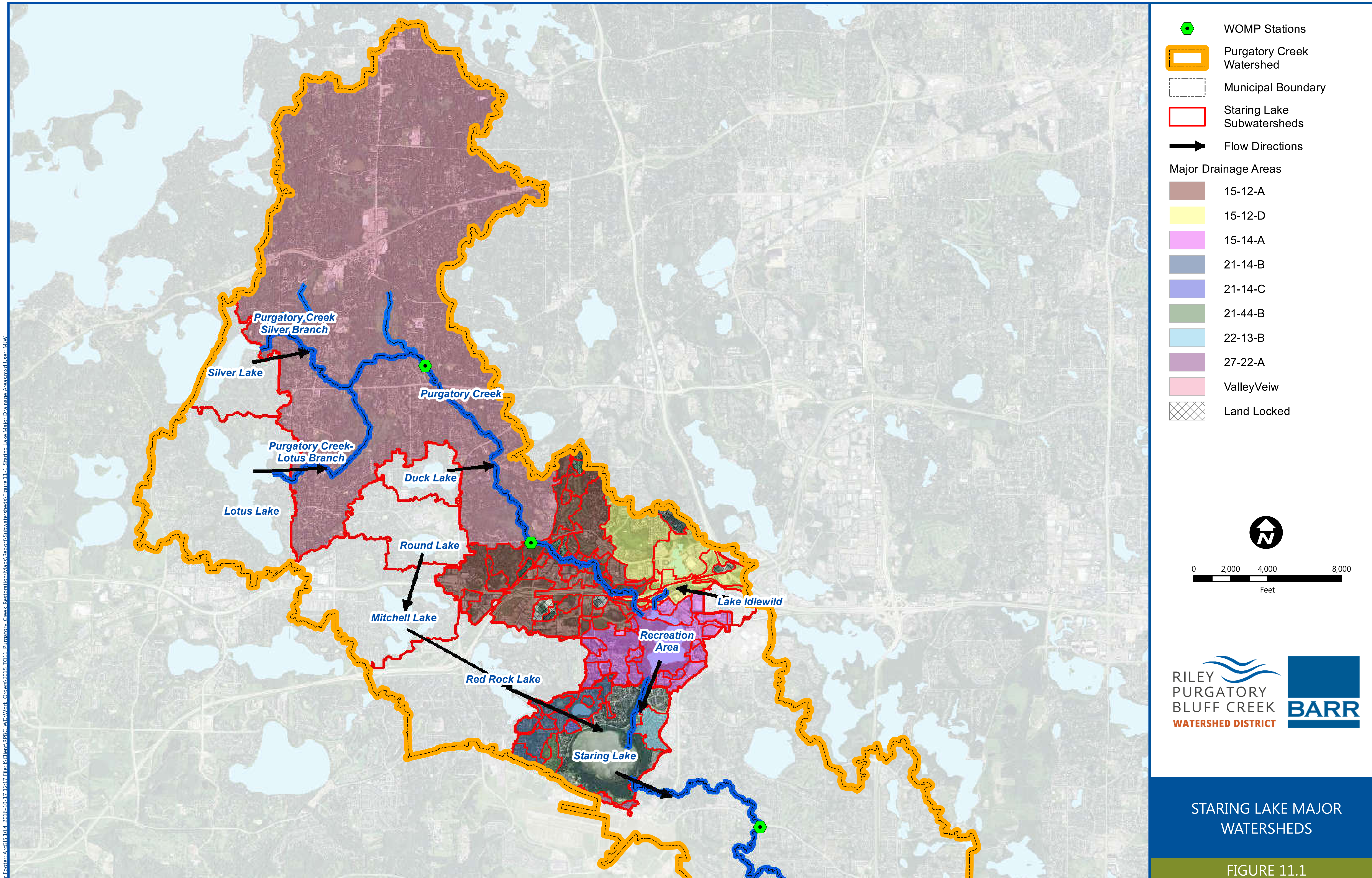
Staring Lake is located in the city of Eden Prairie in the southern part of the Purgatory Creek Watershed. Purgatory Creek flows through Staring Lake providing a large watershed comprising 10,206 acres including the 166-acre surface area of the lake. The watershed area excludes the drainage areas of contributing lakes including Red Rock, Mitchell, Round, Duck, Lotus, and Silver Lakes. The total watershed of Staring Lake including all upstream lakes is 14,785 acres. The Staring Lake watershed lies mostly within the cities of Minnetonka, and Eden Prairie. The watershed also encompasses parts of the cities of Deephaven, Shorewood, and Chanhassen (Figure 11.1).

11.1.1 Drainage Patterns

The stormwater conveyance system in the Staring Lake watershed is comprised of storm sewer networks, constructed stormwater detention ponds, and natural wetlands within the watersheds, upstream lakes routed to Staring Lake through storm sewer network, and Purgatory Creek (Figure 11.1). Most of the constructed stormwater ponds within the Staring Lake watershed are wet detention ponds. These ponds are designed to provide water quality treatment of stormwater runoff, by allowing particles to settle out in the permanent pool of water and by having the capacity to temporarily store excess runoff volumes and release it at lower rates than incoming flows.

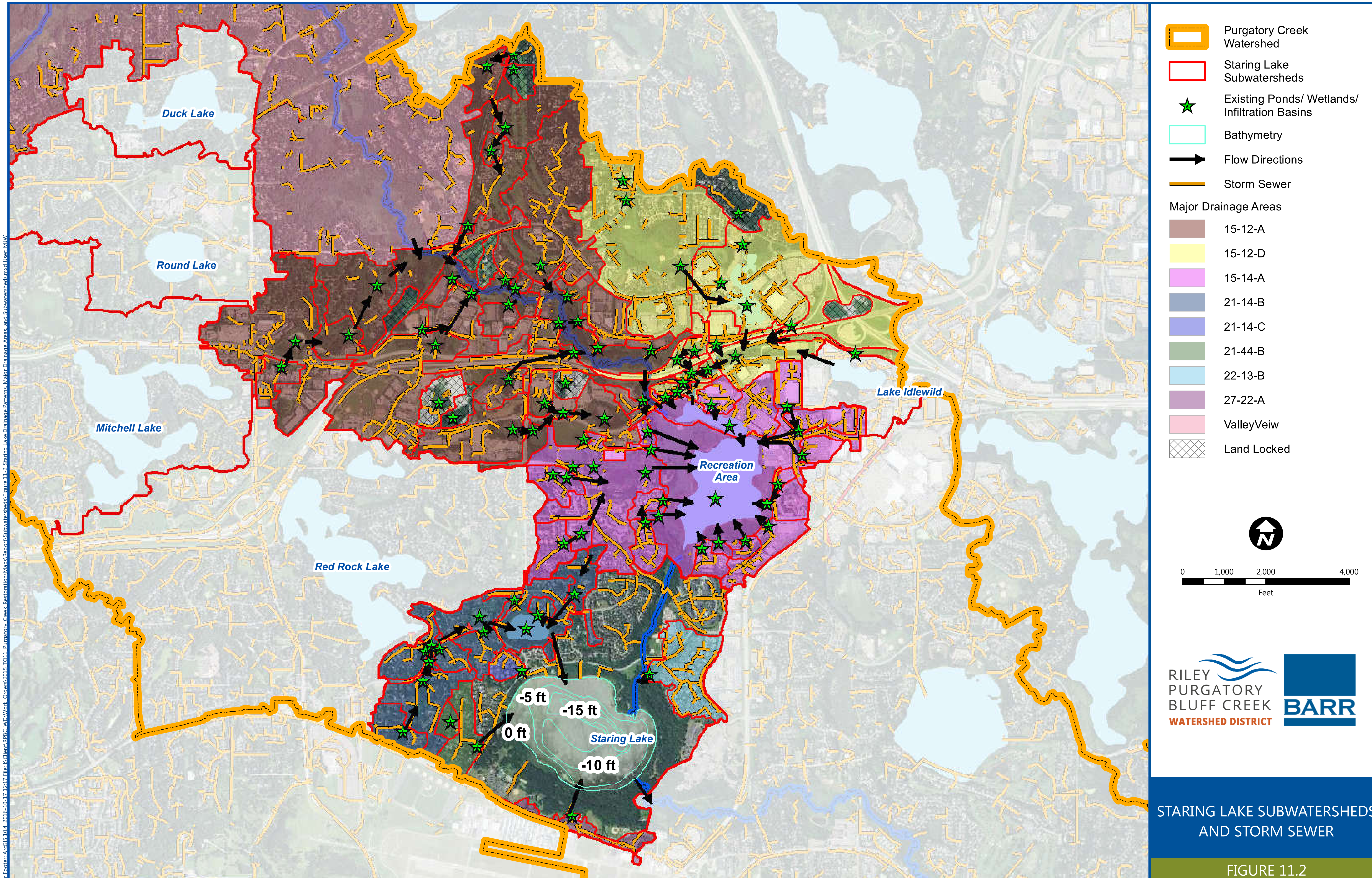
Purgatory Creek flows through Staring Lake. Before it enters Staring Lake the creek flows through the Purgatory Creek Recreation Area (Recreation Area) designed to removal pollutants from the creek water before entering Staring Lake. Lake Idlewild, Duck Lake, Lotus Lake, and Silver Lake all contribute flow to Purgatory Creek which discharges into the Recreation Area prior to being conveyed to Staring Lake. The Eden Prairie Chain of Lakes also flows into Staring Lake. Round Lake, Mitchell Lake, and Red Rock Lake are connected to one another through a series of storm sewer systems. Outflow from Red Rock Lake travels through a series of ponds into Lake McCoy and finally into Staring Lake.

The entire drainage area of Staring Lake was divided into subwatersheds tributary to ponds and wetlands. The subwatershed delineations and conveyance networks are based on the subwatershed divides provided by the city of Eden Prairie that were updated based on topographic data (MDNR, 2011), storm sewer data, and other information from the cities. Due to a modeling limitation of the P8 model, which limits the number of devices that can be incorporated into a single model, detailed subwatersheds were delineated for the area south of the Valley View-Purgatory Creek intersection and a single watershed was used for the areas north of Valley View. This watershed was calibrated using monitoring data at the RPBCWD Valley View WOMP station. A discussion of this approach is given in Appendix D. Figure 11.2 shows a zoomed in view of the Staring Lake subwatersheds.



STARING LAKE MAJOR WATERSHEDS

FIGURE 11.1



STARING LAKE SUBWATERSHEDS AND STORM SEWER

FIGURE 11.2

The subwatersheds were grouped into 9 major drainage areas within the Staring Lake watershed (Figure 11.1 and Figure 11.2). Each major drainage area is named after the terminating watershed in each conveyance network. In addition to the major drainage areas is the lakes direct watershed. The direct watershed includes areas along the shoreline of the lake that contribute flow directly to the lake through surface flow as well as small stormsewered sections that do not receive treatment before discharging into the lake.

11.1.2 Land Use

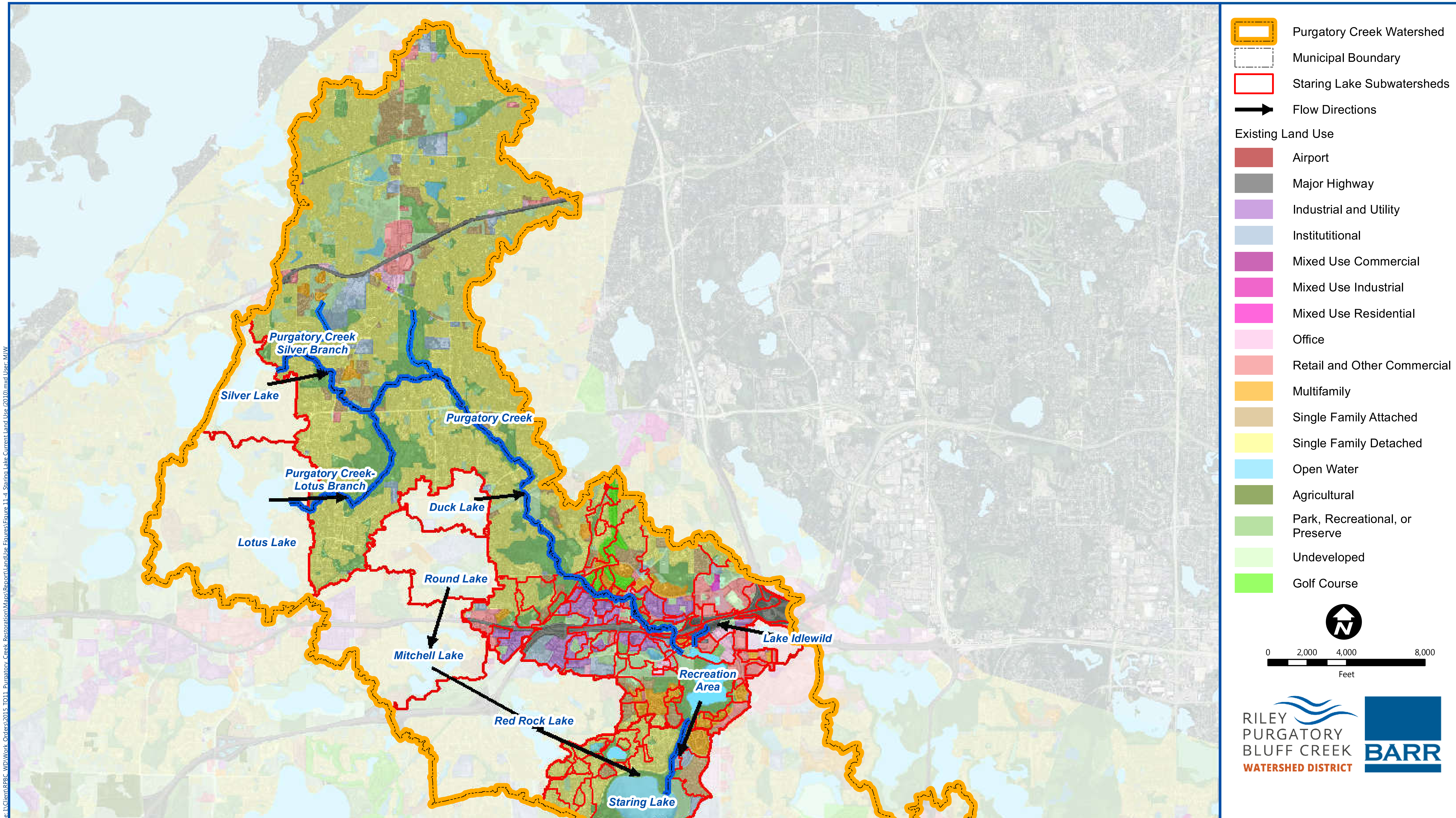
Land use within a lake's watershed can impact the hydrology and water quality of a lake. Varying land uses contribute different quantities of sediments and TP to downstream waterbodies, due primarily to differences in the amount of impervious surfaces associated with the different land-use types.

Existing land use patterns used to estimate the amount of impervious surface and expected change in imperviousness for each watershed were based on information from the Metropolitan Council. The land-use classifications and the amount of total impervious surface and directly connected impervious surface (i.e., impervious surfaces that contribute runoff directly to a stormwater conveyance system) associated with each type are summarized in Appendix D.

Over half of the Staring Lake watershed is covered by single family residential land use. The other major land uses present include park and recreation areas (14%), and undeveloped (8%). Figure 11.3 shows the existing land uses present in the Staring Lake watershed.

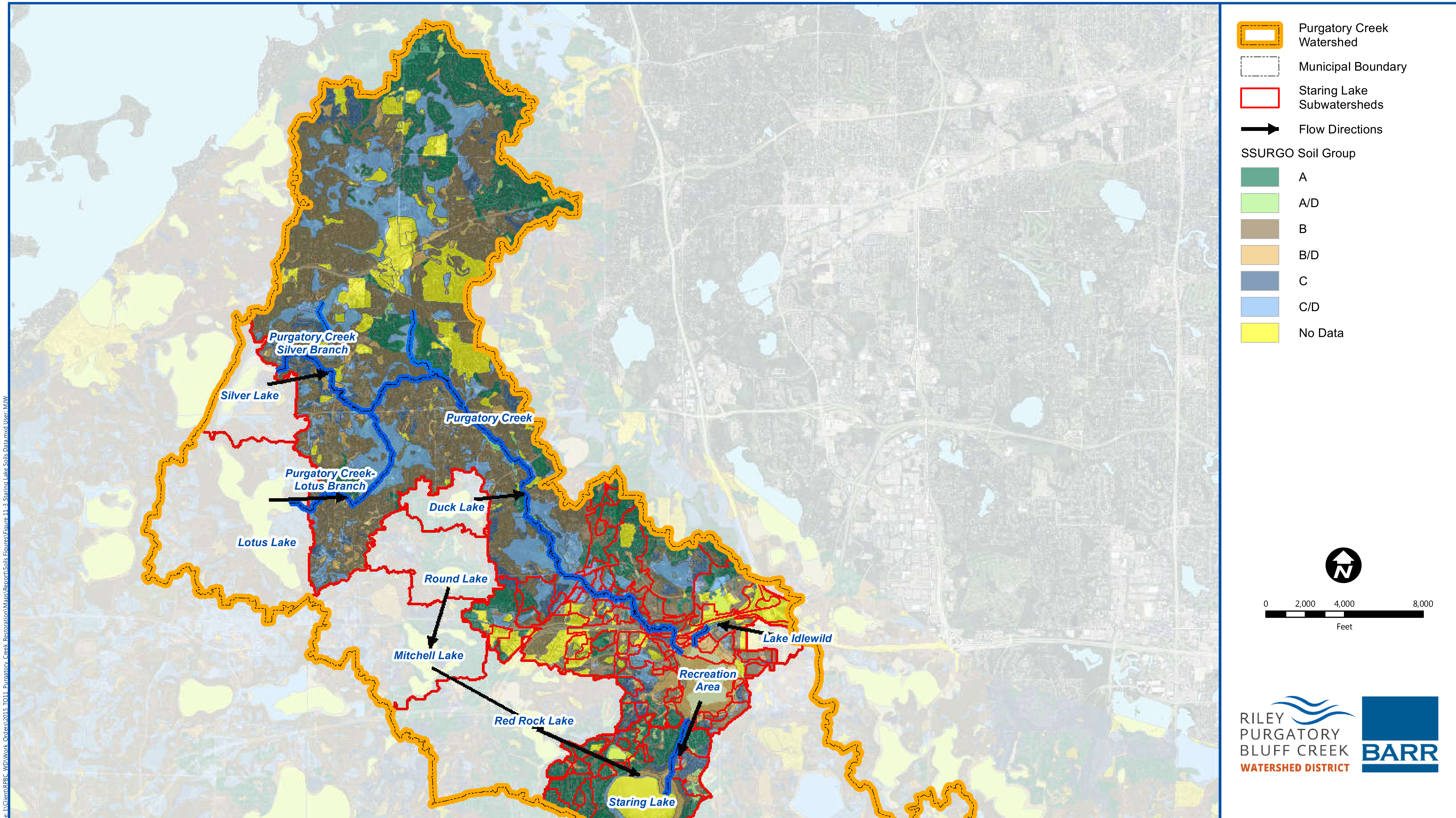
11.1.3 Soils

The infiltration capacity of soils affects the amount of direct runoff resulting from rainfall. Soils with a higher infiltration rate have a lower runoff potential. Conversely, soils with low infiltration rates produce high runoff volumes and high peak runoff rates. According to the Natural Resource Conservation Service's (NRCS) Soil Survey Geographic (SSURGO) database map for Carver and Hennepin counties, the underlying soils in the direct Staring Lake watershed downstream of the Recreation Area are predominantly classified as hydrologic soil group (HSG) A with high infiltration rates (Figure 11.4). The larger Purgatory Creek watershed that contributes runoff to Staring Lake is largely covered in A and B soils with areas along the creek and in wetlands classified as B/D or C/D.



STARING LAKE LAND USE CLASSIFICATION

FIGURE 11.3



STARING LAKE SOILS CLASSIFICATIONS

FIGURE 11.4

11.2 Lake Characteristics

Table 11.1 provides a summary of the physical characteristics for Staring Lake. Staring Lake has an open-water surface area of approximately 166 acres. The lake is shallow, with a maximum depth of approximately 16 feet and mean depth of approximately 7 feet. The lake area, depth, and volume depend on the water level of the lake, which has been observed to vary between a high measurement of 820 feet mean sea level (MSL) (1987) to a low measurement of 812.84 feet MSL (1977). Since 2011 water levels in Staring Lake have averaged 814.76 feet mean sea level (MSL). The outlet of Staring Lake is Purgatory Creek at an elevation of 813.84. At the average water elevation of 814.76 feet the total water volume in Staring Lake is 1,220 acre-ft.

Table 11.1 Staring Lake Physical Characteristics

Lake Characteristic	Staring Lake
Lake MDNR ID	27-0078-00
MPCA Lake Classification	Shallow
Water Level Control Elevation (feet MSL)	813.84
Average Water Elevation (feet MSL)	814.76[1]
Surface Area (acres)	166
Mean Depth (feet)	7
Maximum Depth (feet)	16
Littoral Area (acres)	155
Volume (at normal water elevation) (acre-feet)	1,220
Thermal Stratification Pattern	polymictic
Estimated Residence Time (years) – 2014-2015 climatic Conditions	0.13 years
Watershed Area Tributary to Upstream Lake	4,745[2]
Total Watershed Area	14,784[2]
Subwatershed Area (acres)	10,206[2]
Trophic Status Based on 2015 Growing Season Average Water Quality Data	Hypereutrophic

1 – Average water elevation 1911-2015.
2 – Watershed area includes surface area of lakes

A review of temperature and dissolved oxygen profiles suggest that Staring Lake is a polymictic lake. Likely because of the shallow nature of the lake and the large fetch. This means that the lake mixes multiple times throughout the year from wind mixing events. Temperature stratification does temporarily form resulting in anoxic conditions near the lake sediments, however wind mixing events during the summer occur that are strong enough to completely mix the lake water column providing oxygen to the sediments and mixing TP throughout the water column.

11.3 Water Quality Conditions

Historical water quality data, in terms of growing-season (June – September) average TP concentrations, chlorophyll *a* concentrations, and Secchi disc transparency for Staring Lake are presented in Figure 11.5. Also shown in these figures are the MPCA water quality standards for each parameter. The growing season average TP concentrations consistently fail to achieve the MPCA water quality standards throughout the record. The most recent growing-season average TP concentration in year 2015 was calculated as 83 µg/L which is higher than the standard value for a shallow lake of 60 µg/L. The 2015 value is the lowest growing season average concentration on record since concentrations were recorded in 1971. TP concentrations reached a maximum value of 140 µg/L in 2009.

Historically Chl-a concentrations in Staring lake have exceeded the MPCA water quality standard for a shallow lake of 20 µg/L every year on record except for 1981. The 2015 growing season average concentrations was 40.6 µg/L, this was lower than the peak value of 115 µg/L recorded in 2004.

Historical Secchi depths in Staring Lake have not achieved the MPCA water quality standard of 1.0 meters. The 2015 average concentration did meet the water quality standard with a value of 1.1 meters. This is only the third time on record and the only time since 1984 that the growing season average depth met the water quality standard. The lowest average Secchi depth calculated was 0.28 meters in 2009.

Trends in the water quality data were determined by calculating a Thiel-Sen slope on the annual average growing season values and the significance of the trend was tested using the Mann-Kendall non parametric test at the 95% confidence internal. Significant trends are present over the recent time period of 1999-2014 and through the entire record since 1971 (Table 11.2). Improving water quality trends are present in all three parameters in the recent time period of 1999-2014 with significant trends in Chl-a and Secchi depth. Looking at the entire record degrading water quality trends are present with significant trends in TP and Secchi depth. This shows that while water quality since 1971 has degraded, improvements have been made in recent years to reverse the degrading trends and are improving the water quality in Staring Lake. As a result, it appears that recent carp control efforts and phosphorus removal at the Recreation Area have had a positive impact on water quality in Staring Lake.

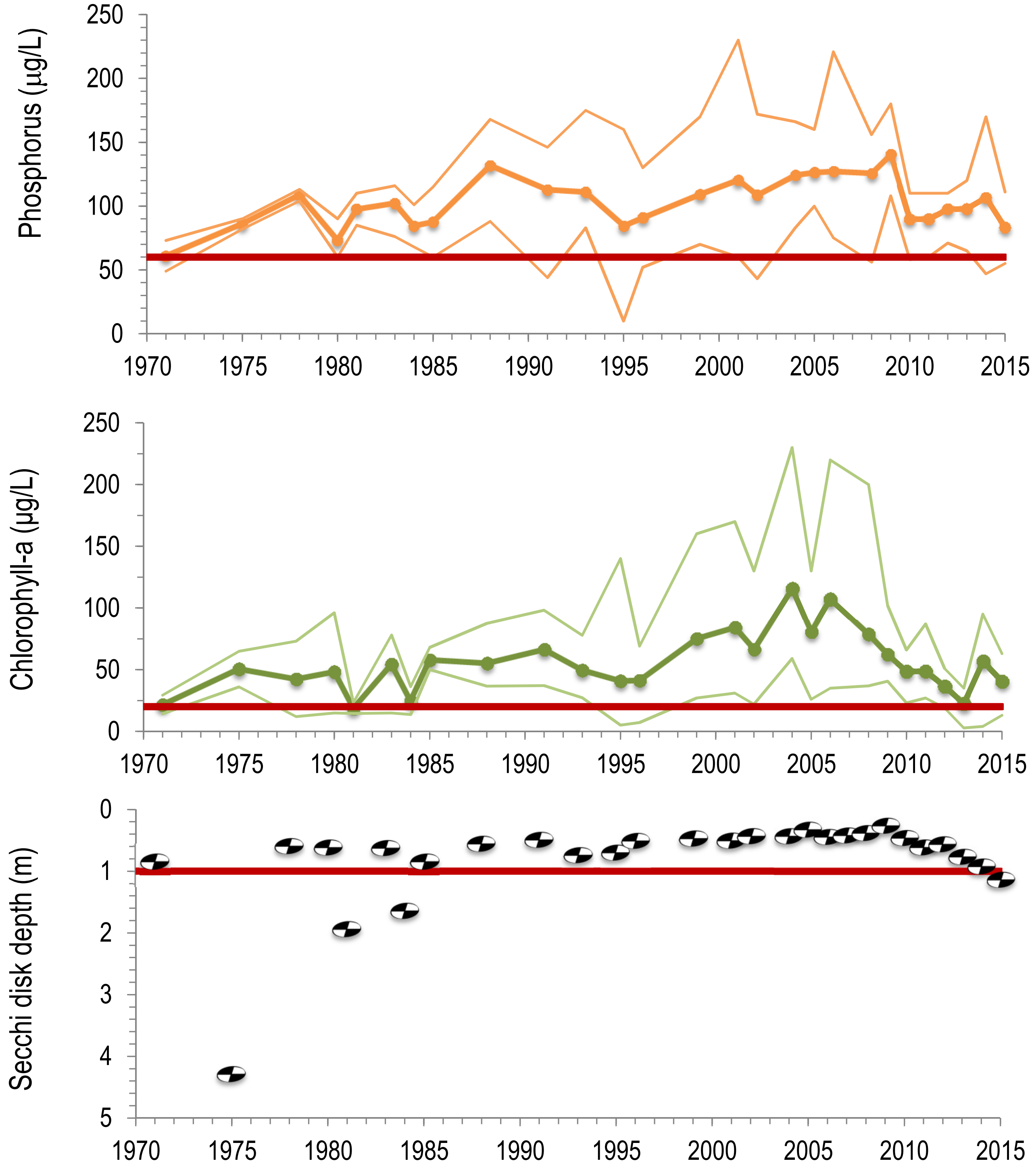


Figure 11.5
Staring Lake Water Quality
Growing Season (June - September) Average, Min and Max

Table 11.2 Staring Lake water quality parameter Thiel-Sen trends for year 1999-2015

Parameter	1999-2015	Entire Record
TP (µg/L/yr)	-2	1*
Chl-a (µg/L/yr)	-3.8*	0.5
Secchi Depth (m/yr)	0.03*	-0.01*

Notes:
* Designates significant trends at the 95% confidence level using Mann-Kendall significance test

11.3.1 Water Quality Relationships

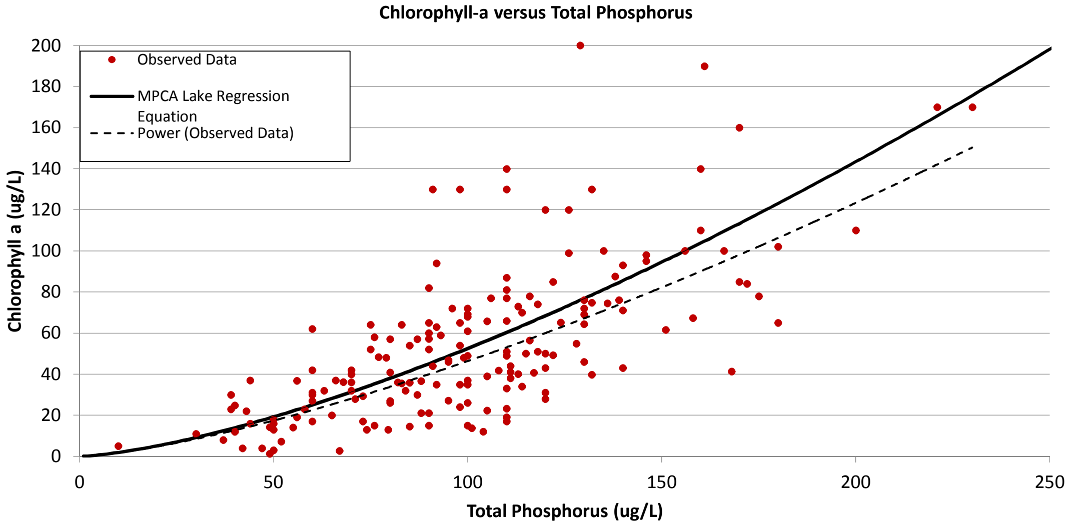
As previously discussed, phosphorus often acts as the limiting nutrient for algal growth (as measured by chlorophyll *a*), which in turn, affects lake water clarity (Secchi depth). This section describes how incremental phosphorus load reductions would be expected to impact perceptible changes in lake water quality. The compiled data for the water quality variables from Staring Lake were analyzed to develop relationships between the water quality parameters: TP, chlorophyll *a*, and Secchi depth. Relationships were evaluated based on individual sampling dates and based on the growing season averages. In addition to developing the water quality relationships based on the observed data, the regression equations developed by the MPCA based on a statewide lake data base (MPCA, 2005) were also plotted against the lake data.

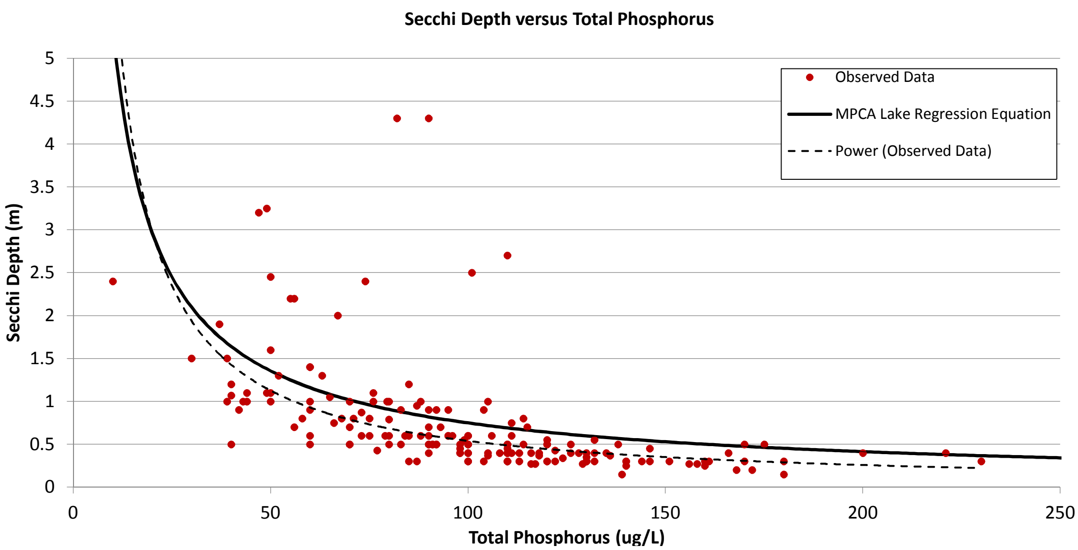
The relationships between the various water quality parameters for the actual Staring data did indicate some correlation between the water quality parameters (Figure 11.6). The MPCA regression equations resulted in similar fit for the chlorophyll *a*, Secchi disc transparency data, and TP. For this reason the MPCA statewide regression equations were selected to estimate the resulting chlorophyll *a* and Secchi disc transparency for Staring Lake based on TP concentration.

Figure 11.6 shows the individual water quality data points for Staring Lake, along with plots of the MPCA statewide regression equations.

The statewide regression equations developed by the MPCA are summarized below:

- Log10 Chla (µg/L) = 1.31 Log10 TP (µg/L) – 0.95
- Log10 Secchi (meters) = -0.59 Log10 Chla (µg/L) + 0.89
- Log10 Secchi (meters)= -0.81 Log10 TP (µg/L) + 1.51





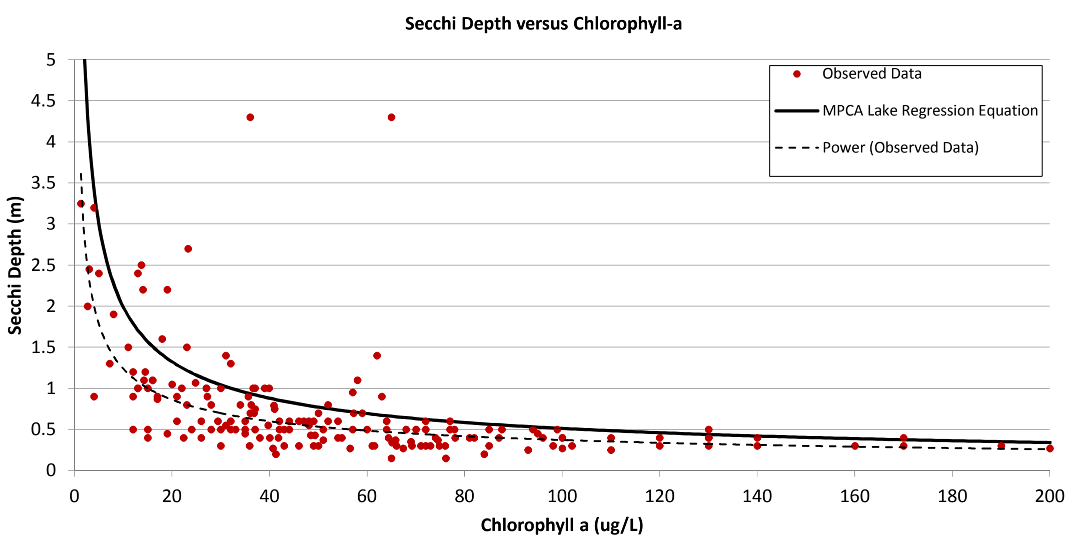


Figure 11.6
Staring Lake Individual Samples
Water Quality Parameter
Regression Relationships

11.4 Ecosystems Data

The term "ecosystem" describes a community of living things and its interaction with the environment in which those living things live with each other. The ecosystem includes all the organisms associated with the lake's food chain including: macrophytes (aquatic plants), phytoplankton (algae), zooplankton (which prey upon algae), and the fisheries (which include the smaller planktivores (small fish that feed on zooplankton) and predator fish (larger fish that feed on the planktivores)). Decomposers, a less visible component of the food chain, include bacteria living at the lake bottom, which break down dead and decaying organisms into nutrients and other essential elements. All life in the lake's food chain is interdependent. If any one group becomes unbalanced, all life in the food chain is adversely impacted. An aquatic ecosystem is managed to maintain balance between the phytoplankton, zooplankton, small fish (bluegill sunfish and crappies), and large fish (bass and northern pike).

11.4.1 Phytoplankton

Phytoplankton, also called algae, are small aquatic plants naturally present in lakes that derive energy from sunlight (through photosynthesis) and from dissolved nutrients found in lake water. The phytoplankton (algae) species form the base of the lake's food web and directly impact fish production in the lakes. An inadequate phytoplankton population reduces the lake's zooplankton population and adversely impacts the lake's fishery. Excess phytoplankton, however, reduce water clarity, and reduced water clarity can interfere with the recreational usage of a lake. Phytoplankton growth is typically stimulated by excess TP loads.

RPBCWD collected phytoplankton data in Staring Lake for years: 2011 and 2012. Additionally, phycocyanin (cyanobacteria (blue-green algae) pigment) readings have been collected in years 2010-2013. Review data of 2010 and 2011 data suggest that in early summer the phytoplankton was dominated by Bacillariophyta (diatoms) with 50-70 % of the biovolume coming from those species. Later in the year in August and September cyanobacteria were found to increase resulting in 40-60% of the phytoplankton.

While green algae are edible to zooplankton and serve as a valuable food source, cyanobacteria are considered a nuisance type of algae because they:

- Are generally inedible to fish, waterfowl, and most zooplankters
- Float at the lake surface in expansive algal blooms
- May be toxic to animals when occurring in large blooms
- Can disrupt lake recreation because they are most likely to be present during the summer months

11.4.2 Zooplankton

Zooplankton are microscopic animals that feed on particulate matter, including algae and are, in turn, eaten by fish. As a result, zooplankton populations are considered vital to the fishery. Protection or enhancement of the lake's zooplankton community through judicious management practices affords protection to the lake's fishery.

The rotifers and copepods graze primarily on extremely small particles of plant matter and do not significantly affect the lake's water quality. However, the cladocera graze primarily on algae and can improve water quality if present in abundance.

The most recent analysis of zooplankton occurred throughout 2010 and 2011. Copepods typically represent over 50% of the zooplankton density throughout the year with peaks in the early spring of over 80%. Cladocerans typically represent between 15 and 30% of the total zooplankton density. Rotifers represent the remaining density of zooplankton. The zooplankton population was dominated by small bodied organisms that were unable to control algal growth.

11.4.3 Macrophytes

Aquatic plants (macrophytes) are a natural part of most lake communities and provide many benefits to fish, wildlife, and people. Typical functions of a lake's macrophyte community include the following:

- Provide habitat for fish, insects, and small invertebrates
- Provide food for waterfowl, fish, and wildlife
- Produce oxygen
- Provide spawning areas for fish in early spring/provide cover for early life stages of fish
- Help stabilize marshy borders and protect shorelines from wave erosion
- Provide nesting sites for waterfowl and marsh birds

Plant surveys have been conducted on Staring Lake in years 2004, 2009, and 2011-2015. The most recent survey conducted on Staring Lake was a set of point intercept surveys conducted every June and August from 2011-2015 by the University of Minnesota (Jaka & Newman, 2014). The U of M found the aquatic plant community in Staring Lake was very poor. The diversity of the plant community peaked in 2014 with 14 total species. However, the frequency of occurrence for each species was very low. The most common occurring plant was curlyleaf pondweed with the most common occurring native species being white and yellow water lilies. In 2015 Eurasian watermilfoil was detected for the first time in Staring Lake. A rapid action plan was implemented which included removal of existing plants and an herbicide treatment (RPBCWD, 2015). The biomass and frequency of occurrence for of all plant species were very low relative to other lakes. The low abundance of plants in Staring Lake is likely due to presence of carp that can root up the plants. Due to carp removal the aquatic plant community did see slight increases in 2014. Continued carp management is recommended along with continued plant monitoring for plant diversity as well as curlyleaf pondweed and Eurasian watermilfoil detection (Jaka & Newman, 2014).

11.4.4 Fishery

Based on the most recent lake fish survey conducted of Staring Lake conducted in 2008. Previous fish surveyed found a declining fish community with an excess of rough fish. The 2008 survey still had an abundance of rough fish but showed an increase in panfish populations.

Bluegills were the most abundant species in Staring Lake during the 2008 survey. Most recently bluegills have been stocked in Staring Lake in 2012-2014. Black crappies were found to have a moderately high abundance. Northern pike abundance was found to be moderately high when compared to similar lakes in the state. Overall growth rates of fish in Staring Lake were found to be low.

The RPBCWD funded the University of Minnesota to conduct multi-year research on the movement of common carp through the Purgatory Creek watershed and document the key factors that influence carp recruitment (Sorensen, et al., 2015). Electrofishing found high number of 26,000 carp in Staring Lake in 2011 with a biomass estimate of 500 kg/ha. Movement studies conducted between Staring Lake and the Recreation Area determined that carp were migrating from Staring Lake to the Recreation Area to spawn, with young carp moving back into Staring Lake. Management activities were implemented in Staring Lake and the Recreation Area to reduce the carp populations. These activities included installing a barrier in Purgatory creek between the Recreation Area and Staring Lake in 2015 to prevent the migration between the two water bodies. Winter seining and systematic removal using netting and electroshocking techniques were also implemented to net and removal large amounts of carp from the system. Through these measures the carp population in Staring Lake was reduced to ~3,000 carp by 2015 with an estimated biomass of ~100 kg/ha. This level of carp biomass meets the water impairment threshold of 100 kg/hectare determined by the University of Minnesota (Sorensen, et al., 2015).

11.5 TP Source Assessment

Watershed and in-lake water quality models were developed to assess both the external and internal TP loads in Staring Lake for the 2015 water year (October 2014 – September 2015). A detailed discussion of the modeling methods used is presented in Section 2.2.2 and Appendix D. Possible lake TP loads include atmospheric deposition, stormwater runoff from the lake watershed, erosion from ravines/channels contributing to the lake, surficial groundwater interactions with the lake waters, internal loads from upstream ponds and wetlands, and load from any upstream lakes that might flow into the waterbody. External loads that applied to Staring Lake are atmospheric deposition, watershed loads, erosion and loads from upstream lakes/ waterbodies. Based on the 2015 water balance there was no net surficial groundwater inflow meaning the inflow of groundwater likely equals the outflow. While the RPBCWD has collected water quality data in several ponds within the Staring Lake watershed, the internal loading within the ponds and wetlands was not evaluated for this study. Internal TP loads can come from sediment TP release, curlyleaf pondweed, or benthivorous fish activity. Figure 11.7 summarizes the 2015 annual water year TP budgets for Staring Lake, including the relative contributions of the external and internal TP loads. This budget helps explain the sources of TP to each of the lakes and help direct and prioritize implementation strategies. Each of the sources are discussed further in the following section(s).

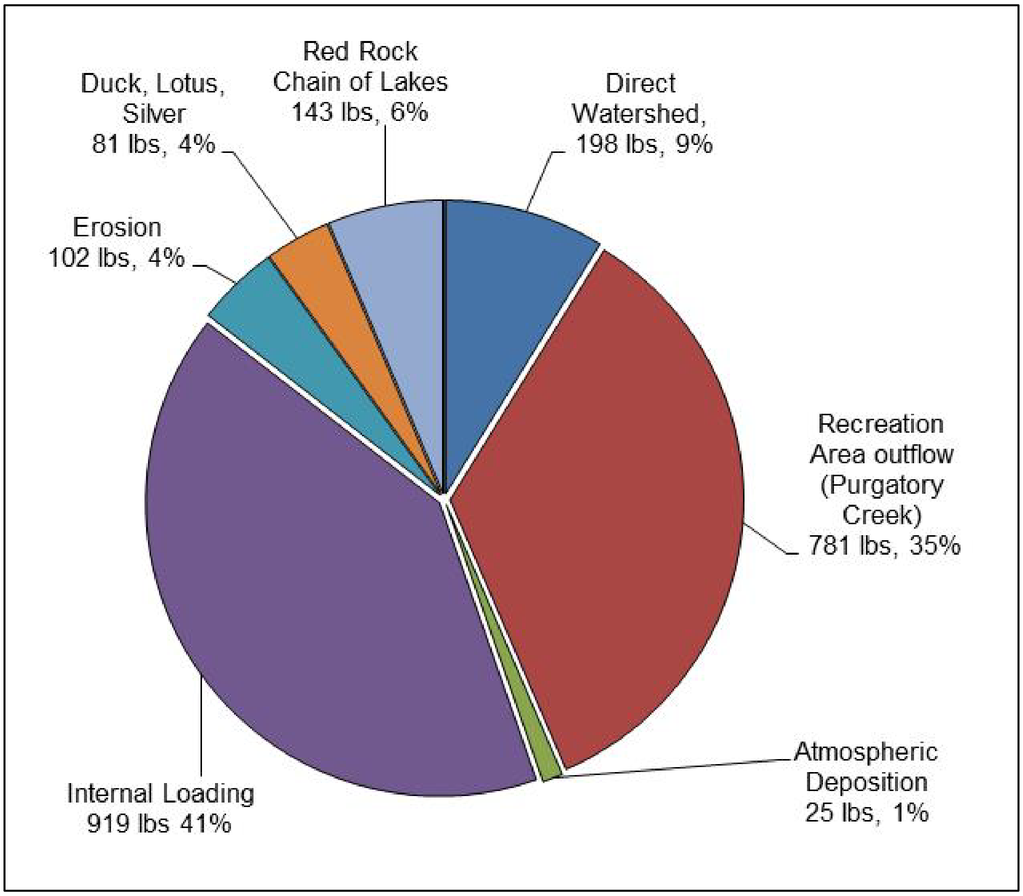


Figure 11.7 Staring Lake TP load sources for 2015 water year

11.5.1 External Loads

11.5.1.1 Atmospheric Deposition

Atmospheric deposition of TP onto the lake water surface was calculated by using the estimated statewide TP atmospheric deposition rate of 0.17 kg/ha/year (Barr Engineering, 2004). For Staring Lake, this loading rate was applied to the combined open water area. The daily rate was applied to the surface area of the lake based on the modeled lake water elevation from the lake water balance model. The resulting atmospheric deposition TP load for the 2015 water year was 25 pounds which amounted to 1% of the TP load to Staring Lake (Figure 11.7).

11.5.1.2 Watershed Loads

The P8 watershed model estimated surface runoff from Staring Lake's subwatersheds (not passing through upstream lakes) based on observed climatic data (precipitation and temperature). Two P8 models were created. The first model calculated watershed flow and TP loads from Staring Lake's direct watershed. A second model calculated the flow and loads from the Purgatory Creek Recreation Area. The total watershed load from the lake's direct watershed that reached Staring Lake for the 2015 water year was modeled to be 198 pounds which represents 9% of the total TP load. The modeled watershed load leaving the Recreation Area was 781 pounds representing 35% of the total TP load. The watershed load travels through existing stormwater ponds, wetlands, infiltration practices, and other BMPs located throughout the watershed providing treatment before it reached the lake. Treatment provided by existing BMPs including the Recreation Area reduces the direct watershed load before treatment of 4,920 pounds down to the 979 pounds that reach the lake. This represents an estimated 80% watershed reduction provided by existing BMPs, wetlands and other waterbodies located throughout the Staring Lake and Purgatory Creek watershed. The largest treatment occurred upstream of the Valley View WOMP station, where existing BMPS and series of wetlands provide storage and infiltration of runoff waters limiting the TP load that travel downstream. This area receives an estimated removal of 84% of the watershed TP load before it reaches Staring Lake. The section between the Valley View WOMP station and the Recreation Area was estimated to receive 73% removal before reaching Staring Lake. Finally, the watershed section that contributes to Staring Lake without traveling through the Recreation Area was estimated to receive 35% removal before reaching Staring Lake.

Watershed loads to the lake were calculated for each of Staring Lake's individual subwatersheds to help evaluate and identify areas that might benefit from additional treatment. The load to the lake is defined as the amount of TP load from that watershed reaching the lake without being removed by an existing BMP within the subwatershed or downstream from the subwatershed. The P8 results were used to calculate the total annual average untreated watershed TP loads from each subwatershed. Next the watershed load to the lake was calculated. This was accomplished by applying the annual average removal efficiencies from each BMP in succession along the watershed flow path until the cumulative flow reached the lake. This calculation resulted in the amount of TP load from each subwatershed that reached the lake without being removed by an existing BMP. The watershed load to the lake for each subwatershed is shown in Figure 11.8.

11.5.1.3 Erosion Loads

TP loads from streambank erosion were approximated for tributaries to Staring Lake based on estimates from the CRAS report (Barr Engineering Co. & Riley Purgatory Bluff Creek Watershed District, November 2015) and associated documentation for the surveys of the stream reaches within the respective watersheds. Because the CRAS methodology quantifies a range in the amount of material that is at-risk of eroding during a 20-year period, the streambank erosion estimates were based on the average of the highest and lowest annual sediment and TP loading rate estimates. These estimates were further reduced to account for a 20 percent delivery ratio to the lake. From this calculation an erosion TP load of 102 pounds was estimated. This load represents 4% of the TP load to Staring Lake (Figure 11.7).

11.5.1.4 Upstream Lakes

Staring Lake has multiple upstream lakes contributing to the overall TP load. Discharge from Lotus Lake, Duck Lake and Silver Lake flow into Purgatory Creek which flows through the Recreation Area and into Staring Lake. The Eden Prairie Chain of Lakes (Round, Mitchell, and Red Rock Lake) flow from Red Rock Lake through a series of ponds into Lake McCoy and finally into Staring Lake. As part of this report all upstream lakes to Staring Lake have a daily time step in-lake TP model that was created for year 2015. The in-lake TP model accounts for the water and TP loads from upstream waterbodies (that have not been modeled as part of the watershed model). Flows and TP concentration from those lakes were added to Staring Lake model to determine the load. Loads from the Eden Prairie chain of lakes were further reduced based on treatment through the series of stormwater ponds and Lake McCoy before entering Staring Lake. This analysis resulted in a total load of 143 pounds of TP (6% of the total load) entering Staring Lake. Lotus, Duck and Silver Lakes combined represent 81 pounds or 4% of the total TP load to Staring Lake.

11.5.2 Internal Loads

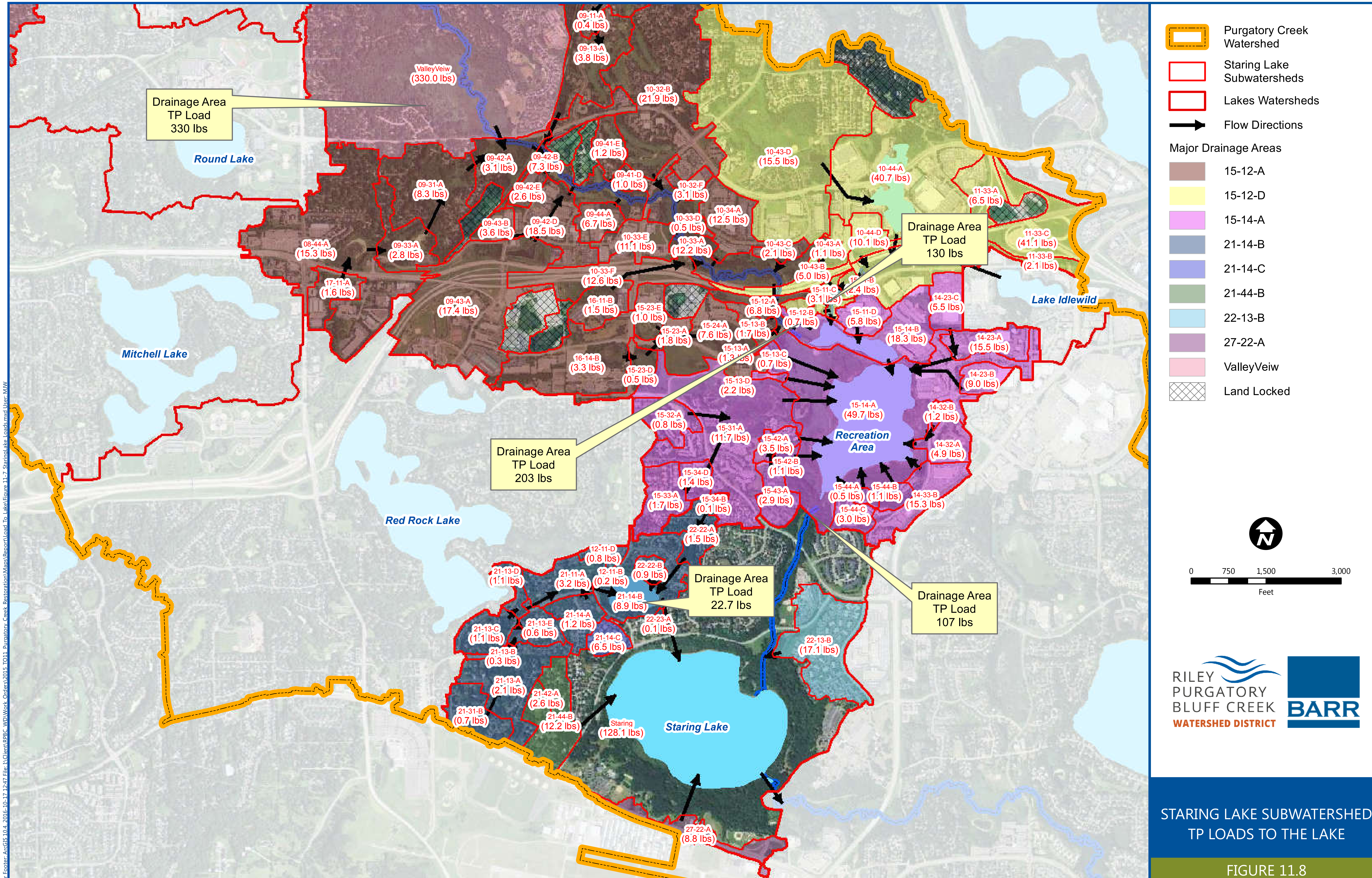
Internal loading in Staring Lakes represented 41% (919 pounds) of the TP loads in the 2015 water year. Internal loading sources to Staring Lake appear to be the result of curlyleaf pondweed die-back, carp activity and sediment P release.

11.5.2.1 Curlyleaf Pondweed

Because of the relatively low occurrence in Staring Lake TP loading from curlyleaf pondweed was not explicitly modeled for this study. The internal loading calibration parameter was used to simulate this release along with other sources of internal loading. Due to the low levels it is likely that curlyleaf pondweed is a very minor source of TP to Staring Lake.

11.5.2.2 Benthivorous Fish Activity

Although carp have historically been present in Staring Lake observed during 2015, with a large population, the current estimated carp densities suggest that carp activity did not have as significant of an impact on the observed water quality in the lake for 2015. Carp populations were successfully reduced to a level that is equal to the water impairment threshold of 100 kg/hectare determined by the University of Minnesota. As a result, this analysis did not explicitly account for the activities of carp and other benthivorous fish the magnitude of the TP load to Staring Lake was not quantified as part of the in-lake water quality modeling in 2015. However, mitigation measures will need to continue in order to maintain this assumption. If carp populations are allowed to increase to 2011 levels significant higher TP loads to the water column would be expected.



STARING LAKE SUBWATERSHED TP LOADS TO THE LAKE

FIGURE 11.8

11.5.2.3 Sediment Release

Internal loading through sediment release occurs during anoxic conditions. A review of dissolved oxygen profiles in Staring Lake showed periodic anoxic conditions in the sediments during the middle summer months. Anoxic conditions are present through most of the summer, but wind mixing periodically occurs re-oxygenating the lakes sediments. The stratification and subsequent anoxic conditions in the hypolimnion allow for the release of phosphorus throughout the growing season months. Elevated TP concentrations have been recorded in the lake hypolimnion corresponding to anoxic conditions. TP concentrations in the hypolimnion have been as high as 160 µg/L since 2014 with concentrations typically seen around 100 µg/L during the summer months. As the lake mixes through wind mixing events and turnover in the fall from temperature changes this phosphorus load is distributed throughout the water column impacting surface water phosphorus concentrations, thus providing nutrients for algal growth.

11.5.3 TP Load Reductions

The in-lake model was used to determine TP load reductions needed to meet the water quality goal for Staring Lake. Table 11.3 shows the measured and modeled growing season average (June – September) concentration, the TP load to the lake under existing conditions, the water quality goal, the TP loading capacity for meeting the water quality standard and the required percent reduction needed to meet the water quality goal. Under existing conditions Staring Lake is not meeting the TP goal for a shallow lake of 60 µg/L. Modeled and measured growing season average concentrations in the lake surfaces waters for the 2015 water year was 83 µg/L and 77 µg/L respectively. Staring Lake was simulated as a completely mixed lake with modeled concentration representing the volumetric average concentrations in the water column. The TP load under existing conditions was 2,249 pounds for the 2015 water year. To meet the water quality goal the load to Staring Lake would need to be reduced to 1,749 pounds, resulting in a 22% TP load reduction.

Table 11.3 Staring Lake estimated load reductions required to meet TP water quality goal for 2015 water year

Measured growing season average TP concentration (µg/L)	Modeled growing season average TP concentration (µg/L)	Estimate 2015 TP loading rate (lbs/yr)	TP concentration goal (µg/L)	Estimated Loading Capacity to meet WQ goal (lbs/yr)	Percent reduction needed to achieve goal (%)
83	77	2,249	60	1,749	22%

Volumetric average concentration for entire water column

The calibrated in-lake models were used to determine in-lake water quality based on the amount of TP load to the lake (Figure 11.9). TP concentrations were estimated using the in-lake model. Chl-a and Secchi depth concentrations were approximated based on the water quality relationships discussed in Section 11.3.1. Figure 10.8 shows how incremental load reductions would impact the water quality in Staring Lake. For example, if the load to Staring Lake was reduced by 200 pounds the lake TP concentration would be projected to be 70 µg/L, the Chl-a concentration would be 29 µg/L, and the Secchi depth would be 1.0 meter.

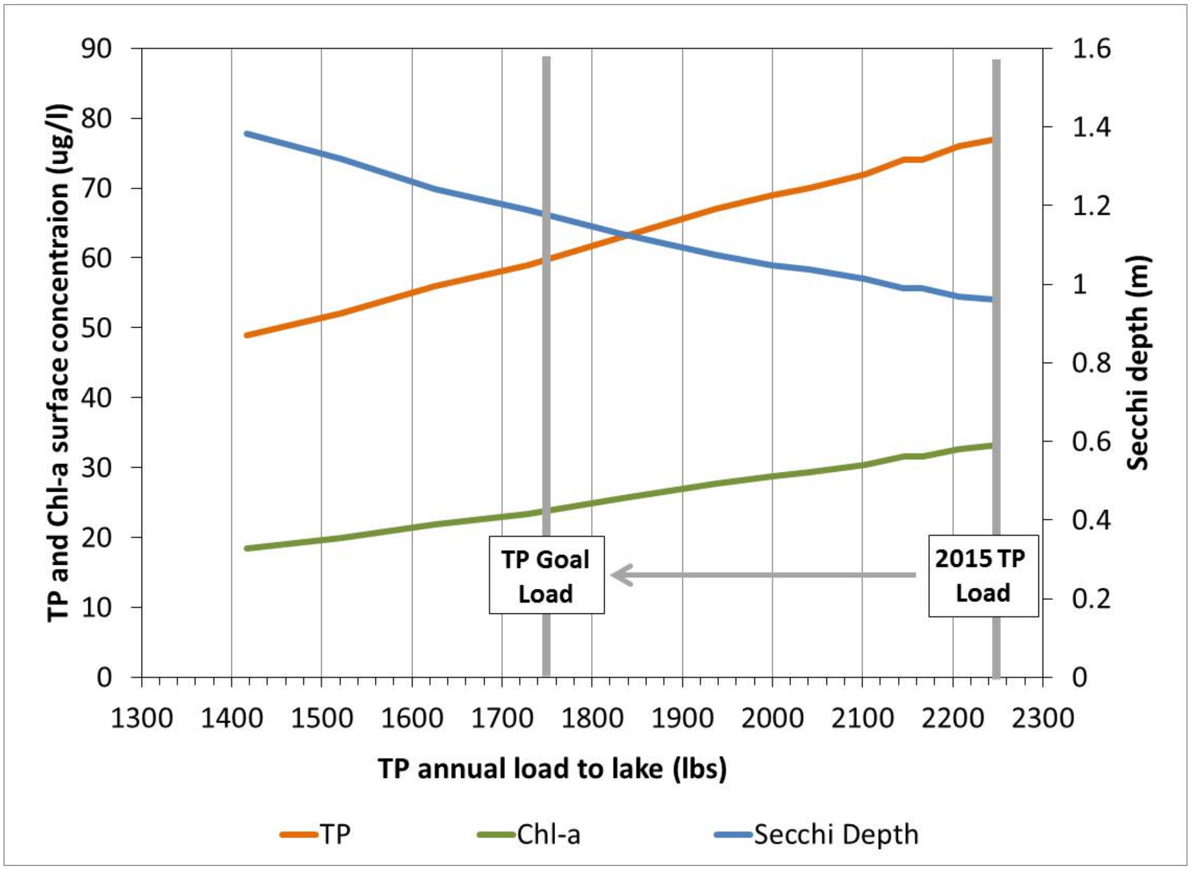


Figure 11.9 Staring Lake TP load relationship with lake water quality (TP, Chl-a and clarity)

11.6 Summary of Diagnostic Findings

Table 11.4 provides a summary of the key water-quality findings for Staring Lake.

Table 11.4 Diagnostic Findings for Staring Lake

Topic	Staring Lake
Water Quality Standards and Goals	- Does not meet MPCA Shallow Lake Standards for TP and Chl-a in 2015. Did meet the standard for Secchi Depth. - Currently listed as impaired for nutrient/eutrophication biological indicators. - Does not meet RPBCWD goals or long term vision
Baseline Water Quality	- Reconstruction sediment core analysis has not been conducted on Staring Lake.
Water Quality Trends	- Significant improving trends detected for Chl-a and Secchi depths from 1999-2015.
Watershed Runoff	- Represents 44% of annual TP load including both direct watershed of Staring Lake and runoff that travel through the Recreation Area before entering Staring Lake. - Watershed load is reduced by 80% by existing BMPs, ponds and wetlands located throughout the watershed.
Macrophyte Status	- Historically has a poor diversity of macrophytes. - Improvements in diversity and coverage were observed in 2015 after carp population was significantly reduced. - Curlyleaf pondweed is present in low numbers in 2015 - Eurasian water milfoil was detected for first time in 2015
Fishery Status	- Carp population was significantly reduced from 2011 through 2015 by district management efforts. 2015 carp levels were below water quality degradation threshold established by UofM
Cyanobacteria (blue green algae)	- Has historically experienced cyanobacteria blooms during the summer
Internal Loading from sediments and fish activity	- A polymictic lake with wind event mixing the entire water column during summer months. Intermittent stratification with anoxic conditions are present. - Internal loading from sediment estimated to be 41% of annual TP load
Methylmercury in Fish Tissues	- Listed as impaired for aquatic consumption due to mercury in fish tissue in 1998. - TMDL completion date set for 2025 by MPCA.

Additional discussion of the diagnostic findings in relation to the sources of TP and water quality of the lakes based on the data analyses, watershed and in-lake modeling, and review of recent studies and information is included. These conclusions influenced the implementation strategies evaluated for the management of Staring Lake water quality (see Section 11.8).

- Staring Lake is currently listed on the MPCA 303(d) impaired waters list for excess nutrients with TP concentrations exceeding the 60 µg/L MPCA shallow lake standard. A TMDL analysis is currently being developed with the MPCA. A complete historic review of water quality conditions in Staring Lake show growing season average values consistently above the standard for TP, Chl-a and Secchi depth. A trend analysis showed significant improving trends in chl-a and Secchi depth since 1999. The recent trends have reversed degrading trends for the entire period of record since 1971. Values appear to have peaked in the mid 2000's and have since been improving.

- Approximately 97 percent of the watershed runoff receives treatment prior to entering Staring Lake due to the number of stormwater ponds and other waterbodies within the watershed. As stormwater runoff passes through the many constructed stormwater ponds and natural wetlands in the watershed, significant removal of TP associated with particulates in the runoff occurs due to particle settling as well as in some cases infiltration of runoff waters. The largest removal occurs in the areas upstream of the Valley View WOMP station with an estimated 84% removal. The section of the watershed that encompasses areas downstream of the Valley View WOMP station that flow into and including the Recreation Area received an estimated 73% TP removal. Areas downstream of the Recreation Area that contribute flow to Staring Lake received an estimated 35% removal.

- The watershed modeling suggests that a significant portion of the TP in the watershed runoff reaching the lake is in a soluble form or associated with very small particles that are difficult to settle. Therefore, treatment practices the can remove dissolved phosphorus such as infiltration and enhanced filtration practices should be examined in addition to practices in currently untreated areas.

- The watershed phosphorous load to Staring Lake represented 44 percent of the total annual TP budget to the lake during the 2015 water year, internal loading represented another 41 percent of the total annual TP budget (see Figure 11.7). Other loads to Staring Lake include flow from upstream lakes. Lotus, Duck, and Silver Lakes contribute flow to Purgatory Creek that travels through the Recreation Area before entering Staring Lake. The Eden Prairie Chain of Lakes flows out of Red Rock Lake and through a series of stormwater ponds and Lake McCoy before entering Staring Lake. In total, upstream lakes appear to provide 10% of the TP load to Staring Lake.

- Water quality data collected along the depth profile of Staring Lake indicates that the interface along the bottom sediments can become anoxic during the summer and elevated TP levels have been observed near the lake bottom, supporting the conclusion that internal loading is a source of TP in Staring Lake.

- Figure 11.9 shows the estimated TP loading from the major drainage basins in the Staring Lake watershed. The watershed modeling suggests that 13 percent of the watershed load to Staring

Lake is from the lake's direct watershed. In addition, another 13 percent passed through 15-11-C, 20 percent passes through 15-12-B, and 10% contributed to the Recreation Area.

- Based on surveys conducted between 2011 and 2015 Staring Lake has a poor diversity of macrophytes with low coverage. Improvements were observed in 2014 and 2015 as the carp population was reduced in Staring Lake. Curlyleaf pondweed historically has been found in Staring Lake but at low levels that are not of concern. Eurasian watermilfoil was first detected in 2015 prompting a rapid response removal and herbicide treatment in the fall of 2015. Continued plant surveys are need to determine the effectiveness of this action.

- The carp population in Staring Lake has been significantly reduced due to management activities from 2011 to 2015. 2015 biomass level of carp were recorded as 100 hg/hectare. This is at the level suggested for water quality impairment (Sorensen, et al., 2015). Further management activities are recommended to prevent young carp from the recreational management area from reaching Staring Lake and increasing the overall carp population past impairment levels (Sorensen, et al., 2015).

11.7 Current and Past Management Actions

The following includes a summary of BMPs either implemented or analyzed in the Staring Lake watershed:

- A total of 26 constructed ponds and stormwater wetlands were identified for expansion of cleanout to improve water quality in Staring Lake through an assessment of 172 total basins in the watershed (Wenck Associates, Inc., 2013)
- Carp density populations in Staring Lake and the adjacent Purgatory Creek Recreation Area were determined to be high. The Recreation Area was found to be the only nursery for carp in the Purgatory Creek chain of lakes (Sorensen, et al., 2015). Mitigation measures were implemented in 2012 and continued in 2013 and 2014, including the placement of fish traps between Staring Lake and the Recreation Area and reduced water levels in the Recreation Area to achieve full freeze throughout the water column to kill carp larvae and eggs during the winter (Sorensen, et al., 2015).
- Other future carp mitigation measures in Staring Lake include yearly carp monitoring, removal of adult carp through winter netting and placing a fish barrier at the mouth of the Purgatory Creek Recreation Area (Sorensen, et al., 2015).
- In 2015 a permanent carp barrier was installed in Purgatory Creek within the existing concrete channel under the walking trail bridge just downstream of the Recreation Area which included a design that enabled the new barrier to be closed quickly so it could serve to both trap/remove adult carp migrating to Recreation Area and (if necessary) to trap them where they might die because of a winter drawdown and freeze-out (Sorensen, et al., 2015).
- Wetlands 1, 42, 44 and 12 in Shorewood and ponds 804_W, 833_p3, 849_W, 850_p1, 861_p1, 866_p1 and 920_W in Minnetonka analyzed in the Staring Lake watershed over years 2012 and

2013, were determined to have TP concentrations above 0.250 mg/l and could benefit from remediation measures (RPBCWD, 2014).

- Other potential BMP and mitigation measures suggested for Staring Lake as part of the "One Water" Water Management Plant (CH2M HILL, 2011) include:
  - control curlyleaf pondweed mechanically and through herbicide treatment,
  - control purple loosestrife with beetles,
  - control cyanobacteria through hypolimnetic oxygenation, sediment oxygenation, or chemical inactivation of phosphorus,
  - control phytoplankton through bio-manipulation and fisheries management,
  - control external TP loading through stormwater infiltration basin construction,
  - control external TP loading through existing wetlands and add ponds.

11.8 Evaluation of Water Quality Improvement Options

All of the BMPs identified for Staring Lake (and the Recreation Area) are listed and described in detail in the following subsections. Some of the BMPs identified in this section were initially identified in the Town Center Report (Wenck Associates, Inc., December 2014). Table 11.5 provides a list of the potential BMPs and Figure 11.10 shows the identified potential BMP locations in the Staring Lake and the Recreation Area watersheds.

11.8.1 Creek restoration and stabilization in subwatershed 09-42-B, StL_1

BMP StL_1 is the restoration and stabilization of a 3,350-foot reach of a creek running through the Bent Creek golf course in subwatershed 09-42-B. This reach of the creek was identified in the CRAS report as a reach with an estimated very severe erosion rate (Barr Engineering Co. & Riley Purgatory Bluff Creek Watershed District, November 2015). The purpose of this BMP is to reduce the soil erosion quantities which will also reduce the TP load from this watershed. The restoration and stabilization of this creek reach is expected to reduce TP loading from the creek by about 260 pounds per year. Due to natural deposition of sediment downstream of this reach, the estimated TP load to the lake could be reduced by 52 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $1,200 per pound of TP per year, assuming the creek remains stable for at least 30 years.

11.8.2 New infiltration basins in subwatershed 09-43-A, StL_2

BMP StL_2 is a series of new infiltration basins in subwatershed 09-43-A along Wallace Road just south of Highway 212, designed to treat about 23.4 acres of impervious area. The soils in this area are uncertain based on available soil map layers, but are surrounded by "B" soils, with a good capacity to infiltrate water. This infiltration basin is proposed to be approximately 0.4 acres at the surface and about 3.0 feet deep. The infiltration basins could potentially remove 48.6 pounds of TP per year based on 30-year modeling results. Based on the location of the BMP relative to Staring Lake, the estimated TP load reduction to the lake is about 8.9 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $1,520 per pound of TP per year, assuming the BMP functions for 30 years.

11.8.3 Enhanced wet pond in subwatershed 10-33-E, StL_3

BMP StL_3 is the enhancement and enlargement of an existing wet pond in subwatershed 10-33-E along Purgatory Creek just to the east of Mitchell Road designed to treat 11 acres of impervious area. The expanded pond is proposed to be approximately 1.0 acre at the surface and about 6 feet deep. The pond would have two inlets from existing storm sewer, and one 24-inch outlet to Purgatory Creek. The enhanced pond could remove an additional 14.3 pounds of TP per year beyond what is currently removed. Based on the location of the BMP in the watershed relative to Staring Lake, the reduction in TP loading to the lake is estimated to be less, about 7.2 pounds of TP per year on average. The cost-benefit of this BMP for Staring Lake is estimated to be about $2,000 per pound of TP, assuming the BMP functions for 30 years.

11.8.4 New wet pond in subwatershed 09-44-A, StL_4

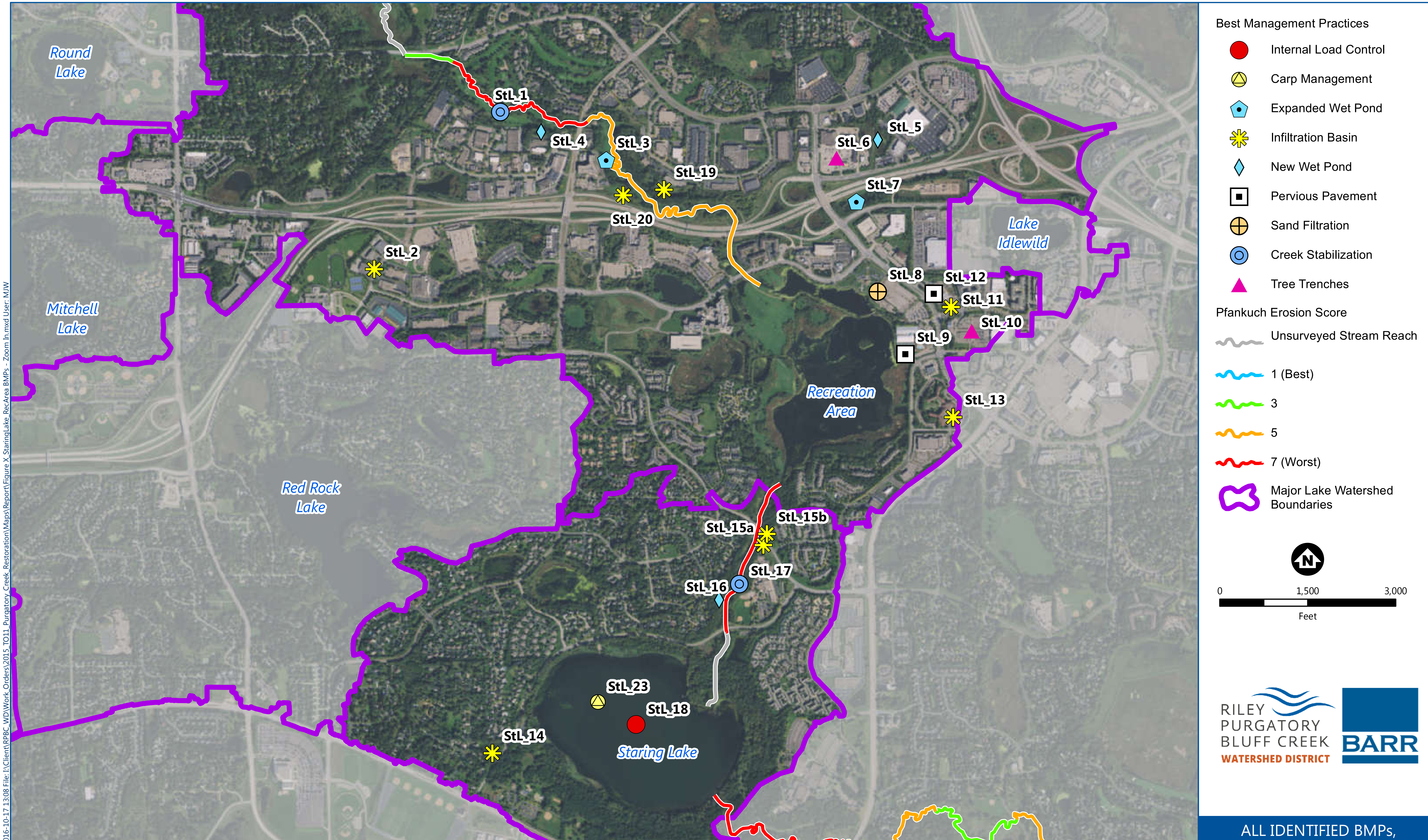
BMP StL_4 is a new wet pond in subwatershed 09-44-A just north of the RPBCWD office, designed to treat 10 acres of impervious area. This pond is proposed to be approximately 0.5 acres at the surface with an average depth of about 6 feet. The pond could remove 7.8 pounds of TP per year. Based on the distance of the BMP in the watershed relative to Staring Lake and intermediate BMPs (i.e., the Recreation Area), the reduction in TP loading to the lake is estimated to be 3.5 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $3,110 per pound of TP, assuming the BMP functions for 30 years.

Table 11.5 - Summary of Staring Lake and Recreation Area BMPs, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
StL_1	Creek Restoration and Stabilization *- Restoration and stabilization of the 3,350-foot reach from the Golf Course to Mitchell Road*	260	52	10%	$1,173,000 ($586,500 - $2,346,000)	$23,500 ($11,700 - $46,900)	$240 ($120 - $480)	$1,200 ($600 - $2,410)
StL_2	Infiltration Basin *- A 0.4 acre, 3-foot deep infiltration basin designed to treat 23.4 acres of impervious area*	48.6	8.9	2%	$253,000 ($202,000 - $354,000)	$5,100 ($4,000 - $7,100)	$280 ($220 - $390)	$1,520 ($1,220 - $2,130)
StL_3	Expanded Wet Pond *- A 1.0 acre, 6-foot deep wet pond designed to treat 11 acres of impervious area*	14.3	7.2	1%	$269,700 ($216,000 - $378,000)	$5,400 ($4,300 - $7,600)	$1,010 ($810 - $1,410)	$2,000 ($1,600 - $2,800)
StL_4	New Wet Pond *- A 0.5 acre, 6-foot deep wet pond designed to treat 10 acres of impervious area*	7.8	3.5	1%	$203,400 ($163,000 - $285,000)	$4,100 ($3,300 - $5,700)	$1,390 ($1,120 - $1,950)	$3,110 ($2,490 - $4,350)
StL_5	New Wet Pond *- A 5.0 acre, 3-foot deep wet pond designed to treat 60 acres of impervious area*	30.8	18.6	4%	$925,700 ($741,000 - $1,296,000)	$18,500 ($14,800 - $25,900)	$1,600 ($1,280 - $2,240)	$2,650 ($2,120 - $3,720)
StL_6	Tree Trenches *- In the parking lot of Lunds & Byerlys, NE corner of Prairie Center Dr. and Plaza Dr.*	10.7	4	1%	$933,300 ($747,000 - $1,307,000)	$18,700 ($14,900 - $26,100)	$4,660 ($3,720 - $6,520)	$12,450 ($9,960 - $17,430)
StL_7	Expanded Wet Pond *- A 4.5 acre, 6-foot deep expanded wet pond designed to treat 26.5 acres of impervious area*	33.6	11.7	2%	$207,200 ($166,000 - $290,000)	$4,100 ($3,300 - $5,800)	$330 ($260 - $460)	$940 ($750 - $1,320)
StL_8	Filtration Basins *- Totalling 1.0 acre around the Anchor Bank and the Purgatory Creek Park Pavilion (Town Center Report)*	11.4	8.4	2%	$628,600 ($502,900 - $880,000)[8]	$12,600 ($10,100 - $17,600)	$2,940 ($2,350 - $4,120)	$3,990 ($3,200 - $5,590)
StL_9	Pervious Pavement *- A 0.8 acre area south of Life Time Fitness (Town Center Report)*	3	2.2	0%	$696,000 ($556,800 - $974,400)[8]	$13,900 ($11,100 - $19,500)	$12,370 ($9,890 - $17,310)	$16,860 ($13,490 - $23,610)
StL_10	Stormwater Planters and Tree Trenches *- Totalling 0.4 acre in the Walmart and Costco parking lots east of Prairie Center Dr. (Town Center Report)*	13.7	11.4	2%	$851,500 ($681,200 - $1,192,100)[8]	$17,000 ($13,600 - $23,800)	$3,310 ($2,650 - $4,640)	$3,980 ($3,180 - $5,570)
StL_11	Infiltration Basins and Tree Trenches *- Numerous infiltration basins and tree trenches (totalling 2.6 acres) around Prairie Center Dr. and Singletree Ln. (Town Center Report)*	41.9	37.2	7%	$5,099,800 ($4,080,000 - $7,140,000)[8]	$102,000 ($81,600 - $142,800)	$6,490 ($5,190 - $9,090)	$7,310 ($5,850 - $10,240)
StL_12	Pervious Pavement *- A 0.3 acre area in the Bachman's parking lot east of Prairie Center Dr. (Town Center Report)*	10.1	7.9	2%	$270,000 ($216,000 - $378,000)[8]	$5,400 ($4,300 - $7,600)	$1,430 ($1,140 - $2,000)	$1,820 ($1,460 - $2,550)
StL_13	Infiltration, Basin & Underground *- A 0.3 acre area around Presbyterian Homes & Services, and Broadmoor of Eden Prairie (Town Center Report)*	7.1	1.7	0%	$357,200 ($285,800 - $500,000)[8]	$7,100 ($5,700 - $10,000)	$2,680 ($2,140 - $3,750)	$11,180 ($8,940 - $15,650)
StL_14	Infiltration Basin *- A 1.4 acre, 1.5-foot deep infiltration basin designed to treat 5.0 acres of impervious area*	14.7	14.7	3%	$975,900 ($781,000 - $1,366,000)	$19,500 ($15,600 - $27,300)	$3,540 ($2,830 - $4,960)	$3,540 ($2,830 - $4,960)
StL_15a & StL_15b	Infiltration Basins *- Two basins totalling 0.55 acres and 2 feet deep, designed to treat 11.0 acres of impervious area*	12.3	12.3	2%	$894,400 ($716,000 - $1,252,000)	$17,900 ($14,300 - $25,000)	$3,880 ($3,100 - $5,430)	$3,880 ($3,100 - $5,430)
StL_16	New Wet Pond *- A 0.8 acre, 3-foot deep wet pond designed to treat 4 acres of impervious area*	5.1	5.1	1%	$499,600 ($400,000 - $700,000)	$10,000 ($8,000 - $14,000)	$5,230 ($4,180 - $7,320)	$5,230 ($4,180 - $7,320)
StL_17	Creek Restoration and Stabilization *- Restoration and stabilization of the 1,000-foot reach between the Recreation Area and Staring Lake, behind Oak Point Elementary School*	20	20	4%	$550,000 ($275,000 - $1,100,000)	$11,000 ($5,500 - $22,000)	$1,470 ($730 - $2,930)	$1,470 ($730 - $2,930)
StL_18	Internal Load Control *- Two treatments of a whole lake alum treatment*	735	735	147%	$812,000 ($650,000 - $1,137,000)	$0	$40 ($30 - $50)	$40 ($30 - $50)
StL_19	Infiltration Basin *- Convert existing pond into an expanded 0.7 acre infiltration basin, treating 20.4 acres of impervious area*	18.9	9.9	2%	$270,500 ($216,000 - $379,000)	$5,400 ($4,300 - $7,600)	$760 ($610 - $1,070)	$1,460 ($1,160 - $2,040)
StL_20	Infiltration Basin *- Convert existing pond into an expanded 1.5 acre infiltration basin, treating 20.8 acres of impervious area*	26.5	12.2	2%	$381,400 ($305,000 - $534,000)	$7,600 ($6,100 - $10,700)	$770 ($610 - $1,070)	$1,670 ($1,330 - $2,330)
StL_21	Creek Restoration and Stabilization *- Restoration and stabilization of the 1,000-foot reach south of Covington Road*	85	17	3%	$450,000 ($225,000 - $900,000)	$9,000 ($4,500 - $18,000)	$280 ($140 - $560)	$1,410 ($710 - $2,820)
StL_22	Assume upstream lakes meet load and quality goals	29	29	6%	See Table 12.1 for the cost for each lake's BMPs			

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. Overall load reduction goal for Staring Lake is 500 pounds of phosphorus per year; 200 lbs/yr from the watershed, and 300 lbs/yr internally.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.
8. Cost estimated by others in the Town Center Report (Wenck Associates, Inc., December 2014).



Note: BMP StL_21 is recommended, but is further upstream in the watershed. This scale was chosen to show the number of BMPs around Staring Lake and the Recreation Area in detail.

ALL IDENTIFIED BMPs, STARING LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 11.10

11.8.5 New wet pond in subwatershed 10-44-A, StL_5

BMP StL_5 is a large proposed wet pond in subwatershed 10-44-A just west of Menards north of highway 212, designed to treat 60 acres of impervious area. This BMP is proposed in the site of an existing wetland, Mintree Pond, with the intention of making this area engineered and more efficient at removing TP. While this BMP would reduce the TP load, the significant wetland impact would likely prohibit implementation. This pond is proposed to be approximately 5.0 acres at the surface with an average depth of about 6 feet. The pond could remove 30.8 pounds of TP per year beyond what is currently removed. Based on the distance of the BMP in the watershed relative to Staring Lake and downstream treatment (i.e., the Recreation Area), the TP loading reduction to the lake is estimated to be 18.6 pounds of TP per year. This does highlight the potential water quality benefits of a wetland enhancement project, instead of the creation of a new wet pond. Without accounting for wetland mitigation costs, the cost-benefit of this BMP for Staring Lake is estimated to be about $2,650 per pound of TP, assuming the BMP functions for 30 years.

11.8.6 Tree trenches in subwatershed 10-44-D, StL_6

BMP StL_6 is tree trenches in subwatershed 10-44-D in the parking lot of Lunds and Byerlys along Prairie Center Drive. These tree trenches are designed to treat runoff from the parking lot. The tree trenches will cover approximately 0.4 acres. The tree trenches could potentially remove 10.7 pounds of TP per year. Because of the distance to the lake, the TP load reduction to the lake is expected to be only 4 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $12,450 per pound of TP, assuming the BMP functions for 30 years.

11.8.7 Enhanced wet pond in subwatershed 11-33-C, StL_7

BMP StL_7 is the enhancement and enlargement of an existing wet pond in subwatershed 11-33-C south of Highway 212 just downstream of proposed BMP StL_5 designed to treat 26.5 acres of impervious area. The expanded pond is proposed to be approximately 4.5 acres at the surface with an average depth of about 6 feet. The enhanced pond could potentially remove an additional 33.6 pounds of TP per year beyond what is currently removed by the existing constructed pond. Based on the location of the BMP in the watershed relative to Staring Lake, the TP load reduction to the lake is estimated to be less, about 11.7 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $940 per pound of TP, assuming the BMP functions for 30 years. It is likely that construction in this area would require coordination with MnDOT and may decrease the feasibility of this potential BMP. If expanding and enhancing the existing wet pond is not feasible, it is possible that this large area could be split into a pre-treatment settling pond and an iron enhanced sand filter.

11.8.8 Filtration basins in subwatershed 15-14-B, StL_8

BMP StL_8 consists of multiple filtration basins in subwatershed 15-14-B around Anchor Bank and the Purgatory Creek Park Pavilion (Wenck Associates, Inc., December 2014). Altogether, these filtration basins would cover approximately 1.0 acre and are designed for receiving 1.1 inches of runoff from the contributing watershed. The filtration basins could remove 11.4 pounds of TP per year and reduce the loading to Staring Lake by 8.4 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $3,990 per pound of TP, assuming the BMP functions for 30 years.

11.8.9 Pervious pavement in subwatershed 15-14-A-TC02, StL_9

BMP StL_9 is pervious pavement in subwatershed 15-14-A-TC02 in the parking lot to the south of Life Time Fitness (Wenck Associates, Inc., December 2014). The parking lot that would be converted to pervious pavement for infiltration covers approximately 0.4 acres. The parking lot would require an underdrain to collect infiltrated water and would likely connect to the Recreation Area immediately to the west. The pervious pavement could remove 3.0 pounds of TP per year and reduce the load to the lake by 2.2 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $16,860 per pound of TP, assuming the BMP functions for 30 years.

11.8.10 Stormwater planters and tree trenches in subwatershed 14-23-B, StL_10

BMP StL_10 is stormwater planters and tree trenches in subwatershed 14-23-B in the parking lots of Walmart and Costco along Prairie Center Drive (Wenck Associates, Inc., December 2014). These stormwater planters and tree trenches are designed to treat runoff from the parking lot. The stormwater planters and tree trenches will cover approximately 0.4 acres. The BMP could remove 13.7 pounds of TP per year and reduce the TP load to the lake by 11.4 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $3,980 per pound of TP, assuming the BMP functions for 30 years.

11.8.11 Infiltration basins and tree trenches in subwatershed 14-23-A, StL_11

BMP StL_11 is a series of new infiltration basins and tree trenches in subwatershed 14-23-A along Prairie Center Drive in the Town Center area (Wenck Associates, Inc., December 2014). The soils in this area are uncertain based on available soil map layers, but are surrounded by “B” soils, with a good capacity to infiltrate water. The infiltration in this area could be through a variety of methods, but the primary method proposed is through underground infiltration features that interrupt existing storm sewer. This collection of infiltration practices could remove 41.9 pounds of TP per year and reduce the loading to Staring Lake by 37.2 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $7,310 per pound of TP, assuming the BMP functions for 30 years.

11.8.12 Pervious pavement in subwatershed 14-23-A, StL_12

BMP StL_12 is pervious pavement in subwatershed 14-23-A in the parking lot of Bachman’s along Prairie Center Drive (Wenck Associates, Inc., December 2014). The parking lot that would be converted to pervious pavement for infiltration covers approximately 0.3 acres. The parking lot would require an underdrain to collect infiltrated water and would likely connect to downstream existing storm sewer. The pervious pavement has the potential to remove 10.1 pounds of TP per year based on 30-year modeling results. Because of the BMP location in the watershed, this translates to an estimated 7.9 pounds of TP per year reduction in the loading to Staring Lake. The cost-benefit of this BMP for Staring Lake is estimated to be about $1,820 per pound of TP, assuming the BMP functions for 30 years.

11.8.13 Infiltration, basin and underground in subwatershed 14-32-A_Pres1, StL_13

BMP StL_13 is two infiltration practices (one basin and one underground) in subwatershed 14-32-A_Pres1 around Presbyterian Homes and Services off of Prairie Center Drive (Wenck Associates, Inc., December 2014). The soils in this area are "B" and "C" soils and may not be highly conducive to infiltration, which could require some practices be converted to filtration. These infiltration practices could potentially remove 7.1 pounds of TP per year. Based on the location of the BMP in the watershed relative to Staring Lake, the TP reduction to the lake is only estimated to be 1.7 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $11,180 per pound of TP, assuming the BMP functions for 30 years.

11.8.14 Infiltration basin in subwatershed 21-44-B, StL_14

BMP StL_14 is a new infiltration basin in subwatershed 21-44-B along Staring Lake Parkway just north of Pioneer Trail, designed to treat 5.0 acres of impervious area. The soils in this area are "A" and "B" soils, with a good capacity to infiltrate water. This infiltration basin is proposed to be approximately 1.4 acres at the surface and about 1.5 feet deep. The infiltration basin could remove 14.7 pounds of TP per year with a similar load reduction possible to Staring Lake. The cost-benefit of this BMP for Staring Lake is estimated to be about $3,540 per pound of TP, assuming the BMP functions for 30 years.

11.8.15 New infiltration basins in subwatershed Staring, StL_15a & StL_15b

BMPs StL_15a and StL_15b are a pair of new infiltration basins in subwatershed Staring along Anderson Lakes Parkway on the east side of Purgatory Creek, designed to treat 11.0 acres of impervious area. Because of the limited space and the terrain in these locations, the BMPs would likely require retaining walls. The soils in this area are "A" soils, with a high capacity to infiltrate water. Combined, these infiltration basins are proposed to be approximately 0.55 acres at the surface and about 2.0 feet deep. The infiltration basins could remove 12.3 pounds of TP per year and provide a similar TP reduction benefit to Staring Lake. The cost-benefit of this BMP for Staring Lake is estimated to be about $3,880 per pound of TP, assuming the BMP functions for 30 years.

11.8.16 New wet pond in subwatershed Staring, StL_16

BMP StL_16 is a new wet pond in subwatershed Staring along Purgatory Creek, designed to treat 4.0 acres of impervious area. This pond is proposed to be approximately 0.8 acres at the surface and about 3 feet deep. Because of the limited space and the terrain in this location, the BMP would likely require a retaining wall. Model simulations suggest the pond could remove 5.1 pounds of TP per year. Based on the proximity of the BMP in the watershed relative to Staring Lake, the removal of TP from the lake is also expected to be 5.1 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $5,230 per pound of TP, assuming the BMP functions for 30 years.

11.8.17 Creek restoration and stabilization in subwatershed Staring, StL_17

BMP StL_17 is the restoration and stabilization of a 1,000-foot reach of a creek running between the Recreation Area and Staring Lake behind Oak Point Elementary School in subwatershed Staring. This reach of the creek was identified in the CRAS report as a reach with an estimated very severe erosion rate (Barr Engineering Co. & Riley Purgatory Bluff Creek Watershed District, November 2015). The purpose of this BMP is to reduce the soil erosion quantities which will also reduce the TP load from this watershed. The restoration and stabilization of this creek reach is expected to reduce TP loading both from the creek and to Staring Lake by about 20 pounds per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $1,470 per pound of TP, assuming the creek remains stable for 30 years.

11.8.18 Internal load control in Staring Lake, StL_18

BMP StL_18 is a method for reducing the internal loading within the lake, likely with an alum treatment to bind mobile TP in the lake sediment. The treatment within the lake could initially reduce the internal TP loading by approximately 80% (Welch & Cooke, 1999), resulting in a reduction of 735 pounds per year. The dose needed to achieve this reduction is estimated to be approximately 1,360 gallons per acre, based on 2005 samples of mobile TP in the sediment cores of Staring Lake (Barr Engineering, 2005). The cost-benefit of this BMP is estimated to be about $40 per pound of TP, assuming treatment is not needed again for at least another 15 years (Huser, et al., 2015). Two treatments will likely be needed over 30 years and the total cost of both treatments is estimated to be $812,000 (Table 11.5). Because of the significant load reduction and the low cost, BMP StL_18 is recommended for the lake after external loads are controlled in order to maximize the design life of the application.

11.8.19 Converted pond to infiltration basin in subwatershed 10-34-A, StL_19

BMP StL_19 is an existing stormwater pond converted to an infiltration basin in subwatershed 10-34-A adjacent to Purgatory Creek north of Highway 212, designed to treat 20.4 acres of impervious area. According to NRCS SSURGO data, the soils in this area are “B” soils, with a good capacity to infiltrate water. This infiltration basin is proposed to be approximately 0.7 acres at the surface. The infiltration basin could potentially remove 18.9 pounds of TP per year, in addition to what the existing stormwater pond is already removing. Based on the distance of the BMP in the watershed relative to Staring Lake, the estimated reduction of TP load to the lake is about 9.9 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $1,460 per pound of TP, assuming the BMP functions for 30 years. However, this area may have trouble infiltrating water because of the proximity to the creek and the elevation of the BMP, despite the “B” soils. Because of the presence of an existing stormwater pond in this location and the proximity to Purgatory Creek, BMP StL_19 may not be feasible.

11.8.20 Converted pond to infiltration basin in subwatershed 10-33-F, StL_20

BMP StL_20 is an existing stormwater pond converted to an infiltration basin in subwatershed 10-33-F adjacent to Purgatory Creek north of Highway 212, designed to treat 20.8 acres of impervious area. According to NRCS SSURGO data, the soils in this area are “B” soils, with a good capacity to infiltrate water. This infiltration basin is proposed to be approximately 1.5 acres at the surface. The infiltration basin could possibly remove 26.5 pounds of TP per year, in addition to what the existing stormwater pond is already removing. Based on the distance of the BMP in the watershed relative to Staring Lake, the estimated reduction of TP load to the lake is about 12.2 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $1,670 per pound of TP, assuming the BMP functions for

30 years. However, this area may have trouble infiltrating water because of the proximity to the creek and the elevation of the BMP, despite the "B" soils. Because of the presence of an existing stormwater pond in this location and the proximity to Purgatory Creek, BMP StL_20 may not be feasible.

11.8.21 Creek restoration and stabilization in subwatershed ValleyView, StL_21

BMP StL_21 is the restoration and stabilization of a 1,000-foot reach of a creek south of Covington Road in subwatershed ValleyView. This reach of the creek was identified in the CRAS report as a reach with an estimated severe erosion rate (Barr Engineering Co. & Riley Purgatory Bluff Creek Watershed District, November 2015). The purpose of this BMP is to reduce the soil erosion quantities which will also reduce the TP load from this watershed. The restoration and stabilization of this creek reach is expected to reduce TP loading from the creek by about 85 pounds per year. Due to natural deposition of sediment downstream of this reach, the estimated TP load reduction to the lake is about 17 pounds of TP per year. The cost-benefit of this BMP for Staring Lake is estimated to be about $1,410 per pound of TP, assuming the creek remains stable for 30 years.

11.8.22 Upstream lakes meet water quality and load goals, StL_22

BMP StL_22 assumes that the upstream lakes contributing to Staring Lake are meeting water quality and load goals through the implementation of BMPs. Recommended BMPs for each lake can be found in earlier sections of this report. If all upstream lakes meet water quality goals, the reduction in TP loading to Staring Lake would be 29 pounds of TP per year on average. The costs for each of the BMPs are shown in the previous chapters and in Appendix E.

11.8.23 Carp management in Staring Lake and the Recreation Area, StL_23

The last year of applied research in Staring Lake and the Recreation Area documented a reduction in the population of adult carp in the inter-connected system to less than 3,000 with a biomass below 100 kg/ha, which was proposed as the desired threshold in carp management (Sorensen et al., 2015). Staring Lake responded very well to carp removal and control by showing substantial increases in water clarity, plant cover and diversity as well as some apparent reduction in TP, TSS and chl-a since 2010. In addition to the 3000 adult carp present in Staring Lake, it was estimated that nearly 3000 juvenile carp are also now present in the lake with more in the Recreation Area. Winter seining was the most effective way to remove adult carp in Staring Lake but its efficacy decreased rapidly with effort, seemingly because the carp learned to avoid nets. While the carp are presently not a problem to the ecology of this system, it will be in few years as the young carp continue to grow and possibly reproduce. Future control effort could focus on preventing more juvenile carp from moving downstream from the Recreation Area to Staring Lake, preventing new spawning by controlling adult movement into the Recreation Area by using the existing barrier in Purgatory Creek and also removing adults (Sorensen et al., 2015).

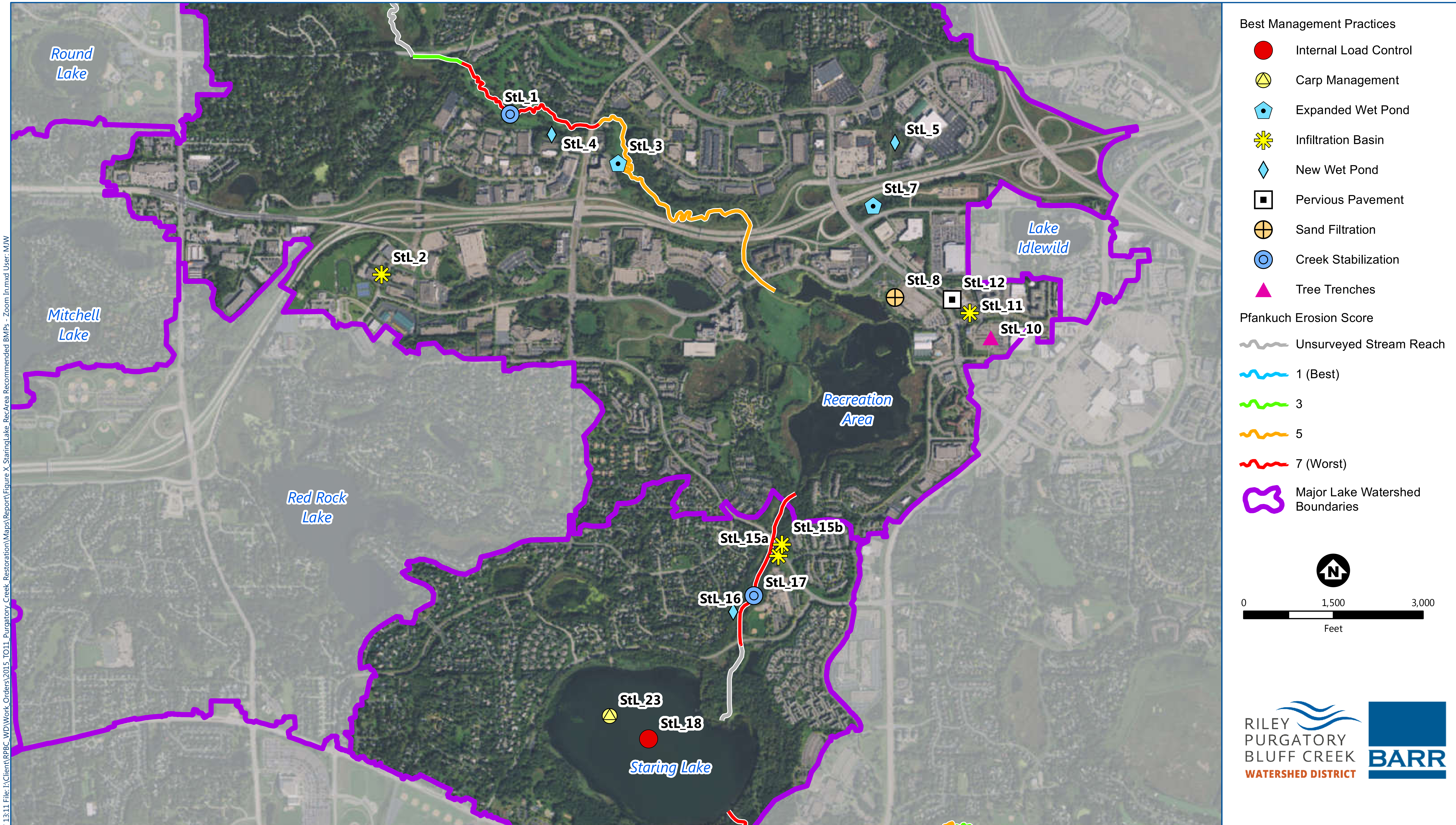
Control of recruitment and additional adult removal, even if modest, should be able to control carp (Sorensen et al., 2015). The survival of young carp and their spread to Staring Lake probably could be controlled using winter drawdowns. Removal of adult carp might be achieved by modifying barrier operation and perhaps seining. The following recommendations have been made to further improve carp management within the Staring Lake-Recreation Area system:

1. Control the production, survival and dispersal of young carp from the Recreation Area to Staring Lake
    a. Fill-in the deep winter refuge located by the lower Recreation Area inlet so that winter freeze-outs can occur more effectively
    b. Consider modifying the barrier with bubble or sound curtains or more screening so that it can reduce the outmigration of juvenile carp from the Recreation Area to Staring Lake
    c. Prevent adult carp from entering the Recreation Area to spawn by keeping the present physical barrier in place continuously, which may also kill all adults in the Recreation Area following a winter freeze
    d. Prevent young carp from recruiting in Staring Lake by installing an aeration system to prevent winter kill
2. Monitor and remove adult carp from Staring Lake
    a. Use telemetry-guided winter seining when biomass exceeds 100 kg/ha based on electrofishing surveys
    b. Use the existing barrier to remove adults by
        i. Letting the carp swim into the Recreation Area, close the barrier and control them with winter freeze-out
        ii. Removing them during spawning migration
3. Conduct annual boat electrofishing surveys to monitor the abundance of carp in Staring Lake
4. Conduct annual trapnet surveys in both Staring Lake and the lower Recreation Area to monitor carp recruitment: 5 small-mesh trapnets set overnight in August –September each year. The presence of carp less than 200 mm in size characterizes a recruitment event and emphasis should be placed on conducting effective freeze-outs in the Recreation Area during the following winter.
5. Use data and adaptive management to adjust strategies as needed

11.9 Recommendations for Water Quality Goal Attainment

The Staring Lake water quality modeling results call for an overall TP load reduction of 500 pounds of TP per year to reach the water quality goal (Section 11.5.3). It is recommended that the TP load reduction is split between watershed load reduction (200 lbs/yr) and internal load reduction (300 lbs/yr). The recommended BMPs for Staring Lake are listed below along with the percent of the overall load reduction goal that each individual BMP provides. The recommended BMPs are also shown in Figure 11.11. The TP reduction expected by the recommended watershed BMPs is approximately 205 pounds per year, and 735 pounds per year internally. Additionally, if the upstream lakes are able to meet the water quality and load goals, an additional reduction of 29 pounds per year can be achieved from upstream lakes. The summary below is intended to be a guide rather than a prioritization list. In general, it is recommended that an adaptive management approach be followed and that watershed BMPs be implemented prior to internal sediment phosphorus release reduction efforts in order to maximize the effectiveness and longevity of internal load controls. This is consistent with the district's "ONE WATER Watershed Management Approach" (Section 2.3.4 of (RPBCWD, 2011)).

- StL_1, creek restoration in subwatershed 09-42-B, ~10% of the total load reduction goal
- StL_2, new infiltration basin in subwatershed 09-43-A, ~2% of the total load reduction goal
- StL_3, expanded wet pond in subwatershed 10-33-E, ~1% of the total load reduction goal
- StL_4, new wet pond in subwatershed 09-44-A, ~1% of the total load reduction goal
- StL_5, new wet pond in subwatershed 10-44-A, ~4% of the total load reduction goal
- StL_7, expanded wet pond in subwatershed 11-33-C, ~2% of the total load reduction goal
- StL_8, filtration basins in subwatershed 15-14-B, ~2% of the total load reduction goal
- StL_10, stormwater planters and tree trenches in subwatershed 14-23-B, ~2% of the total load reduction goal
- StL_11, infiltration basins and tree trenches in subwatershed 14-23-A, ~7% of the total load reduction goal
- StL_12, pervious pavement in subwatershed 14-23-A, ~2% of the total load reduction goal
- StL_15a & StL_15b, new infiltration basins in subwatershed Staring, ~2% of the total load reduction goal
- StL_16, new wet pond in subwatershed Staring, ~1% of the total load reduction goal
- StL_17, creek restoration in subwatershed Staring, ~1% of the total load reduction goal
- StL_18, internal load control in Staring Lake, ~147% of the total load reduction goal
- StL_21, creek restoration in subwatershed ValleyView, ~3% of the total load reduction goal
- StL_22, upstream lakes meeting water quality and load goals, ~6% of the total load reduction goal
- StL_23, carp management in Staring Lake and the Recreation Area



RECOMMENDED BMPs, STARING LAKE WATERSHED WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 11.11

12.0Recommendations and Capital Improvement Planning

Through the review of past studies, water quality data, and the watershed and in-lake modeling performed for this study, several BMPs and streambank stabilization measures have been identified that will improve health of Purgatory Creek and the lakes within the Purgatory Creek Watershed. Structural and nonstructural types of remedial measures were assessed during this study, and all play a role in the improvement and protection of the water resources with the watershed. A summary of the water quality management recommendations for Purgatory Creek and the lakes are provided below.

- **Structural BMPs**
  - Reduce the volume of stormwater runoff to Purgatory Creek waterbodies, which will reduce the pollutants to Purgatory Creek and the lakes in the watershed, reduce erosion in streams related to high stream flows and velocities, and help Cities meet MPCA NPDES nondegradation requirements. Many of these types of projects can be implemented on a small or large scale and can be an integral part of the District's cost-share program. Additional discussion is provided in Section 12.1.
  - Implement streambank stabilization measures to reduce the sediment and phosphorus loads to downstream creek reaches and lakes.
  - Implementation of the recommended BMPs described in Section 12.2 through an adaptive management approach would significantly reduce the phosphorus loads to the lakes and allow time to evaluate the effectiveness of the measures implemented to ensure cost-effective use of District resources while striving to improve the overall water quality.
  - Continue to work with the cities, developers and other stakeholders to identify potential redevelopment (e.g., Eden Prairie Center) and road reconstruction projects that might provide the opportunity to retrofit additional BMPs into the watershed. Additionally, retrofits of iron-enhanced sand filtration benches to existing ponds should be pursued as opportunities arise.
- **Nonstructural Measures and Programs**
  - Continue routine monitoring of the creek and lakes. This would include the collection of water quality data, stream flow data, lake level data, and biological data (such as macroinvertebrates, fish, macrophytes, zooplankton, and phytoplankton).
  - Continue carp management within Staring Lake and the Purgatory Creek Park Area including operating the barrier at the PCPA and monitoring carp population.
  - Continued implementation of the RPBCWD stormwater management rules to help reduce runoff volume, minimize phosphorus load increase and degradation of water quality, and promote natural shoreline and streambank stabilization methods as future development/redevelopment occurs within the watershed.

- o Evaluate opportunities to work with stakeholders in the direct untreated watersheds riparian to the lakes. These efforts should focus on implementing stormwater BMPs on private parcels and educating about shoreline/vegetation management (if applicable). The RPBCWD could target the promotion of the cost-share program to residents in the watersheds riparian to Purgatory Creek and the lakes within the watershed.
- o Continue herbicide treatments to control curlyleaf pondweed.
- o Improving streambank and riparian vegetation throughout the stream system will improve the resistance of the stream to erosion.
- o Pursue alum treatment of the internal sediment loading for lakes experiencing high internal loads as part of an adaptive management approach to restore a balanced ecosystem.

12.1 Purgatory Creek Watershed-Wide Volume Reduction Project

An effective way to limit watershed pollutant loading, minimize damage due to high flows and velocities, and improve the health of the water resources is to reduce the amount of stormwater runoff. This would not only benefit Purgatory Creek and lakes but also the numerous wetlands upstream of these resources. This can be accomplished by increasing rainfall abstraction. Rainfall abstraction includes hydrologic processes such as evaporation, interception of rainfall by plants, transpiration, infiltration, and water storage in depression areas. The portion of rainfall that is not abstracted through these processes represents stormwater runoff. Several stormwater BMPs that increase rainfall abstraction, and therefore reduce runoff volume, are listed below:

- Rainwater Gardens (Infiltration basins)
- Permeable pavement
- Rainwater harvesting (rain barrels, underground storage)
- Vegetation Management (tree planting)

Runoff volume can also be reduced by minimizing the amount of impervious surface on the landscape, which allows for additional rainfall abstraction. Several impervious surface reduction techniques to minimize runoff are listed below:

- Conservation development design
- Street design (narrow driving lanes, reduce parking to one side of the street, create bump-outs that eliminate selected parking stalls where they are not required)
- Soil decompaction
- Cul-de-sac design
- Driveway design
- Parking lot design
- Alternative pavements
- Green Rooftops

12.2 Summary of BMP Cost-Benefit for whole watershed

The previous sections discussed the potential BMPs that were identified, modeled, and assessed based on performance and cost. The list of identified BMPs was reduced to a list of recommended BMPs which is provided in Table 12.1. The locations of each of the recommended BMPs are shown in Figure 12.1. The recommended BMPs are not prioritized in the table below, only listed in alpha-numeric order.

Table 12.1 - Summary of Recommended BMPs for all lakes, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
Lotus Lake LL_1	New Wet Pond *- A 0.6 acre, 3-foot deep wet pond designed to treat 4.0 acres of impervious area*	6.4	6.4	2%	$186,300 ($149,000 - $261,000)	$3,700 ($3,000 - $5,200)	$1,550 ($1,240 - $2,170)	$1,550 ($1,240 - $2,170)
Lotus Lake LL_3	Infiltration Basin *- A 1.6 acre, 1.7-foot deep infiltration basin designed to treat 20.9 acres of impervious area*	58.8	48.5	12%	$389,700 ($312,000 - $546,000)	$7,800 ($6,200 - $10,900)	$350 ($280 - $500)	$430 ($340 - $600)
Lotus Lake LL_6	Internal Load Control *- Two treatments of a whole lake alum treatment*	586	586	147%	$1,258,000 ($1,006,000 - $1,762,000)	$0	$70 ($60 - $100)	$70 ($60 - $100)
Lotus Lake LL_7	Iron Enhanced Sand Filter *- A 0.8 acre, 1.6-foot deep iron enhanced sand filter designed to treat 8.9 acres of impervious area.*	58.7	58.7	15%	$585,700 ($469,000 - $820,000)	$11,700 ($9,400 - $16,400)	$530 ($430 - $740)	$530 ($430 - $740)
Lotus Lake LL_8	New Wet Pond *- A 0.45 acre, 3-foot deep wet pond designed to treat 12.1 acres of impervious area*	8.7	6.7	2%	$142,400 ($114,000 - $199,000)	$2,800 ($2,300 - $4,000)	$870 ($690 - $1,210)	$1,130 ($900 - $1,580)
Lotus Lake LL_9	New Wet Pond *- A 0.9 acre, 4-foot deep wet pond designed to treat 4.2 acres of impervious area*	10	10	3%	$556,200 ($445,000 - $779,000)	$11,100 ($8,900 - $15,600)	$2,960 ($2,370 - $4,150)	$2,960 ($2,370 - $4,150)
Lotus Lake LL_3 & LL_7	Infiltration Basin and Iron Enhanced Sand Filter *- Combination of BMPs LL_3 and LL_7 as described above.*	73.1	73.5	18%	$975,400 ($780,000 - $1,366,000)	$19,500 ($15,600 - $27,300)	$710 ($570 - $1,000)	$710 ($570 - $990)
Silver Lake SiL_1	Underground Filtration *- Construct / retrofit a 0.6 acre, 1.5-foot deep underground sand filter designed to treat 6.0 acres of impervious area*	16.3	16.3	47%	$810,700 ($649,000 - $1,135,000)	$16,200 ($13,000 - $22,700)	$2,650 ($2,120 - $3,710)	$2,650 ($2,120 - $3,710)
Silver Lake SiL_2	Sand Filter *- A 0.4-acre area that treats road runoff before it runs down the slope to Silver Lake*	6.3	6.3	18%	$534,700 ($428,000 - $749,000)	$10,700 ($8,600 - $15,000)	$4,530 ($3,620 - $6,340)	$4,530 ($3,620 - $6,340)
Silver Lake SiL_3	Slope Stabilization *- Stabilization of an eroding slope*	16	10	29%	$86,000 ($43,000 - $172,000)	$1,700 ($900 - $3,400)	$290 ($140 - $570)	$460 ($230 - $910)
Silver Lake SiL_4	Slope Stabilization *- Stabilization of an eroding slope*	6	3	9%	$80,000 ($40,000 - $160,000)	$1,600 ($800 - $3,200)	$710 ($360 - $1,420)	$1,420 ($710 - $2,840)
Silver Lake SiL_5	Slope Stabilization *- Stabilization of an eroding slope*	6	4	11%	$80,000 ($40,000 - $160,000)	$1,600 ($800 - $3,200)	$710 ($360 - $1,420)	$1,070 ($530 - $2,130)
Silver Lake SiL_6	Slope Stabilization *- Stabilization of an eroding slope*	4	3	9%	$52,000 ($26,000 - $104,000)	$1,000 ($500 - $2,100)	$680 ($340 - $1,370)	$910 ($460 - $1,820)
Silver Lake SiL_7	Internal Load Control *- Two treatments of a sediment-phosphorus precipitant*	52	52	149%	$332,000 ($266,000 - $464,000)	$0	$210 ($170 - $300)	$210 ($170 - $300)
Duck Lake DL_3	Rainwater Gardens *- Six rainwater gardens totaling about 0.1 acres, designed to treat 4.5 acres of impervious around Prairie View Elementary School*	8.1	2.4	N/A	$213,400 ($171,000 - $299,000)	$4,300 ($3,400 - $6,000)	$1,410 ($1,130 - $1,970)	$4,760 ($3,800 - $6,660)
Round Lake RL_1	Infiltration Basin *- A 0.4 acre, 1-foot deep infiltration basin designed to treat 2.7 acres of impervious area*	6.8	6.8	N/A	$118,300 ($95,000 - $166,000)	$2,400 ($1,900 - $3,300)	$930 ($750 - $1,310)	$930 ($750 - $1,310)
Round Lake RL_2	Underground Infiltration Basin *- A buried 0.3-acre, 1.5-foot deep chamber intercepting storm sewer, designed to treat 10.9 acres of impervious area*	27.1	24.4	N/A	$245,300 ($196,000 - $343,000)	$4,900 ($3,900 - $6,900)	$480 ($390 - $680)	$540 ($430 - $750)
Round Lake RL_4	Infiltration Basin *- Convert the existing 1.4 acre pond to an infiltration basin, designed to treat 13 acres of impervious area*	20.6	20.6	N/A	$361,700 ($289,000 - $506,000)	$7,200 ($5,800 - $10,100)	$930 ($750 - $1,310)	$930 ($750 - $1,310)
Mitchell Lake ML_1	New Wet Pond *- A 0.9 acre, 3-foot deep wet pond designed to treat 23.2 acres of impervious area north of Duck Lake Trail*	29.5	7.5	13%	$132,900 ($106,000 - $186,000)	$2,700 ($2,100 - $3,700)	$240 ($190 - $340)	$950 ($760 - $1,330)
Mitchell Lake ML_2	Internal Load Control *- Two treatments of a whole lake alum treatment*	120	120	203%	$518,000 ($414,000 - $725,000)	$0	$140 ($120 - $200)	$140 ($120 - $200)
Mitchell Lake ML_3	Iron Enhanced Sand Filter *- A 0.3 acre iron enhanced sand filter designed to treat 14.6 acres of impervious area*	32.7	21.1	36%	$578,800 ($463,000 - $810,000)	$11,600 ($9,300 - $16,200)	$940 ($760 - $1,320)	$1,460 ($1,170 - $2,050)
Mitchell Lake ML_4	Underground Infiltration *- Infiltration vault under S Bay Curve, treating 4.4 acres of impervious area*	7.7	7.7	13%	$314,500 ($252,000 - $440,000)	$6,300 ($5,000 - $8,800)	$2,180 ($1,740 - $3,050)	$2,180 ($1,740 - $3,050)
Red Rock Lake RRL_1	New Wet Pond *- A 1.5 acre, 3-foot deep wet pond designed to treat 10.9 acres of impervious area*	22.7	9.5	N/A	$305,900 ($245,000 - $428,000)	$6,100 ($4,900 - $8,600)	$720 ($570 - $1,010)	$1,720 ($1,370 - $2,400)
Red Rock Lake RRL_2	Infiltration Basin *- A 0.15 acre, 1.5-foot deep infiltration basin designed to treat 0.9 acres of impervious area*	2	2	N/A	$89,700 ($72,000 - $126,000)	$1,800 ($1,400 - $2,500)	$2,400 ($1,920 - $3,350)	$2,400 ($1,920 - $3,350)
Red Rock Lake RRL_4	Sand Filter Trench *- A 2.5 acre, 1.5-foot deep iron enhanced sand filter designed to treat 6.5 acres of impervious area*	24.5	24.5	N/A	$979,800 ($784,000 - $1,372,000)	$19,600 ($15,700 - $27,400)	$2,130 ($1,710 - $2,990)	$2,130 ($1,710 - $2,990)
Red Rock Lake RRL_6	Expanded Wet Pond *- A 2.5 acre, 4-foot deep infiltration basin designed to treat 1.8 acres of impervious area*	2.9	2.9	N/A	$194,000 ($155,000 - $272,000)	$3,900 ($3,100 - $5,400)	$3,570 ($2,860 - $5,000)	$3,570 ($2,860 - $5,000)
Red Rock Lake RRL_7	Iron Enhanced Sand Filter Benches *- A 1.0 acre filter around an existing wet pond, designed to treat 12.3 acres of impervious area*	17.5	10	N/A	$440,500 ($352,000 - $617,000)	$8,800 ($7,000 - $12,300)	$1,340 ($1,070 - $1,880)	$2,350 ($1,880 - $3,290)
Red Rock Lake RRL_9	Assume Mitchell Lake meets load and quality goals	37	37	N/A	See Table 12.1 for the cost for Mitchell Lake BMPs			
Lake Idlewild LI_2a & LI_2b	Infiltration *- 0.5 acres of infiltration along Flying Cloud Drive and Eden Road (Town Center Report)*	20	20	N/A	$667,300 ($534,000 - $934,000)8	$13,300 ($10,700 - $18,700)	$1,780 ($1,420 - $2,490)	$1,780 ($1,420 - $2,490)
Lake Idlewild LI_4	Infiltration *- Underground infiltration and pervious pavement, treating 1.2 acres of impervious area (already approved, Hampton Inn permit)*	2.5	2.5	N/A	$0	$0	$0	$0
Staring Lake StL_1	Creek Restoration and Stabilization *- Restoration and stabilization of the 3,350-foot reach from the Golf Course to Mitchell Road*	260	52	10%	$1,173,000 ($586,500 - $2,346,000)	$23,500 ($11,700 - $46,900)	$240 ($120 - $480)	$1,200 ($600 - $2,410)

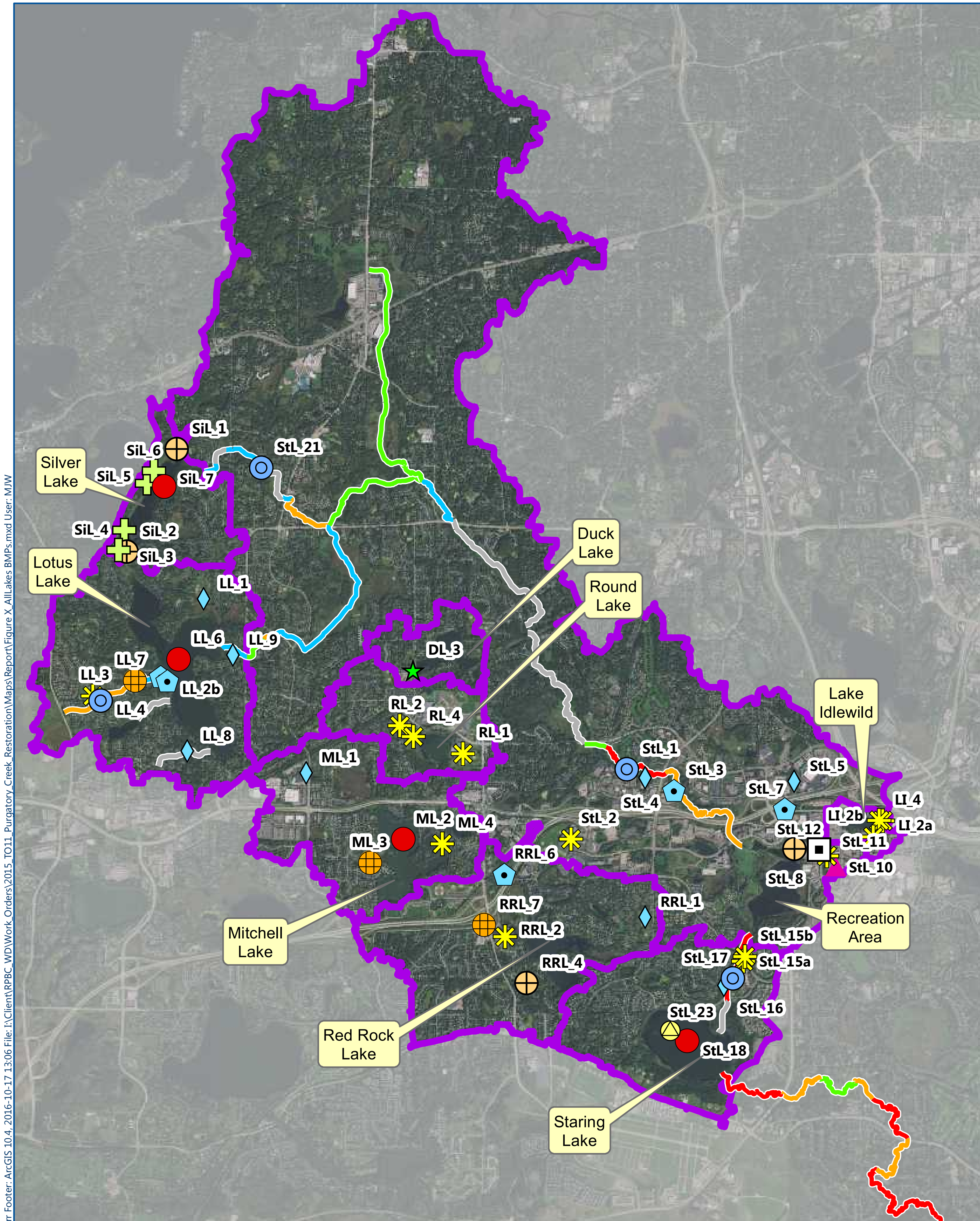
Table 12.1 - Summary of Recommended BMPs for all lakes, Resulting Load Reductions, and Cost Estimates

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - P Load Reduction to Lake (lbs/yr)[2]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound Removed at BMP ($/lb)[6]	Cost per Pound Removed at Lake ($/lb)[7]
Staring Lake StL_2	Infiltration Basin *- A 0.4 acre, 3-foot deep infiltration basin designed to treat 23.4 acres of impervious area*	48.6	8.9	2%	$253,000 ($202,000 - $354,000)	$5,100 ($4,000 - $7,100)	$280 ($220 - $390)	$1,520 ($1,220 - $2,130)
Staring Lake StL_3	Expanded Wet Pond *- A 1.0 acre, 6-foot deep wet pond designed to treat 11 acres of impervious area*	14.3	7.2	1%	$269,700 ($216,000 - $378,000)	$5,400 ($4,300 - $7,600)	$1,010 ($810 - $1,410)	$2,000 ($1,600 - $2,800)
Staring Lake StL_4	New Wet Pond *- A 0.5 acre, 6-foot deep wet pond designed to treat 10 acres of impervious area*	7.8	3.5	1%	$203,400 ($163,000 - $285,000)	$4,100 ($3,300 - $5,700)	$1,390 ($1,120 - $1,950)	$3,110 ($2,490 - $4,350)
Staring Lake StL_5	New Wet Pond *- A 5.0 acre, 3-foot deep wet pond designed to treat 60 acres of impervious area*	30.8	18.6	4%	$925,700 ($741,000 - $1,296,000)	$18,500 ($14,800 - $25,900)	$1,600 ($1,280 - $2,240)	$2,650 ($2,120 - $3,720)
Staring Lake StL_7	Expanded Wet Pond *- A 4.5 acre, 6-foot deep expanded wet pond designed to treat 26.5 acres of impervious area*	33.6	11.7	2%	$207,200 ($166,000 - $290,000)	$4,100 ($3,300 - $5,800)	$330 ($260 - $460)	$940 ($750 - $1,320)
Staring Lake StL_8	Filtration Basins *- Totalling 1.0 acre around the Anchor Bank and the Purgatory Creek Park Pavilion (Town Center Report)*	11.4	8.4	2%	$628,600 ($502,900 - $880,000)8	$12,600 ($10,100 - $17,600)	$2,940 ($2,350 - $4,120)	$3,990 ($3,200 - $5,590)
Staring Lake StL_10	Stormwater Planters and Tree Trenches *- Totalling 0.4 acre in the Walmart and Costco parking lots east of Prairie Center Dr. (Town Center Report)*	13.7	11.4	2%	$851,500 ($681,200 - $1,192,100)8	$17,000 ($13,600 - $23,800)	$3,310 ($2,650 - $4,640)	$3,980 ($3,180 - $5,570)
Staring Lake StL_11	Infiltration Basins and Tree Trenches *- Numerous infiltration basins and tree trenches (totalling 2.6 acres) around Prairie Center Dr. and Singletree Ln. (Town Center Report)*	41.9	37.2	7%	$5,099,800 ($4,080,000 - $7,140,000)8	$102,000 ($81,600 - $142,800)	$6,490 ($5,190 - $9,090)	$7,310 ($5,850 - $10,240)
Staring Lake StL_12	Pervious Pavement *- A 0.3 acre area in the Bachman's parking lot east of Prairie Center Dr. (Town Center Report)*	10.1	7.9	2%	$270,000 ($216,000 - $378,000)8	$5,400 ($4,300 - $7,600)	$1,430 ($1,140 - $2,000)	$1,820 ($1,460 - $2,550)
Staring Lake StL_15a & StL_15b	Infiltration Basins *- Two basins totalling 0.55 acres and 2 feet deep, designed to treat 11.0 acres of impervious area*	12.3	12.3	2%	$894,400 ($716,000 - $1,252,000)	$17,900 ($14,300 - $25,000)	$3,880 ($3,100 - $5,430)	$3,880 ($3,100 - $5,430)
Staring Lake StL_16	New Wet Pond *- A 0.8 acre, 3-foot deep wet pond designed to treat 4 acres of impervious area*	5.1	5.1	1%	$499,600 ($400,000 - $700,000)	$10,000 ($8,000 - $14,000)	$5,230 ($4,180 - $7,320)	$5,230 ($4,180 - $7,320)
Staring Lake StL_17	Creek Restoration and Stabilization *- Restoration and stabilization of the 1,000-foot reach between the Recreation Area and Staring Lake, behind Oak Point Elementary School*	20	20	4%	$550,000 ($275,000 - $1,100,000)	$11,000 ($5,500 - $22,000)	$1,470 ($730 - $2,930)	$1,470 ($730 - $2,930)
Staring Lake StL_18	Internal Load Control *- Two treatments of a whole lake alum treatment*	735	735	147%	$812,000 ($650,000 - $1,137,000)	$0	$40 ($30 - $50)	$40 ($30 - $50)
Staring Lake StL_21	Creek Restoration and Stabilization *- Restoration and stabilization of the 1,000-foot reach south of Covington Road*	85	17	3%	$450,000 ($225,000 - $900,000)	$9,000 ($4,500 - $18,000)	$280 ($140 - $560)	$1,410 ($710 - $2,820)
Staring Lake StL_22	Assume upstream lakes meet load and quality goals	29	29	6%	See Table 12.1 for the cost for each lake's BMPs			

BMP ID	BMP Type and Description	30-year - P Load Reduction at BMP (lbs/yr)[1]	30-year - Sediment Load Reduction at BMP (tons/yr)[9]	P Load Reduction to Lake as a Percentage of Goal (%)[3]	Planning Level Cost Estimate & Range[4]	Estimated Annual O&M Cost ($/yr)[5]	Cost per Pound P Removed at BMP ($/lb)[6]	Cost per Ton Sediment Removed at BMP ($/ton)[10]
PC_1	Creek Restoration and Stabilization *- Restoration and stabilization of 10 locations (725 feet) downstream of Pioneer Trail (Group 1)*	3.8	19.6	N/A	$265,000 ($133,000 - $531,000)	$5,300 ($2,700 - $10,600)	$3,720 ($1,860 - $7,440)	$720 ($360 - $1,440)
PC_2	Creek Restoration and Stabilization *- Restoration and stabilization of 6 locations (380 feet) downstream of Pioneer Trail (Group 2)*	7.2	36.6	N/A	$185,000 ($93,000 - $370,000)	$3,700 ($1,900 - $7,400)	$1,370 ($690 - $2,740)	$270 ($130 - $540)

Notes:

1. Estimated annual average phosphorus load reduction at the outlet of the BMP or downstream end of the creek reach
2. Estimated annual average phosphorus load reduction to the receiving lake, taking into account delivery ratios. Most BMPs are modeled in P8 as described in this report, others are estimated by erosion estimates (BWSR Pollution Reduction Estimator, Pfankuch erosion indices, and assumed 80% reduction with alum treatment).
3. Overall load reduction goal for all of the lakes is 995 pounds of phosphorus per year.
4. Planning level probable cost detailed in Appendix E; range is generally +40%/-20% but is dependent on the BMP
5. Planning level estimate of annual operation and maintenance costs rounded to nearest $100; 2% of the construction cost, except for internal load reduction where it is $0.
6. Cost per pound of phosphorus removed per year of operation at the outlet of the BMP, including both construction and O&M.
7. Cost per pound of phosphorus removed per year of operation to the receiving lake, including both construction and O&M.
8. Cost estimated by others in the Town Center Report (Wenck Associates, Inc., December 2014).
9. Estimated annual average sediment load reduction at the outlet of the BMP or downstream end of the creek reach
10. Cost per ton of sediment removed per year of operation at the outlet of the BMP, including both construction and O&M.



Structural and nonstructural types of remedial measures, along with recommendations for further study that were assessed/developed include:

- **Structural BMPs**
  - o Reduce the volume of stormwater runoff to Purgatory Creek waterbodies, which will reduce the pollutants to Purgatory Creek and the lakes in the watershed and reduce erosion in streams related to high stream flows and velocities.
  - o Implement streambank stabilization measures to reduce the sediment and phosphorus loads to downstream creek reaches and lakes.
  - o Implementation of the recommended BMPs described in Section 12.2 through an adaptive management approach would significantly reduce the phosphorus loads to the lakes.
  - o Continue to work with the cities, developers and other stakeholders to identify potential redevelopment (e.g., Eden Prairie Center) and road reconstruction projects that might provide the opportunity to retrofit additional BMPs into the watershed.
- **Nonstructural Measures and Programs**
  - o Continue routine monitoring of the creek and lakes.
  - o Continue carp management within Staring Lake and the Purgatory Creek Park Area including operating the barrier at the PCPA and monitoring carp population.
  - o Continued implementation of the RPBCWD stormwater management rules to help reduce runoff volume, minimize phosphorus load increase and degradation of water quality, and promote natural shoreline and streambank stabilization methods as future development/redevelopment occurs within the watershed.
  - o Evaluate opportunities to work with stakeholders in the direct untreated watersheds riparian to the lakes. The RPBCWD could target the promotion of the cost-share program to residents in the watersheds riparian to Purgatory Creek and the lakes within the watershed.
  - o Continue herbicide treatments to control curlyleaf pondweed.
  - o Improving streambank and riparian vegetation throughout the stream system will improve the resistance of the stream to erosion.
  - o Pursue alum treatment of the internal sediment loading for lakes experiencing high internal loads.
- **Recommendations for further study and adaptive management**
  - o Aquatic Vegetation Surveys and Lake Vegetation Management Planning
  - o Fish IBI Determinations and Shoreline Assessments
  - o Wild Rice Protection and Internal Load Control in Silver Lake
  - o Lower Purgatory Creek Monitoring
  - o Additional Assessment for Areas Upstream of Recreation Area

Major Lake Watershed Boundaries

Pfankuch Erosion Score

- Unsurveyed Stream Reach
- 1 (Best)
- 3
- 5
- 7 (Worst)

Best Management Practices

- Internal Load Control
- Carp Management
- Expanded Wet Pond
- Infiltration Basin
- Iron Enhanced Filter
- New Wet Pond
- Pervious Pavement
- Sand Filtration
- Slope Stabilization
- Creek Stabilization
- Stormwater Planter
- Tree Trenches

N

0 4,500 9,000
Feet

RILEY PURGATORY BLUFF CREEK WATERSHED DISTRICT

BARR

ALL RECOMMENDED BMPs WATER QUALITY MANAGEMENT STRATEGIES

FIGURE 12.1

12.3 Recommendations for further study and adaptive management

12.3.1 Aquatic Vegetation Surveys and Lake Vegetation Management Planning

While a recent study (Newman, 2014) indicated that further management of curlyleaf pondweed was not necessary, it is recommended that RPBCWD continue to complete surveys of aquatic plants every three to four years in each lake to assess how the coverage and density of various plant species have changed over time, with special emphasis on invasive species. It is further recommended that RPBCWD use the plant survey data to work with MnDNR on the development of Lake Vegetation Management Plans (LVMP) for each lake that will prescribe the actions that should be taken to control aquatic invasives and promote the diversity and growth of native plants.

MnDNR is currently developing an aquatic macrophyte integrity index for lake vegetation, similar to the FIBI scoring developed for fish. It is expected that future assessments and IBI scoring for lake vegetation could result in impairment listings for RPBCWD lakes. As a result, it is recommended that RPBCWD work with MnDNR to better understand, and possibly apply, the sampling and analysis protocols to future vegetation surveys. Data used in MnDNR's IBI development indicates that there is an inverse relationship between lake TP levels and floristic quality and aquatic plant richness (Radomski and Perleberg, 2012). This information could be used, along with IBI protocols, to further evaluate the RPBCWD goals for shallow lakes and wetlands.

12.3.2 Fish IBI Determinations and Shoreline Assessments

As discussed in Section 4.4.4, the MnDNR staff completed assessments of the fishery and lakeshore habitat of Lotus Lake in 2015. As a result of these assessments, Lotus Lake was placed on the 2016 draft list of impaired waters as not supporting for aquatic life based on a low fish IBI score. The analysis gave the shoreline habitat of Lotus Lake a score of 74 out of 100 which corresponds to an overall fair lakeshore condition. MnDNR has currently limited their selection of lakes for IBI analysis to Lake Classes 22-25 and 27-43 that are greater than 100 acres in surface area and do not experience winterkill.

It is recommended that RPBCWD work with the MnDNR to complete training and develop consistency in fish surveys and complete score the shore training and surveys of the other study lakes to assess how the fishery and lakeshore habitat changes over time. It is expected that aspects of the score the shore analysis may also be used to qualitatively evaluate the shoreline buffering capacity of the study lakes. It is expected that MnDNR staff will be developing Stressor Identification reports on the impaired lakes to examine the influence of watershed and shoreline disturbances on the fish IBI score. It is recommended that RPBCWD work with the MnDNR on the development of future Stressor Identification reports for lake impairments and the potential applicability of the IBI protocols to smaller lakes and/or other lake classes.

12.3.3 Wild Rice Protection and Internal Load Control in Silver Lake

As discussed in Section 4.4.3, the continued presence of wild rice in Silver Lake is a unique feature that warrants protection and/or enhancement. As a result, it is recommended that the following work activities be conducted to test current factors that affect continued growth of wild rice in Silver Lake and set a baseline for comparison with future sediment monitoring and efforts to control internal TP load to the lake:

- Survey and map the current extent and stem density of wild rice in each area of the lake and compare with MPCA's (2016) draft criteria for designation of wild rice waters
- Test the following sediment and water transparency conditions that the MPCA (2016) claims influence wild rice:
    - Measure sediment extractable iron and total organic carbon to determine an acceptable sulfate level. Test whether differences exist between MPCA derived sulfate values and measured surface water sulfate based on surface water and sediment results
    - Test whether surface water transparency exceeds the MPCA threshold of 30 cm based on Secchi depth measurements
    - Test whether other macrophytes are present, influence water transparency, and potentially compete for light.
- Test whether water depth, or rapid changes in water level, affects wild rice based on existing data and/or a proposed sampling plan
- Sample matching sediment cores from Silver Lake and analyze effects of various TP precipitants on TP release and sediment porewater sulfide levels in laboratory microcosm experiment.

12.3.4 Lower Purgatory Creek Monitoring

Follow-up monitoring should also be completed to both evaluate progress toward the water quality targets and to inform and guide implementation activities. For that reason it is recommended that RPBCWD establish a monitoring station to measure continuous turbidity and collect TSS samples near the mouth of the creek, likely at the Riverview Road crossing. This would enable direct comparison of the continuous turbidity measurements with the data that is currently being collected at the Pioneer Trail WOMP station and allow RPBCWD to evaluate water quality improvements associated with the implementation of projects in the lower valley area.

In addition to the water quality monitoring, RPBCWD staff have also been installing bank pins in eroding streambanks that will be monitored for relative amounts of erosion throughout the system. It is recommended that this information be combined with information regarding channel and flow characteristics and mapped to evaluate patterns and develop additional improvement options, as well as refinements to the sediment loading rates.

12.3.5 Additional Assessment for Areas Upstream of Recreation Area

Prior to implementation of streambank stabilization measures along Purgatory Creek, a feasibility study should be completed to identify watershed and streambank remedial measures for areas upstream of the Recreation Area. The feasibility study should assess the potential benefits of implementing additional watershed detention and volume reduction efforts to help mitigate the impacts of urbanization on the creek. The assessment could follow the outline of the Watershed Assessment of River Stability and Sediment Supply (WARSSS) and further define the Rosgen classifications for the various subreaches of Purgatory Creek. WARSSS considers the interactions of such land use changes as urban development, agriculture, grazing, etc. and their potential direct and indirect impacts to the sediment supply to a stream system.

13.0 References

American Society for Testing and Materials, 2006. *ASTM E2516-06 Standard Classification for Cost Estimate Classification System,* West Conshohocken, PA: ASTM International.

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Wenck Associates, Inc., 2014. *Mitchell Lake Aquatic Plant Management Plan,* Eden Prairie, MN: City of Eden Prairie and Riley-Purgatory-Bluff Creek Watershed District.

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Wenck Associates, Inc, 2014. *Duck and Red Rock Lake Watersheds Basin Inventory and Maintenance Assessment,* Eden Prairie, MN: CITY OF EDEN PRAIRIE.

Appendices

Appendix A

Annotated Bibliography

Appendix A: Annotated Bibliography of Past Studies

Bajer, P. G., Sorensen, P. (2014) Development and implementation of a sustainable strategy to control carp in Purgatory Creek chain of lakes. Final outline of Report. December 2, 2014. University of Minnesota.

An outline of activities to monitor and mitigate carp in the Purgatory Creek chain of lakes.

Barr Engineering. (1999). Round Lake Use and Attainability Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District

The Round Lake UAA includes diagnosis of observed problems and prescriptions for alternative remedial measures. The analysis is based upon historical water quality data, results of an intensive 1996 through 1997 lake and watershed runoff monitoring program, and runoff and in lake modeling calibrated to the 1996 and 1997 monitoring data. An evaluation of water quality data from 1972 to 1997 indicate a historical degradation of water quality and present poor conditions related to excessive inputs of runoff born phosphorus. Trend analysis of the monitored data indicate a significate degradation of the lake's water quality with Secchi depth decreasing from 3.2 meters to 1.5 meters, phosphorus concentration increasing from 0.05 to 0.07 mg/l and chlorophyll-a rising to 20 µg/l from 13 µg/l over the 25 year period. A phosphorus budget for Round Lake indicated that 55 percent of the lake's annual phosphorus load comes from inflow point RLP. The Round Lake direct watershed contributes 23 percent and atmospheric deposition contributes 7 percent. Macrophyte surveys performed in 1997 indicate that invasive species Curly-leaf pondweed and Eurasian water milfoil were present. Excess nutrients have caused an imbalance in the lake's ecosystem with algal blooms throughout the summer that is exacerbated by the lack of zooplankton population. A large Canadian geese population is also contributing the excessive phosphorus issue in addition to fecal coliform bacteria. Recommended management practices include upgrading treatment basin M, RLP, and RLE; add a basin to treat subwatershed RLNE; treat runoff entering pond RLD with alum; annual feeding of bluegills from June to Mid-September and annual stocking of northern pike; spring treatment of the lake's Curly-leaf pondweed with herbicide; and formulate a geese management plan with the University of Minnesota.

Barr Engineering. (2002). 2002 Round Lake Water Quality Monitoring Report. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

Summary of water quality monitoring and macrophyte surveys conducted on 2002. Water quality during 2002 was found to be worse than conditions observed in 2001. No changes in the macrophyte community were observed from 2001.

Barr Engineering. (2003). Silver Lake Use Attainability Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

The Silver Lake UAA included diagnosis of observed problems and prescriptions for protective measures to insure continued attainment of intended beneficial uses of Silver Lake. The analysis is based on the results of 1996 and 2000 lake water quality monitoring programs and models of watershed runoff. Evaluation of the 1996 and 2000 water quality data indicated that the lake's water quality is poor and has remained stable over the 4 year period. A phosphorus budget for Silver Lake indicated that on average 42 percent of the lakes phosphorus load comes from the direct watershed, 20 percent is from atmospheric depositions and 38 percent from internal loading. Plant surveys indicate a stable plant community with two invasive species present: Curly-leaf pondweed and purple loosestrife. The phytoplankton community was dominated by blue green algae in 1996 and 2000. The zooplankton community was dominated by small-bodies zooplankton limiting biological control of the phytoplankton community. The UAA recommended changing the lake water quality goals to a TSI_{sd} of 83 which would correspond to a Secchi disc measurement of 0.2. This goal was attainable with no action. Plant management recommendations included the introduction of predator beetles along the shore of Silver Lake to reduce the purple loosestrife coverage, and to treat the lake with a low dose fluridone to reduce the Curly-leaf pondweed.

Barr Engineering. (2005a). Duck Lake Use Attainability Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

The Duck Lake Use and Attainability Analysis included diagnosis of observed problems and prescriptions for alternative remediation measures. The analysis is based on historical water quality data, intensive lake water quality monitoring in year 2002, sediment sampling in 2003, evaluation of the application of BMPs, and modeled watershed runoff. No signification trends in water quality parameters (TP, Chl-a, and Secchi depth) were present from 1971 to 2002. The 2002 analysis indicated that the water quality in Duck Lake at the time was poor and impaired by invasive aquatic vegetation growth such as Curly-leaf pondweed and summer algal blooms that are very severe. Lake and watershed modeling determined that during an average year 63 percent of the phosphorus load to that lake came from internal loading, 31 percent from watershed loads and the reaming 6 percent from atmospheric deposition. The implementation plan selected for the UAA includes herbicide treatment (Endothall) for the Curly-leaf pondweed, alum treatment and rain garden construction for phosphorus reduction. Based on fish species present in Duck Lake a recommended goal change from TS_{lsd} of 54.5 to 57.7 for shallow lakes in the North Central Hardwood Forest Ecoregion was recommended. During June of 2002 the phytoplankton community was dominated by small bodied algae that are easily eaten by zooplankton. In July through September the small bodied algae were replaced by large bodies blue green algae that were inedible to the large bodied Cladocera. This prevented control of the algae community.

Barr Engineering. (2005b). Lotus Lake Use Attainability Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

The Lotus Lake UAA included diagnosis of observed problems and prescriptions for alternative remedial measures. The analysis is based upon historic water quality data, results of an intensive lake monitoring program in 1999, and in lake and watershed models. The overall water quality in the lake is poor and has been throughout the monitoring time frame (1972-2000). The poor water quality is caused by stormwater runoff and phosphorus release from the lakes sediments. Trend analysis over the period of record 1975-2000 indicated significant improvement in the lake's water quality. Despite the improvement the lake still fails to meet MPCA-criteria for full support of swimmable use. 93 years under the current water quality trend would be required to meet the lakes water quality goals of a TSI of 53 or lower. Under existing conditions internal loading of phosphorus is responsible for 50% (wet conditions) to 66% (dry conditions) of the total phosphorus load to the lake. Aquatic plant surveys indicate three invasive species in the lake: Curly-leaf pondweed, Eurasian water milfoil, and purple loosestrife. Management recommendations include using herbicide to manage Curly-leaf pondweed and Eurasian water milfoil, introduce beetles to control shoreline purple loosestrife, and conduct three consecutive years of alum treatment to follow the fourth year of herbicide treatment.

Barr Engineering. (2005c). Mitchell Lake Use Attainability Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

The Mitchell Lake UAA included diagnosis of observed problems and prescriptions for alternative remedial measures. The analysis is based upon historic water quality data, results of an intensive lake monitoring program in 1999, and in lake and watershed modeling. An evaluation of the historical water quality data in Mitchell Lake determined that the water quality has been poor and has remained poor over time. Trend analyses from 1972 to 1999 indicated that there have been no significant changes in water quality in Mitchell Lake. Over the same time period Mitchell Lake was able to meet the MNDNR criteria of a TSI score less than 62 in 6 of the 11 years monitored. Under existing conditions through modeling it was determined that 58 percent of the total phosphorus load to the lake is coming from watershed loading, while 29 percent is coming from internal loading and the remain 13 percent from atmospheric deposition. Plant surveys conducted in 1999 indicate the presence of three invasive plant species: Curly-leaf pondweed, Eurasian water milfoil, and purple loosestrife. Curly-leaf pondweed density is determined by water clarity. When water clarity is good Curly-leaf pondweed density increases. Implementation recommendations included herbicide treatment for Curly-leaf pondweed and Eurasian Water milfoil for four years followed by six years of alum treatments, and the introduction of beetles in purple loosestrife infested areas to control shoreline populations. All three population of zooplankton are well represented in Mitchell Lake. Declining presence of grazer in July and August correspond with an increase in blue green algae through October.

Barr Engineering. (2005d). Purgatory Creek Use Attainability Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

An inventory of plant communities and a bird habitat evaluation along the Purgatory Creek riparian corridor was conducted in 2003. Bird habitat within the corridor is fragmented. Recommendations for managing the corridor include: prioritizing sites based on ecological quality, control invasive species particularly reed canary grass, buckthorn, garlic mustard, and purple loosestrife, maintain restored areas, control deer, control erosion, maintaining corridor width, reduce the impact of impervious surfaces, educate corridor constituents to garner support for restoration efforts. A physical evaluation of the creek showed signs of significant degradation in reaches P-6 and P-7 which should be monitored in the future for further degradation. Recommendations for watershed improvement include introduction of extended detention basin and rainwater gardens, channel improvements such as bank protection measures grade control and improving adjacent vegetation.

Barr Engineering. (2006a). Red Rock Lake Use Attainability Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

The Red Rock Lake UAA included diagnosis of observed problems and prescriptions for alternative remedial measures. The analysis is based upon historical water quality data, results of an intensive lake monitoring program in 1999, sediment sampling in 2003 and 2005, evaluations of the applications of BMPs for the watershed and lake and watershed runoff models. Evaluation of the lake water quality data from 1972 to 1999 indicate that the lake's water quality is poor and has remained poor over time. The water quality is perpetuated by the presence of invasive aquatic vegetation such as Curly-leaf pondweed, phosphorus release from the sediments, inputs of storm water runoff that is high in phosphorus, and inputs from Mitchell Lake which is of poor quality. Historical trends in TP, Chl-a, and Secchi depth indication no signification trends between 1972 and 1999. During an average year watershed loading represents 44% of the total phosphorus load tot Red Rock Lake, with 30% coming from internal loading, 13 percent from Mitchell Lake and the remaining 13% from atmospheric deposition. The selected implementation plan for Red Rock Lake includes herbicide treatment for the Curly-leaf pondweed for four years followed by four years of alum treatment. Beetles will also be introduced to manage the purple loosestrife infested areas along the shoreline. An aeration system was installed in Red Rock Lake in 1991 and was operational through the publication of this report

Barr Engineering. (2006b). Engineer's Report Round Lake Water Quality Improvement Project. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

This report Summarizes proposed actions for the improvement of water quality in Round Lake as a continuation of the Round Lake UAA. Improvements include a new runoff detention pond in subwatershed RLNE (north east area) constructed to satisfy NURP standards; expand dead storage in ponds M, RLE, RLP to meet NURP standards; an in lake alum treatment; construction of a fishing pier; and up to 4 years of Endothall treatment to control the Curly-leaf pondweed population.

Barr Engineering. (2014a). Operations and Maintenance Plan for the Purgatory Creek Conservation Area. Eden Prairie, MN: City of Eden Prairie and Riley-Purgatory-Bluff Creek Watershed District.

On December 6, 1995, the Minnesota Department of Natural Resources (DNR) issued a Protected Waters Permit (Permit) jointly to the City of Eden Prairie (City) and the Riley Purgatory Bluff Creek Watershed District (District) authorizing construction of an outlet control structure for the Purgatory Creek Conservation Area (PCCA). The outlet was to be located in the proximity of an existing creek crossing used by the adjacent property owner, Northrup King, and was designed to replicate the hydraulic capacity of the 60-inch steel culvert that it replaced. This plan was created to meet the permit requirements. The plan objectives included maintaining flood storage capacity in the PCCA's upper pool while maintaining water level fluctuation of the lower pool, manage fisheries to reduce invasive common carp and improve native fisheries, provide desirable habitat for a variety of wildlife species while controlling muskrat and beaver activity, maintain diversity of submerged aquatic and emergent vegetation, manage small trees and maintain existing park amenities.

Barr Engineering (2014b).Engineering's Report: Purgatory Creek Stabilization at County Roads 101 and 62. Prepared for Riley-Purgatory-Bluff Creek Watershed District. Eden Prairie, MN

This report summarizes the proposed actions for the stabilization of Purgatory Creek at County Roads (CR2) 101 and 62 in Minnetonka, Minnesota. Erosion was documented along a 2000 ft. reach of Purgatory Creek near the intersection of CR101 and CR62. Recommendation included a combination of soft armoring and vegetation at most sites. At tall or steep sites recommendations included bioengineering with riprap toe protection. These recommendations are needed to improve water quality and overall stream and riparian health.

Blue Water Science. (2005a). Aquatic Plant Survey for Mitchell Lake Eden Prairie, Minnesota in 2004. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant surveys were conducted on Mitchell Lake (112 acres) in 2004. The aquatic plant community had seven species of submerged plants in early summer and nine species in late summer. This was a moderate plant diversity condition. Curly-leaf pondweed covered 102 acres in early summer but its density was generally low. No significant nuisance growth of Eurasian water milfoil was observed, although the shallow areas had abundant aquatic plant growth which was composed of water lilies, coontail, and filamentous algae.

Blue Water Science. (2005b). Aquatic plant survey for Red Rock Lake, Eden Prairie, Minnesota in 2004. Eden Prairie, MN: City of Eden Prairie.

Summary of two aquatic plant surveys conducted in Red Rock Lake in 2004. The aquatic plant community had six species of submerged plants in early summer and eight species in late summer. This was a moderate plant diversity condition. Curly-leaf pondweed was the only exotic plant found.

Blue Water Science. (2005c). Aquatic Plant Surveys for Duck Lake, Eden Prairie, Minnesota in 2004. Eden Prairie, MN: City of Eden Prairie.

Details two aquatic plant surveys conducted on Duck Lake in 2004. The aquatic plant community had four species of submerged plants in early summer and seven species in late summer resulting in a modest plant diversity condition. Curly-leaf pondweed was the only exotic plant present. Curly-leaf pondweed grew sparsely and did not require management. No Eurasian water milfoil was found.

Blue Water Science. (2005d). Aquatic Plant Surveys for Staring Lake, Eden Prairie, Minnesota in 2004. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant surveys were conducted on Staring Lake (155 acres) in 2004. The aquatic plant community had three species of submerged plants and two species of floating leaf plants in early summer. In late summer no species of submerged plants were observed while the same two species of floating leaf plants were present. This was a low plant diversity condition. In early summer, Curly-leaf pondweed covered 57 acres and then died back. In late summer, floating leaf aquatic plants covered about 12 acres and grew out to about 3 feet of water depth. Low Secchi depths along with carp and bullhead fish populations could have limited plant growth.

Blue Water Science. (2005e). Updated Lake Management Plan for Round Lake, Eden Prairie, Minnesota. Eden Prairie, MN: City of Eden Prairie.

The July and August total phosphorus lake concentration average in 2005 was 34 ppb. The nutrient input into Round Lake in 2005 was estimated at approximately 26 kilograms or 57 pounds of phosphorus per year. This is a lower amount of phosphorus than what was found in 1997 when the lake phosphorus concentration was at 60 ppb and the estimated phosphorus load was 132 pounds per year. New projects include checking for fish in two stormwater ponds and if fish density is low install barley straw, maintain shoreline vegetation buffers, use organic carbon amendment, maintain aquatic plant base, manage invasive plants using mechanical harvesting, control goose population, and continue water quality monitoring.

Blue Water Science. (2006). Summary of Round Lake Management Activities for 2006. Eden Prairie, MN: City of Eden Prairie.

Water quality data from 2006 shows that Round Lake continued to meet water quality goals for Secchi depth, total phosphorus and chlorophyll-a. E. coli levels were below the swimming beach criteria for the summer months. Pond data showed that Bren Lane Pond and RLP Pond had elevated phosphorus concentrations and Park Pond had good water quality. Watershed projects for the year 2006 included: use of barley straw in Bren Lane and RLP stormwater ponds which did not appear to significantly reduce phosphorus concentrations in the ponds. To help reduce phosphorus concentrations in the two ponds fish removal was recommended for 2007. Aquatic plant cover for 2006 was 64% with coontail as the dominant aquatic plant. Eurasian water milfoil is widespread but not to nuisance conditions. In 2006, 21 geese were removed from Round Lake Park as part of goose control.

Blue Water Science. (2008a). Aquatic Plant Surveys for Round Lake, Eden Prairie, Minnesota in 2008. Eden Prairie, MN: City of Eden Prairie.

Two plant surveys were taken in Round Lake in 2008, one on May 28th and the other on August 25th. Three submerged plant species were found in early summer and two in lake summer. Curly-leaf pondweed was found but it grew sparsely and did not require control at the time. Eurasian water milfoil was also found to grow to the surface in patches with some heavy growth conditions.

Blue Water Science. (2008b). Aquatic Plant Surveys, Water Quality Data, and Zooplankton Monitoring for Mitchell Lake, Eden Prairie, Minnesota in 2007. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant surveys were conducted on Mitchell Lake (112 acres) in 2007. The aquatic plant community had five species of submerged plants in early summer and seven species in late summer.

This was a moderate plant diversity condition. Curly-leaf pondweed covered 102 acres in early summer but density was generally low. No significant nuisance growth of Eurasian water milfoil was observed, although the shallow areas had abundant aquatic plant growth which was composed of water lilies, coontail, and filamentous algae. Zooplankton numbers indicated that the fish community was not severely impacted by the winterkill primarily because the copepod to cladoceran ratio was high for most of the summer. Big daphnia were present in May but their numbers declined after that. Water clarity was good in May, and declined as the summer went on. Although water quality started out in the summer with high clarity, by July it had declined to eutrophic conditions. It did not appear the winter fish kill had a beneficial impact on water quality in 2007.

Blue Water Science. (2008c). Lake Monitoring Results for Duck, Red Rock, Round, and Staring Lakes 2008. Eden Prairie, MN: City of Eden Prairie.

This report describes water quality monitoring results for Duck, Red Rock, Round and Staring lakes for the summer of 2008. Water clarity was poor to moderate for all four lakes. All lakes had periods of clarity but periodic algae blooms. Round Lake had the lowest summer average total phosphorus concentration while Duck Lake had the highest. Round Lake had the lowest summer average chlorophyll a concentration while Staring Lake had the highest. The water quality grade for Duck Lake was D+, Red Rock Lake was a C, Round Lake was a B, and Staring Lake was a D-.

Blue Water Science. (2008d). Summary of Round Lake Management Activities for 2007. Eden Prairie, MN: City of Eden Prairie.

This report summarizes water quality data and watershed projects for year 2007 in Round Lake and 3 stormwater ponds contributing to Round Lake. Seasonal results show that the lake continued to meet water quality goals. E. coli levels were below US EPA swimming beach criteria for the summer months. All three ponds had elevated phosphorus concentrations although Park Pond had low chlorophyll concentration. The installation of barley straw into the two stormwater ponds did not appear to significantly reduce phosphorus concentrations in the ponds. The status of aquatic plants in Round Lake is good. Coontail is the dominant aquatic plant. Eurasian water milfoil was widespread but did not grow to nuisance conditions.

Blue Water Science. (2010a). Aquatic plant survey for Red Rock Lake, Eden Prairie, Minnesota in 2009. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant surveys were conducted on Red Rock Lake (71 acres) in 2009. The aquatic plant community had six species of submerged plants in early summer and eight species in late summer. This was a moderate plant diversity condition. Curly-leaf pondweed was the only exotic plant found. Water lilies, including the rare lotus, were abundant in the east side of Red Rock Lake. Coontail was abundant in the north end of Red Rock Lake.

Blue Water Science. (2010b). Aquatic Plant Surveys for Duck Lake, Eden Prairie, Minnesota in 2009. Eden Prairie, MN: City of Eden Prairie.

Details two aquatic plant surveys conducted on Duck Lake in 2009. The aquatic plant community in 2009 had six species of submerged plants in early summer and four species in late summer. This was a modest plant diversity condition. Curly-leaf pondweed was the only non-native plant present.

Blue Water Science. (2010c). Aquatic Plant Surveys for Round Lake, Eden Prairie, Minnesota in 2009. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant surveys were conducted on Round Lake (31 acres at normal water levels) in the summer of 2009. The aquatic plant community has two species of submerged plants in early summer and three species in late summer. This was a low plant diversity condition. Eurasian water milfoil was the only non-native plant found in Round Lake in 2009. Eurasian water milfoil was first observed in Round Lake in 1995.

Blue Water Science. (2010d). Lake Monitoring Results for Purgatory Creek Pond and Purgatory Creek, Eden Prairie, Minnesota in 2010. Eden Prairie, MN: City of Eden Prairie.

The report summarized the results for water quality monitoring in Purgatory Creek pond and lower Purgatory Creek.

Blue Water Science. (2010e). Aquatic Plant Surveys for Staring Lake, Eden Prairie, Minnesota in 2009. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant surveys were conducted on Staring Lake (155 acres) in 2009. The aquatic plant community had three species of submerged plants and two species of floating leaf plants in early summer in 2009. In late summer two species of submerged plants were observed while the same two species of water lilies were present. This was a low plant diversity condition. In early summer, Curly-leaf pondweed covered less than an acre and then died back. In late summer, water lilies covered about 12 acres and grew out to about 3 feet of water depth.

Blue Water Science. (2010f). Lake Monitoring Results for Duck, Red Rock, Round, and Staring Lakes 2009. Eden Prairie, MN: City of Eden Prairie.

Duck, Red Rock, Round and Staring Lakes were monitored in year 2009. Secchi disc transparency was poor to moderate with periodic algae blooms. Round lake had the lowest summer average TP concentration while Staring Lake had the highest. Round and Duck Lakes had the lowest summer average chlorophyll a concentration while Staring had the highest. Overall grades for the lakes were a C for Duck Lake, C- for Red Rock Lake, C+ for Round Lake, and D- for Staring Lake.

Blue Water Science. (2011a). Aquatic Plant Surveys for Round Lake and Water Quality for Three Round Lake Tributary Ponds, Eden Prairie, Minnesota in 2010. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant surveys were conducted on Round Lake (31 acres at normal water levels) in the summer of 2010. The aquatic plant community had two species of submerged plants in early and late summer. This was a relatively low plant diversity condition. Eurasian water milfoil was first observed in Round Lake in 1995 and was widespread in 2010. On July 9, 2010, brittle naiad, another non-native aquatic plant was found just north of the public access. Curly-leaf pondweed had previously been found in Round Lake, but was not observed in 2010. Water quality data for three Round Lake ponds in 2010 tributary to Round Lake are summarized. Round Lake Pond was dredged and expanded and refilled with water in 2010. It had slightly elevated phosphorus concentrations whereas Bren Lane Pond and Park Pond had acceptable phosphorus concentrations for stormwater ponds.

Blue Water Science. (2011b). Lake Data Summary for Red Rock Lake, Eden Prairie, Minnesota, 2010. Eden Prairie, MN: City of Eden Prairie.

This report includes water quality monitoring results for the summer of 2010 and results from aquatic plant surveys conducted in 2004 and 2009 in Red Rock Lake. The overall water quality grade for Red Rock Lake was a C. Red Rock Lake had large shallow area to the north that supported plant growth including the rare lotus lily. Clarity was generally good, but algae blooms in August decreased clarity. Six plant species were present in the early summer and eight in the late summer with Curly-leaf pond weed as the only invasive species. In both 2009 and 2004 coontail and duckweed were the most dominate plant species with coontail being more abundant in 2009.

Blue Water Science. (2012a). Lake and Pond Monitoring Results for Eden Prairie, Minnesota 2012. Eden Prairie, MN: City of Eden Prairie.

Results shown from water quality sampling of TP, Secchi depth, and Chl-a in six lakes including Duck, Red Rock, Round, Mitchell, and Staring Lake from May through September in year 2012.

Blue Water Science. (2012b). Water Quality and Aquatic Plant Surveys for Mitchell Lake, Eden Prairie, Minnesota, 2011. Eden Prairie, MN: City of Eden Prairie.

Mitchell Lake (112 acres) was monitored 10 times between mid-May through September, 2011. The overall lake quality grade for Mitchell Lake, determined from the three individual grades, was C+. Two aquatic plant surveys were conducted on Mitchell Lake (112 acres) in 2011. The aquatic plant community had as little as five species of submerged plants in early summer and as high as ten species in late summer. This was a moderate plant diversity condition. Curly-leaf pondweed covered 12 acres in early summer but its density was generally low. No Eurasian water milfoil was observed, although the shallow areas had abundant aquatic plant growth which was composed of water lilies, coontail, and filamentous algae.

Blue Water Science. (2012c). Water Quality and Aquatic Plant Surveys for Purgatory Creek Wetland Complex, Eden Prairie, Minnesota, 2011. Eden Prairie, MN: City of Eden Prairie.

This report includes a summary of monitoring conducted on Purgatory Creek complex, both the wetland and stormwater pond, in the summer of 2011 in addition to two aquatic plant surveys. The overall lake quality grade for the Purgatory Creek Wetland and stormwater pond were determined to be a C and C- respectively. Aquatic plant surveys found coontail as the dominate species during both the early and late summer surveys. Curly-leaf pondweed was found in the Purgatory Creek wetland, but no Eurasian water milfoil. During the late summer survey the no native plant brittle naiad was found in both the wetland and the stormwater pond.

Blue Water Science. (2012d). Water Quality and Aquatic Plant Surveys for Staring Lake, Eden Prairie, Minnesota in 2011. Eden Prairie, MN: City of Eden Prairie.

Staring Lake (155 acres) was monitored 6 times between mid-May through September, 2011. The overall lake quality grade for Staring Lake was D. Two aquatic plant surveys were conducted on Staring Lake in 2011. In the early summer of 2011, the aquatic plant community had five species of submerged plants and two species of floating leaf plants. In late summer two species of submerged plants were observed while the same two species of water lilies were present. This is a low plant diversity condition. In early summer, Curly-leaf pondweed covered less than an acre and then died back. In late summer, water lilies covered about 12 acres and grew out to about 3 feet of water depth.

Blue Water Science. (2013a). Aquatic Invasive Species Suitability Assessment For Mitchell Lake, Eden Prairie Minnesota. Eden Prairie, MN: City of Eden Prairie.

As of 2012, Curly-leaf pondweed, Eurasian water milfoil, purple loosestrife, and possibly common carp were the only non-native species known to be present in Mitchell Lake.

Blue Water Science. (2013b). Aquatic Invasive Species Suitability Assessment for Red Rock Lake, Eden Prairie Minnesota. Eden Prairie, MN: City of Eden Prairie.

Summary of the aquatic invasive species assessment conducted in Red Rock Lake in year 2012. As of 2012, Curly-leaf pondweed and possibly common carp were the only non-native species known to be present in Red Rock Lake. Common carp may be present in Red Rock Lake, but at a low density. Curly-leaf pondweed is present in Red Rock Lake.

Blue Water Science. (2013c). Aquatic Invasive Species Suitability Assessment for Round Lake, Eden Prairie, Minnesota. Eden Prairie, MN: City of Eden Prairie.

As of 2012, Curly-leaf pondweed, Eurasian water milfoil, Chinese Mystery snail, and brittle naiad were the only non-native species known to be present in Round Lake. Eurasian water milfoil was present in Round Lake and ongoing annual scouting activities were recommended with control to be considered in areas of heavy growth. Curly-leaf pondweed is present in Round Lake and occasionally Curlyleaf management may be needed.

Blue Water Science. (2013d). Aquatic Invasive Species Suitability Assessment For Staring Lake, Eden Prairie, Minnesota. Eden Prairie, MN: City of Eden Prairie.

As of 2012, Curly-leaf pondweed, the common carp, and purple loosestrife were the only non-native species known to be present in Staring Lake. Curly-leaf pondweed was already established in Staring

Lake and past the point of eradication. Ongoing activities will concentrate on management including possible herbicide treatments. Carp were present at high densities in Staring Lake. High carp abundance typically decreases water clarity and decreases aquatic plant coverage. At the time, carp management was ongoing.

Blue Water Science. (2013e). Aquatic Plant Surveys for Duck Lake, Eden Prairie, Minnesota in 2013. Eden Prairie, MN: City of Eden Prairie.

Details two aquatic plant surveys conducted on Duck Lake in 2012. The aquatic plant community in 2012 had six species of submerged plants in early summer and four species in late summer. This was a modest plant diversity condition. Curly-leaf pondweed was the only non-native plant present.

Blue Water Science. (2014a). Aquatic Plant Surveys and Water Quality for Round Lake and Key Tributary Pond, Eden Prairie, 2014. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant point-intercept surveys were conducted on Round Lake (31 acres at normal water levels) in the summer of 2014. The aquatic plant community had 6 species of submerged plants in early season and 8 species in late summer surveys. This was a moderate plant diversity condition for urban lakes. Eurasian water milfoil was found growing at low to moderate densities in 2014. On July 24, 2014, brittle naiad was again observed in Round Lake at 9 sample sites. In general, Round Lake had good water quality but it fluctuated from year to year. Phosphorus concentrations were moderate to high in the RLP Pond in 2014.

Blue Water Science. (2014b). Aquatic Plant Surveys and Water Quality for Round Lake and Two Tributary Ponds, Eden Prairie, 2013. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant point-intercept surveys were conducted on Round Lake (31 acres at normal water levels) in the summer of 2013. The aquatic plant community had four species of submerged plants in early season and four species in late summer. This was a relatively low plant diversity condition. Eurasian water milfoil was found growing at low densities. Brittle naiad was observed in Round Lake at two sample sites. Water quality values were reported for Round Lake at two tributary ponds: Round Pond NE and Round Pond NW.

Blue Water Science. (2014c). Lake and Pond Monitoring Results for Eden Prairie, Minnesota 2014. Eden Prairie, MN: City of Eden Prairie.

This report shows results from water quality sampling of four lakes including Duck, Round, Mitchell, and Idlewild from May through September in year 2014. The combined water quality grade of Duck Lake was a B, the combined grade of Idlewild Lake was a B, the combined grade of Mitchell Lake was a B, and the combined grade of Round Lake was a B.

Blue Water Science. (2014d). Water Quality and Aquatic Plant Surveys for Mitchell Lake, Eden Prairie, Minnesota, 2013. Eden Prairie, MN: City of Eden Prairie.

Two aquatic plant surveys were conducted on Mitchell Lake (112 acres) in 2013. The aquatic plant community had as few as five species of submerged plants in early summer and as many as eleven species in late summer. This was a moderate plant diversity condition. Curly-leaf pondweed covered up to 55 acres in early summer and its density ranged from light growth to some areas of heavy growth. Eurasian watermilfoil was observed in the late season surveys but coontail typically was the dominant plant. Mitchell Lake (112 acres) was monitored 10 times between mid-May through September, 2013. The overall lake quality grade for Mitchell Lake, determined from the three individual grades, was C+.

Blue Water Science. (2015a). Aquatic plant survey for Idlewild Lake, Eden Prairie, Minnesota in 2014. Eden Prairie, MN: City of Eden Prairie.

Details two aquatic plant surveys conducted on Idelwild Lake in 2014. The aquatic plant community in 2014 had 2 species of submerged plants in early summer and 3 species in late summer. This was a low plant diversity condition. No non-native submerged aquatic plants were found in 2014.

***Blue Water Science. (2015b). Aquatic Plant Surveys for Purgatory Creek Recreational Area, Eden Prairie, Minnesota 2014. Eden Prairie, MN: City of Eden Prairie*.**

Summary of two aquatic plant surveys conducted within the Purgatory Creek Recreation Area encompassing both the stormwater pond and the wetland in the summer of 2014. Sago pondweed was found throughout the wetland with light growth. In the stormwater pond coontail was dominant. The non-native species brittle naiad was not found in the early summer but was the most common aquatic plant with almost 100% coverage in the later summer survey of the wetland. Coontail was also more abundant in the late summer while sago pondweed decreased substantially in the late summer.

Blue Water Science. (2015c). Curlyleaf pondweed delineation and assessment for Red Rock Lake, Eden Prairie, Minnesota, 2014. Eden Prairie, MN: City of Eden Prairie.

A Curly-leaf pondweed and coontail delineation and assessment program was conducted on Red Rock Lake (71 acres) in the summer of 2014. The first survey on June 3 showed curlyleaf as widespread with potential for moderate to high growth. Harvesting occurred on June 17th with a total of 15 acres of pondweed, coontail and filamentous algae removed. A June 30th survey showed coontail and Curly-leaf plant growth as light to moderate. The same techniques were recommended for 2015.

Blue Water Science. (2015d). Curlyleaf Pondweed Delineation and Assessment Surveys for Mitchell Lake, City of Eden Prairie, 2014. Eden Prairie, MN: City of Eden Prairie.

Blue Water Science. (2015e). Purgatory Creek Wetland Water Quality Monitoring Results for Eden Prairie Minnesota 2013 and 2014. Eden Prairie, MN: City of Eden Prairie.

Summary of water quality results at the Purgatory Creek wetland inlet and outlet in 2013 and 2014. Samples were taken twice a month from May through October.

Blue Water Science (2015f) ***Alum Application Assessment for Round Lake, Eden Prairie, Minnesota***

Details the water quality improvements of a alum treatment in Round Lake in November of 2012. After the treatment modest surface water TP concentrations improvements were observed, but large reductions in hypolimnion TP concentrations were observed.

CH2MHILL. (2008). Lotus Lake Hydrologic and Hydraulic Model Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

A SWMM5 model was created for Lotus Lake to determine the cause of large fluctuations in water levels in the lake. The model determined that blockage of the outlet pipe may have been the cause of large water elevation fluctuation during storm events. The report recommends that debris management be taken into consideration when alternative outlet configurations are discussed.

CH2MHILL. (2009a). Dredging Plan for Round Lake Water Quality Improvement Project.

This report documents the findings from stormwater pond sediment sampling and the procedures to be utilized to manage dredging sediments from ponds M, RLE and RLP in the Round Lake watershed. The sediments were classified as organic silty sand and organic clay with sand. Results indicated that for all soil samples, both metals and all non-carcinogenic PAHs were below Level 1 SRVs. For carcinogenic PAHs, the Benzo(a)pyrene (BaP) Equivalent was found to be at the Level 3 SRVs for ponds RLE and RLP as well as sample M1 taken in the northern lobe of pond M. The BaP equivalent in the southern lobe of pond M, sample M2, was below Level 1 SRV. Dredging was proposed for the winter of 2009 to a depth and area required according to the design conditions provided by the MPCA.

CH2MHILL. (2009b). Purgatory Creek Restoration Basic Water Management Project. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

A petition requested evaluation of the City of Minnetonka proposed projects that require planning ahead of a County Road 101 (CR 101) expansion scheduled for construction not sooner then 2012-2013. Three alternatives were evaluated for the project area on the Silver Lake branch of Purgatory Creek. Alternative include some of the following: erosion mitigation and stream bank stabilization, possible full channel restoration of Purgatory Creek near reconstruction, construction of bioretention areas, and removal of buckthorn near construction site. Report includes the development of a HEC-HMS/HEC-RAS model to evaluate existing conditions of flows under Highway 101 and proposed conditions with the addition of a culvert under Highway 101. Proposed conditions showed increased flows in the creek.

CH2MHILL. (2009c). 2008 Lake Sampling and Analysis. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

This report summarizes monitoring data for priority lakes for year 2008. The lakes studied include Lotus Lake, Mitchell Lake, and Round Lake. Lotus Lake was found to be a dimictic weekly stratified eutrophic to hypereutrophic lake. The primary productivity of the lake was driven by the relative abundance of bio-available phosphorus. The lack of large bodied zooplankton to keep the algae concentration in balance allowed blooms of harmful cyanobacteria to develop. A significant source of phosphorus was internal loading from lake sediments. Mitchell Lake was found to be a dimictic, weakly stratified eutrophic to hypereutrophic lake. The primary productivity of the lake was driven by the relative abundance of labile phosphorus. The lack of large bodied zooplankton to keep the algae concentration in balance allowed blooms of harmful cyanobacteria to develop. One of the sources of phosphorus release was the lake sediments. The high sediment oxygen demand (3.12 g oxygen/m2/day) of the lake meant that phosphorus released as ferric iron was reduced to ferrous iron. Round Lake was found to be a dimictic strongly stratified eutrophic lake. The primary productivity of the lake was driven by the relative abundance of phosphorus which is due to the lack of dissolved oxygen in the hypolimnion of the lake.

CH2MHILL. (2010a). Mitchell Lake Phosphorus Management Study Report - 2009. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

Pilot testing and evaluation of two phosphorus management strategies, pure oxygen injection and calcium peroxide addition, were conducted during the summer of 2009 to reduce internal phosphorus loading in Mitchell Lake. Internal phosphorus loading has been shown to be a dominate contributor of phosphorus to Mitchell Lake. The goal of both pilot implementations was to maintain the ORP at the sediment surface at values greater than +100 mV1, conditions which will keep phosphorus bound to ferric iron in an insoluble form. A DynamOx pure oxygen injection system was installed to inject oxygen into the hypolimnion of one of the basins in Mitchell Lake. This injection suppresses phosphorus release. Mechanical issues limited the effectiveness, but the overall goal was still achieved. In a second basin of Mitchell Lake calcium peroxide was added to improve the lake water quality. Invasive species were first harvested from the lake before the applications of IXPER 70C into the basin on June 18th. The slow release calcium peroxide dose applied was not enough to elevate the ORP at the sediment water interface. Further analysis is needed to determine proper dosing and application requirements.

CH2MHILL. (2010b). Silver Lake Outlet, Flood Potential and MCES Interceptor.

This report details an analysis of flood potential for Silver Lake. The report found that lowest alternate spillway for Silver Lake into Purgatory Creek is at an elevation of 901.5. The outlet of Silver Lake was subject to plugging due to the size of the pipe. The submerged configuration prevented floating debris from clogging the outlet. A flood analysis found that the lake would rise to an elevation of 900.4 during the 10-year, 48-hour storm event.

CH2MHILL. (2010c). 2009 Lake and Stream Data Report. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District

This report provides a summary of water quality monitoring on priority water bodies in the Riley Purgatory Bluff Creek Watershed District. Water bodies in Purgatory Creek that were monitored include Lotus Lake, Mitchell Lake, and Round Lake. In Lotus Lake, no change in TP, Secchi depth, or chl-a were found in the five year running averages. Mitchell Lake also showed no changes in five year running averages for TP, chl-a and Secchi depth. Weed harvesting in May and June removed approximately 1,000,000 wet pounds of weeds from the lake. A calcium peroxide pilot study was conducted but did not show any statistically significant results. A hypolimnetic oxygenation study showed clear results of oxygenated sediments and suppression of phosphorus release from the sediments. In Round Lake, no changes were observed in the 5 year running averages for TP, chl-a and Secchi. Data was also summarized for monitoring in Purgatory Creek. Results showed that dissolved oxygen was present in the creek through the sampling season. Conductivity in the creek spiked in the winter months. Sampling point P-2 showed the most biodiversity, location P-4 was the only location where carp was found, and location p-5 had the least biodiversity.

CH2MHILL. (2011a). Round Lake Calcium Nitrate Pilot Test. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

Due to anoxic conditions in the deep portions of Round Lake from June through October sulfate reduction and the release of phosphate and methyl mercury from the sediments occurs. This report details the strategy to add nitrate to raise the oxidation reduction potential suppressing the release of phosphorus from the profundal sediments and inhibit sulfide and methyl mercury formations. Column tests were performed and liquid calcium nitrate (LCN) was added to Round Lake on June 15, 2010.The addition of LCN increased the oxidation reduction potential above the desired level of +100 mV SHE for a period of 64 days. During this time methyl mercury production was reduced, phosphorus release from the sediments was stopped and hydrogen sulfide formation was suppressed.

CH2MHILL. (2011b). 2010 Lake and Stream Data Report. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District

Summary of monitoring results in priority water bodies for year 2010. Water bodies in Purgatory Creek include Mitchell Lake, Round Lake, Staring Lake, and Purgatory Creek. Mitchell Lake showed no change in the five year running average TP, chl-a, and Secchi depth. Weed harvesting produced 900,000 wet pounds of weeds from the lake. In Round Lake, the five year running average TP concentration showed a leveling off from a decrease that started in the 1990's. Secchi depth displayed no change in the 5 year running averages. Chl-a exhibited a slight increase in 5 year running average concentrations. All three parameters exceeded the MPCA water quality standards. In Staring Lake TP, chl-a, and Secchi depth all displayed no changes in 5 year running averages, and all three exceeded the MPCA water quality standards. In Purgatory Creek sample point P-4 had the most bio diverse fish population, P-5 had the most diverse macroinvertebrate community, and carp was found in reaches P-4 and P-5. Dissolved oxygen levels were found to be below the MPCA standard at location P-1 and turbidity levels were found to be above the MPCA standard at P-4 and P-5.

CH2MHILL. (2012a). Stormwater Pond Protocols and Prioritization Report: 2011. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

This study evaluated the hypothesis that some stormwater ponds discharge substantially more total phosphorus (TP) than current models predict. High TP concentrations occur when phosphorus attached to settled particles become soluble. Bacteria in highly organic sediments make settled phosphorus soluble. The hypothesis was validated by modeling a few ponds with P8 (a common stormwater design tool used in Minnesota). Some ponds matched the model results within the accuracy of the P8 model, but some monitoring results indicated much higher concentrations and delivered more TP than modeled, even up to 20 pounds more TP (up to 17 percent of a lake's phosphorus budget) for 4 storm events.

CH2MHILL. (2012b). 2011 Lake and Stream Data Report. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

This report provides a summary of water quality data for priority water bodies collected in 2011. Water bodies in Purgatory Creek include Duck Lake, Red Rock Lake, Silver Lake and Staring Lake. Duck Lake TP and chl-a data were found to be too sparse to determine a trend. Secchi depth data show no change when looking at 5 year running averages. All three parameters meet the MPCA water quality standards for 2011. In Red Rock Lake, TP and chl-a five year running average concentration showed a slight decrease while Secchi depth showed a slight increase. Chl-a, Secchi depth and TP summer averages all meet the MPCA water quality standard. Improved water quality was hypothesized to be caused by reduced Curly-leaf pondweed due to deep snow pack and an early freeze in the lake. Winter sampling found hypoxia and internal phosphorus release from the sediments. High water levels were present until August. In Silver Lake, TP, chl-a and Secchi depth data were too sparse to determine a trend. All three parameters had at least one value that did not meet the MPCA water quality standards. Water elevation remained high throughout the sampling period. Staring Lake TP, chl-a, and Secchi depth showed no change when examining the 5 year running averages. Winter sampling did not reveal a significant period of anoxia at the sediment water interface. Purgatory Creek dissolved oxygen levels were below the MPCA standard levels at location P-1 on multiple occasions, turbidity was found to be above the MPCA standard at location P-4 and P-5 on multiple occasions. The location with the most diverse fish population was P-5, and the most diverse macroinvertebrate community was P-2. Carp were found in reached P-4 and P-5.

David L. Smith, T. L. (2012). Modeling the Hydrodynamics and Water Quality of the Lower Minnesota River Using CE-QUAL-W2. US Army Corps of Engineers, St. Paul, MN.

Contains information on the water quality model of the Lower Minnesota River (Jordan, Minnesota, to the mouth) using the CE-QUALW2 modeling framework. Calibration and validation of the model used data from years 2001-2006. Purgatory Creek was used as a model segment in the development of the model. The Lower Minnesota River Model (LMRM) provides a tool for load allocation studies and facility or watershed planning, in addition to providing a bridge to other water quality modeling efforts in the area.

Dunne, J. and Newman, R. 2016. Aquatic Plant Community of Lakes Lotus, Lucy, Mitchell, Susan, Riley, and Staring within the Riley Purgatory Bluff Creek Watershed: Annual Report 2015. University of Minnesota.

Freshwater Scientific Services. 2015. Aquatic Plant Community of Red Rock Lake.
Summary of aquatic plant surveys conducted on Red Rock Lake in June and August 2015. Found Coontail to be most abundant aquatic plant species at >70% of survey sites. Curlyleaf pondweed was found at 5% and 2% of the sites in the June and August surveys respectively. Curlyleaf pondweed turions were sampled Based on the abundance of the turions it was determined that Red Rock Lake has the potential to be moderately impaired for recreational from curlyleaf pondweed. Localized analysis found some locations that could have high potential for severe impairment.

Freshwater Scientific Services. 2015 Curlyleaf pondweed in Red Rock Lake
Summary of curlyleaf pondweed survey conducted April 2015. Included rake densities and possible treatment locations

Freshwater Scientific Services. 2015. Staring Lake Eurasian Watermilfoil Early Detection and Rapid Response.

Guentzel, K. S. (2013). Measurement and modeling of denitrification in sand-bed streams of varying land use. Masters Thesis, UNIVERSITY OF MINNESOTA, Minneapolis, MN.

In this study denitrification was measured from sediment cores in 5 streams in central Minnesota, USA, using denitrification enzyme activity (DEA) assays as well as microbiological techniques including the amplification of nirS gene fragments through qPCR. Hydraulic and environmental variables were measured in the vicinity of the sediment cores to determine a possible mediating influence of fluid flow and chemical variables on denitrification activity. Measurements for this study were taken in 2 transects downstream of Purgatory Park and just upstream of the intersection with Scenic Heights Drive. Low or moderate NO3 and TDN concentrations were observed in Purgatory Creek. Denitrification rates were highest in Purgatory Creek during spring sampling ranging from 2.9 to 10.1 mg-N m-2 hr-1 and were significantly greater than every other stream.

HydrO2. (2008). Measurement of In situ Sediment Oxygen Demand Lake Mitchell, Lotus Lake, and Round Lake, MN.

Sediment oxygen demand was measured at one location each in Mitchell, Lotus, and Round Lakes.

Ramstack, J., & Edlund, M. (2011). Historical Water Quality and Ecological Change of Three Lakes in the Riley-Purgatory-Bluff Creek Watershed District, MN. Science Museum of Minnesota,, St. Croix Watershed Research Station. Marine on St. Croix, Minnesota: Final Report submitted to CH2M Hill.

Paleolimnological techniques were used to reconstruct the trophic and sedimentation history of Mitchell, Lotus, and Round Lakes in Hennepin and Carver Counties, Minnesota. Sediment cores were collected from each lake and lead-210 activity was analyzed to develop dating models and determine sediment accumulation rates. Sediments were analyzed for inorganic, organic, and carbonate components using loss-on-ignition analysis, and subfossil diatoms in the sediments were analyzed for reconstruction of changes in lake ecology and trophic state. Sedimentation rates increased dramatically in all three lakes during the 1900s. Peak sedimentation occurred in the 1940s in Mitchell Lake, Lotus Lake had peaks in 1966 and 1993, and the peak in Round Lake occurred in the 1980s. Diatom community assemblages and diatom-inferred total phosphorus (TP) histories in all three lakes suggest that these systems have been in the meso- to eutrophic range during the past 150-200 years. Nutrient levels in Mitchell Lake have historically been highly variable, fluctuating between eutrophic and hypereutrophic levels. Lotus Lake was a mesotrophic system until the 1940s with diatom-inferred TP levels generally below 30 µg/l. Total phosphorus levels in Lotus Lake increased to eutrophic levels after the 1940s; recent changes in diatom communities hint at declining nutrient levels although alternative ecological

drivers may be driving the recent community shifts. Round Lake had mesotrophic nutrient levels (<40 µg/l TP) prior to European settlement; diatom inferred TP values since the 1960s have been steady in the slightly eutrophic range (40-60 µg/l TP).

Ramstack Hobbs, J., & Edlund, M. (2015). Paleolimnoligy Analysis of Silver Lake, Hennepin County, Minnesota. Science Museum of Minnesota,, St. Croix Watershed Research Station. Marine on St. Croix, Minnesota: Final Report submitted to Riley Purgatory Creek Watershed District. December 2015.

Summarizes the paleolimnological techniques used to reconstruct the trophic and sedimentation history of Silver Lake. Found that the sedimentation rate rose in the 1940s to a peak in 2002. Since 2002 the rate has declined, but still remains approximately 3 times higher than the pre-settlement sedimentation rate. The largest shift in diatom communities occurs in the drought periods of the 1920s. Shifts in the recent decades suggest increased nutrient enrichments. The data suggests that Silver Lake has been eutrophic for over 200 years with a slight rise in recent years. The lowest TP reconstruction concentration were calculated at approximately 30 ug/l during the time period of 1928-1949. Recent reconstruction concentration were recorded at 65 ug/l.

Riley Purgatory Bluff Creek Watershed District. (2006). Riley-Purgatory-Bluff Creek Watershed District Annual Report For Year Ending December 31, 2006. Eden Prairie, MN.

Report highlight the District's accomplishments for the year including the completion of lake use attainability analyses for major lakes, analysis of habitat within the corridor of Purgatory Creek, monitoring at 8 sites within Purgatory Creek, and operating three Watershed Outlet Monitoring Stations on Purgatory Creek. During 2006 the City of Eden Prairie petitioned the District for the construction of a new stormwater basin and the expansion of three existing basins in Round Lake.

Riley Purgatory Bluff Creek Watershed District. (2007). Riley-Purgatory-Bluff Creek Watershed District Annual Report For Year Ending December 31, 2007. Eden Prairie, MN.

This report summarizes activities in the District for year 2007. Basic water management project highlighted in the report for Purgatory Creek include establishing the Round Lake Basin Water Management Project that will involve the construction of one new stormwater basin and upgrades to three existing basins expected to reduce phosphorus loading to Round Lake by 18 to 25 percent. The District also closed out the Staring Lake/ Purgatory Creek Recreation Area project which was designed to treat surface runoff and provide water quality control of discharges into Purgatory Creek.

Riley Purgatory Bluff Creek Watershed District. (2008). Riley-Purgatory-Bluff Creek Watershed District Annual Report For Year Ending December 31, 2008. Eden Prairie, MN.

This report summarized activities in the District for year 2008. Basin water management activities highlighted in the report for Purgatory Creek included the updating of plans and cost and scheduling the completion of the Round Lake Water Management Project for 2009, harvesting more than 190 tons of invasive plant species and excessive plant growth from Round Lake, and the completion of a SWMM5 model for the Lotus Lake watershed, plant harvesting in Mitchell Lake, and an investigation into the use of Solar Bees as a treatment for cyanobacteria in Mitchell Lake was determined to be inconclusive and recommended to be continued in 2009. Projects proposed include measurement of sediment oxygen demand in Lotus Lake to help design a restoration and treatment strategy for internal loading.

Riley Purgatory Bluff Creek Watershed District. (2009). Riley-Purgatory-Bluff Creek Watershed District Annual Report For Year Ending December 31, 2009. Eden Prairie, MN.

This annual report summarizes activities in the District for year 2009. Projects completed in the Purgatory Creek watershed included the following: sediment and disposal requirements for the Round Lake Basic Water Management Project were completed and construction on the four stormwater ponds was scheduled to be completed in the winter of 2009/2010, continued plant harvesting in Round lake yielded 190 tons of invasive and plant overgrowth, an Engineer's report was completed on 1400 ft. of creek restoration and stabilization as part of the TH101 expansion, the Lotus Lake SWMM5 model was completed but calibration showed further analysis was needed which was scheduled to be completed in 2010, as part of District-wide carp analysis young of the year carp were only found in the Staring Lake Outlet/Purgatory Creek Recreational Area which lacked predatory fish, and plant harvesting continued in Mitchell Lake along with a Oxygenation Pilot Project.

Riley Purgatory Bluff Creek Watershed District. (2010). Riley-Purgatory-Bluff Creek Watershed District Annual Report For Year Ending December 31, 2010. Eden Prairie, MN.

This annual report summarized activities in the District for year 2010. Projects highlight in Purgatory Creek include the following: The Round Lake Water Management Project was completed and a control study was conducted to assess the effectiveness of the stormwater pond in comparison with MPCA design recommendation with a report to be completed in 2011, the Purgatory Creek hydraulic and hydrology model was extended from Lotus Lake to the eastern crossing under TH 62, a systematic analysis of carp in Lotus Lake was scheduled for 2011/2012, and in Mitchell Lake Curly-leaf pondweed and Eurasian water milfoil were harvested along with plant overgrowth for a total of 900,000 pounds of plants removed.

Riley Purgatory Bluff Creek Watershed District. (2011a). Riley-Purgatory-Bluff Creek Watershed District Annual Report For Year Ending December 31, 2011. Eden Prairie, MN.

This report summarizes activities in the District for year 2011. Projects highlighted in Purgatory Creek include the following: carp surveys indicated dense carp populations in Staring Lake and moderate populations in Lotus Lake with the other lakes in Purgatory Creek Chain being mostly carp free, carp removal was scheduled to being in Staring and Lotus Lakes in 2012; Aquatic plant community was surveyed in Staring Lake indicating low vegetation, consistent with high carp concentrations, making Staring Lake a good candidate for re-vegetation options after carp removal; winter fish kills were observed in Duck, Mitchell, and Silver Lakes.

Riley Purgatory Bluff Creek Watershed District. (2011b).Purgatory Creek "One Water. In: Section 5 of Water Management Plan – Riley-Purgatory-Bluff Creek Watershed District. Eden Prairie, MN

This report details past water quality data collected and mitigation measures develop through the 3rd generation management plan and the individual lake UAAs. Mitigation measures for the lakes in Purgatory Creek include: control Curly-leaf pondweed mechanically and through herbicide treatment (Round Lake, Lotus Lake, Duck Lake, Silver Lake, Mitchell Lake, Staring Lake); control Eurasian water milfoil mechanically and/or through herbicide treatment (Lotus Lake, Duck Lake, Round Lake, Mitchell Lake, Staring Lake); control Eurasian milfoil with biological controls (Mitchell Lake); control the carp population through a collaboration with the University of Minnesota (Lotus Lake, Duck Lake, Silver Lake, Round Lake, Mitchell Lake, Red Rock Lake, Staring Lake); control internal loading of phosphorus and mercury methylation through oxygenation, aeration, sediment oxygenation or a combination of methods (Lotus Lake, Duck Lake, Silver Lake); control internal loading through an alum treatment (Lotus Lake, Duck Lake) control purple loosestrife with beetles (Lotus Lake, Silver Lake, Mitchell Lake, Red Rock Lake, Staring Lake); control cyanobacteria through destratification (Lotus Lake, Silver Lake); control cyanobacteria through hypolimnetic oxygenation, sediment oxygenation, or chemical inactivation of phosphorus (Round Lake, Mitchell Lake, Red Rock Lake, Staring Lake); control phytoplankton through biomanipulation and fisheries management (Silver Lake, Round Lake, Mitchell Lake, Staring Lake); control external phosphorus loading through stormwater infiltration basin construction (Duck Lake, Staring Lake); control external phosphorus loading through existing wetlands and add ponds (Staring Lake); develop effective Canadian goose management plan (Round Lake), fisheries management to develop a sustainable blue gill and northern pike population (Round Lake). Controls on Purgatory Creek highlighted include invasive species management for upland and wetland vegetation including purple loostrife, reed canary grass, common buckthorn, and garlic mustard; Increase habitat effective areas and mitigate the effects of development; protect, preserves and enhance stream corridor width and composition; provide channel stability through the implementation of channel and floodplain restoration including streambank protection, and riparian vegetation management.

Riley Purgatory Bluff Creek Watershed District. (2012). Riley-Purgatory-Bluff Creek Watershed District 2012 Annual Report. Eden Prairie, MN

This report summarizes District activities for the year 2012. Projects discussed for Purgatory Creek include the following: Silver Lake debris was removed from outlet pipe causing high water levels; a Lotus Lake subwatershed pilot program implementing low impact development projects was conducted in the Carver Beach neighborhood; a shoreline restoration project was implemented along Lotus Lake; carp management was implemented in Purgatory Park Recreational Area including placing fish traps between Staring Lake and the Recreational Area and water levels were reduced in the fall and winter months to achieve a full freeze of the waters to kill larvae and eggs; Carp sensing activities were conducted in Staring Lake estimating that 21,000 carp will need to be removed; The hydraulic and hydrologic model was extended to highway 212/5 from the headwaters; 380 tons of plants were removed from Red Rock and Mitchell Lakes combined.

Riley Purgatory Bluff Creek Watershed District. (2013a). Riley-Purgatory-Bluff Creek Watershed District 2013 Annual Report. Eden Prairie, MN.

This report summarizes District activities for the year 2013. Projects conducted in the Purgatory Creek watershed include the following: the District completed the hydrology and hydraulic model for all of Purgatory Creek; weed harvesting continued in Red Rock and Mitchell Lake; and carp management continued in Staring Lake.

Riley Purgatory Bluff Creek Watershed District. (2014a). Purgatory Creek Assessment Erosion site. Eden Prairie, MN.

This report details the site assessment of the overall impact of the erosion/landslide event that occurred on May 11, 2014 at 11201 Burr Ridge Road, Eden Prairie, MN. The bluff failure was caused by a rain event that overwhelmed a broken storm sewer. Significant sediment deposition occurred at the erosion site and along the bank downstream and immediately upstream from the site.

Riley Purgatory Bluff Creek Watershed District. (2014b). Purgatory Creek Assessment Lotus Lake Branch. Eden Prairie, MN.

On the 17th of October 2014, District staff conducted a stream corridor assessment of the south branch of Purgatory Creek. Staff started from the origination of the branch at Lotus Lake and walked downstream to the streams confluence with the Silver Lake branch located directly above West 62nd Street or Townline Road (approximately 2 stream miles). Areas of concern included below Duck Lake Road along section 11 where an old culvert was being washed out. This washout was causing considerable erosion at the site as well as at the small stretch above the culvert. In section 10 there was also a series of dump sites where landowners were dumping landscape clippings in or near the stream. A significant gully is forming from the road runoff coming from Highway 101. This gully may eventually threaten the structural integrity of the road in the future. Overall the stream conditions were good to excellent.

Riley Purgatory Bluff Creek Watershed District. (2014c). Purgatory Creek Assessment Silver Lake Branch. Eden Prairie, MN.

On the 22nd of October 2014, District staff conducted a stream corridor assessment of the north branch of Purgatory Creek. Staff started from the origination of the branch at Silver Lake and walked downstream to Highway 101 (approximately 1 river mile). This stream section was overall in good condition except for the section between Covington Road and the stream bend just south of Red Cherry Circle where the creek enters a wetland. High erosion sites occurred along the entirety of this section which is believed to be caused by the failing culvert under Covington Road.

Riley Purgatory Bluff Creek Watershed District. (2014d). Riley-Purgatory-Bluff Creek Watershed District 2014 Annual Report. Eden Prairie, MN.

This report details goals and water quality monitoring results for 2014. Specific goals related to Purgatory Creek for 2014 include reviewing and finalizing the hydrologic and hydraulic model for Purgatory Creek, continue Curly-leaf pondweed harvesting in Red Rock Lake and Mitchell Lake, delisting Red Rock Lake from the impaired waters list, and continue work with the U of M on carp management in Staring Lake. Goals are the same for 2015 as 2014 with the addition of using the hydrologic and hydraulic model to review flow profiles in the watershed using Atlas 14. 2014 lake monitoring found summer average concentrations of chlorophyll-a exceeding the state standard in Lotus, Red Rock, Staring and Silver Lakes, summer average total phosphorus exceeded the standard in Red Rock, Lotus, Staring and Silver; and summer average Secchi depth exceeded the standard in Silver Lake. Water quality monitoring along Purgatory Creek found 5 of the 8 sites with 2 water quality violations and 2 of the sites with 1 water quality violation. Violations include exceedances for TP, TSS, and DO.

Riley Purgatory Bluff Creek Watershed District. (2014e). Stormwater Pond Project 2012 Report. Eden Prairie, MN.

The purpose of the project was to determine if stormwater ponds were sources of pollution and to identify ponds with exceptionally high phosphorus concentrations that could be targeted for remediation projects. In years 2012 and 2013, 61 and 98 stormwater ponds were sampled, respectively, throughout the District. Average total phosphorus levels were higher than the MPCA estimated typical total phosphorus range (0.1 mg/L to 0.25 mg/L) for effluent stormwater in all five of the cities sampled. 71% of the ponds sampled in 2013 had total phosphorus levels that were greater than the typical effluent estimated by the MPCA. No relationship was found between the age of the pond and the total phosphorus concentration measured in the pond. It was also determined that the presence and/or amount of macrophytes in a stormwater pond is not a reliable indicator of poor overall health.

Sorensen, P., & Bajer, P. (2012). 2012 Annual Report: Developing and implementing a sustainable program to control common carp in the Riley Purgatory Bluff Creek Watershed District. University of Minnesota. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

This report summarizes progress achieved in carp management in Purgatory Creek. Progress was slow in the Purgatory Creek watershed where winter removal of carp aggregations using radio-tagged Judas fish was frustrated by a warm winter with poor ice conditions. Radio-tagged Judas fish provided insight into the spring-time movement of carp between Staring Lake and the wetland upstream (Purgatory Creek Park Area or 'PCPA') which functions as a carp nursery. Fish capture data also suggest that most carp waited until their second year of life to leave this nursery area, meaning that draw-downs to create winterkill could in theory control them. Carp movement into and out of PCPA is extensive and occurs every few weeks with fluctuating water levels suggesting that spring-time trapping for removal may be reasonable in the creek. A plan to draw-down the PCPA was put into effect as a first step in carp control; the idea is to kill all surviving juvenile carp in the nursery each year in a cost-effective and ecologically safe manner. Water and plant sampling continued in this system so that when carp are eventually removed from it, the effects of carp in shallow lakes can be ascertained.

Sorensen, P., Bajer, P., Headrick, M. (2015) Development and implementation of a sustainable strategy to control common carp in Purgatory Creek Chain of Lakes. University of Minnesota. Eden Prairie, MN: Riley-Purgatory-Bluff Creek Watershed District.

Stefanova, V., & Wright, H. (2011). THE EFFECTS OF EUROPEAN SETTLERS ON THE VEGETATION IN HENNEPIN AND CARVER COUNTIES SINCE 1850. University of Minnesota, Limnological Research Center. Minneapolis, MN: Final Report submitted to CH2M Hill.

Sediments were analyzed at 50-year intervals for fossil pollen, spores, non-pollen palynomorphs (fungal spores, algae), microscopic charcoal, and fly ash to reconstruct vegetation changes around Mitchell, Round, and Lotus lakes in Hennepin and Carver counties, Minnesota since AD 1850, when the first European settlements were made. The initial forest of oak, along with other mesic deciduous trees was subject to prairie fires, as recorded by charcoal horizons in the lake sediment and was converted to farmland as the area was settled by homesteaders immigrating after the government surveys. Land clearance and associated farming are recorded by the reduction of oak pollen and the spread of ragweed on cultivated land as farming spread westward from Hennepin to Carver County. The occurrence of dung spores in the sediment implies that the farmers raised livestock as well as crops. In AD 1950 the occurrence of fly ash in the lake sediments represents the introduction of diesel for engines of trains and trucks as urbanization expanded. By this time the percentage of ragweed pollen had decreased, especially in Hennepin County, probably because more farmland was eliminated in the outer suburbs of Minneapolis.

TOTH, T. A., & FRITZ, S. J. (1997). AN Fe-BERTHIERINE FROM A CRETACEOUS LATERITE: PART I. CHARACTERIZATION. Clays and Clay Minerals, 45(4), 564-579.

A Fe-berthierine occurs in a buried laterite from the Late Cretaceous (Cenomanian) in southwestern Minnesota (Purgatory Creek). It formed beneath a lignitic horizon in which reducing solutions percolated through a laterite comprising gibbsite, kaolinite and goethite. Morphologic differences suggest two separate conditions of Fe-berthierine formation. Early forms of Fe-berthierine include radial bladed or radial blocky crystallites coating pisoids, along with alteration of kaolinite at crystal boundaries. These morphologies formed in the vadose zone. Later forms precipitated under subaqueous conditions as macroscopic, porefilling cement. The large size of the later-formed Fe-berthierines enabled microprobe characterization. This first reported occurrence of Mg-free berthierine has a structural formula close to an idealized Feberthierine: Fe2A12SiO~(OH)4 . Apart from their chemistry, the unique feature of the Minnesota Fe-berthierines is their formation in an exclusive nonmarine depositional environment. They formed in situ as part of a lateritic weathering profile developed on a broad, low relief peneplain. Physical evidence of formation under nonmarine conditions includes the presence of 1) scattered lignitic fragments; 2) concretions forming casts and molds of woody material; and 3) a nonmarine fossil (Unio sp. undet). Chemical evidence includes siderites collected from the berthierine-bearing horizon having stable isotope values indicating freshwater formation.

WENCK ASSOCIATES, INC. (2013). Staring Lake Watershed Basin Inventory and Maintenance Assessment. Eden Prairie, MN: CITY OF EDEN PRAIRIE.

The MPCA asked the City of Eden Prairie to evaluate the treatment effectiveness of key water treatment basins in the Staring Lake watershed. Wenck assessed 172 basins (58 constructed ponds, 7 mitigation wetlands, 87 stormwater wetlands) including a sediment survey, plain sight maintenance needs, and bathymetric surveys. Data collected were used to estimate sedimentation amounts and calculate pollutant removal effectiveness and sediment removal rates using the P8 water quality model. A total of 26 constructed ponds and stormwater wetlands were identified for expansion or cleanout to improve water quality in Staring Lake. An in-lake nutrient model was created using the model annual average BATHTUB model for years 2001, 2002, 2004, 2005, 2006, and 2010. Internal loading was found to be contributing 10% of the total phosphorus load to Staring Lake with 90% coming from stormwater. To meet water quality goals in Staring Lake a total reduction of 2,829 lbs. of phosphorus per year would be needed. Improvements to basins were made totaling $1.2 million for an annual reduction of 36 lbs. of phosphorus.

WENCK ASSOCIATES, INC. (2014a). Duck and Red Rock Lake Watersheds Basin Inventory and Maintenance Assessment. Eden Prairie, MN: CITY OF EDEN PRAIRIE.

In 2009, the MPCA asked the City to take an additional step to monitor stormwater basins that are either City-owned, under a drainage easement, receive public drainage or are within a City right-of-way. This phase of the project covers the Duck and Red Rock Lake watersheds. A total of 74 basins were assessed for functionality and sedimentation. Of the inventoried basins, there were 15 constructed ponds, 50 stormwater wetlands, 3 swales, 4 segments of Purgatory Creek, and 2 lakes (Duck and Red Rock). Data collected from the sedimentation survey was used to determine sedimentation amounts, pollutant removal effectiveness, and sediment removal. A watershed-wide P8 model and a lake-response model were created for Duck Lake and Red Rock Lake. The basin inventory and assessment identified 7 basins as high priority basins that should be routinely inspected. Using a BATHTUB model, it was determined that Duck Lake would require a 42% (14.4 lbs. per yr.) reduction from all watershed inputs to meet the water quality standard. Red Rock Lake already meets water quality standards and does not require reductions. In-lake management including mitigation of Curly-leaf pondweed and fish management should be explored in Duck Lake before large scale watershed changes.

WENCK ASSOCIATES, INC. (2014b). Mitchell Lake Aquatic Plant Management Plan. Eden Prairie, MN: City of Eden Prairie and Riley-Purgatory-Bluff Creek Watershed District.

This report details a long term aquatic management plan for Mitchell Lake. Two invasive species were currently in Mitchell Lake including Curly-leaf pondweed and Eurasian water milfoil. Continued management of Curly-leaf pondweed was recommended while no management is needed for Eurasian water milfoil only continued monitoring. Some management of native plant species is also recommended. Recommended management practices include a maximum of 10 acres of invasive area being treated with Aquathol K and the remaining 13 acres mechanically harvested annually in the early spring. Harvesting would include providing access paths to residents docks and harvesting an open areas in the middle bay of the lake along with a navigation channel to open areas.

WENCK ASSOCIATES, INC. (2014c). Red Rock Lake Aquatic Plant Management Plan. Eden Prairie, MN: City of Eden Prairie.

This report details a long term aquatic plant management plan for Red Rock Lake. Issues include over-abundant aquatic vegetation in the lake leading to limits on lake use and function. Dominate species in the lake are coontail and water lily. Curly-leaf pondweed is the only invasive species present. Recommended management practices include a maximum of 10 acres of invasive area being treated with Aquathol K and the remaining 13 acres mechanically harvested annually in the early spring. Harvesting would include providing access paths to residents' docks.

Wenck Associated Inc. 2015. Red Rock Lake Plant Management Plan.

Appendix B

Structural, In-Lake, and Nonstructural BMPs

Appendix B: structural, in-lake, and nonstructural BMPs

B.1 Structural Watershed Practices

B.1.1 Wet Detention Ponds

Wet detention ponds (sometimes called "NURP" ponds after the Nationwide Urban Runoff Program) are impoundments that have a permanent pool of water and the capacity to hold runoff and release it at slower rates than incoming flows. Wet detention ponds are one of the most effective methods available for treatment of stormwater runoff. They are used to interrupt the transport phase of sediment and pollutants associated with it, such as trace metals, hydrocarbons, nutrients, and pesticides. When designed properly, wet detention ponds can also provide some removal of dissolved nutrients. In addition, detention ponds have been credited with reducing the amount of bacteria and oxygen-demanding substances as runoff flows through the pond.

During a storm, polluted runoff enters the detention basin and displaces "clean" water until the plume of polluted runoff reaches the basin's outlet structure. When the polluted runoff does reach the outlet, it has been diluted by the water previously held in the basin. This dilution further reduces the pollutant concentration of the outflow. In addition, much of the total suspended solids and total phosphorus being transported by the polluted runoff and the pollutants associated with these sediments are trapped in the detention basin. A well-designed wet detention pond could remove approximately 80 to 95 percent of TSS and 40 to 60 percent of TP entering the pond (MPCA, 1989).

As storm flows subside, finer sediments suspended in the pond's pool will have a relatively longer period of time to settle out of suspension during the intervals between storm events. These finer sediments eventually trapped in the pond's permanent pool will continue to settle until the next storm flow occurs. In addition to efficient settling, this long detention time allows some removal of dissolved nutrients through biological activity (Walker, 1987). These dissolved nutrients are mainly removed by algae and aquatic plants. After the algae die, the dead algae can settle to the bottom of the pond, carrying with them the dissolved nutrients that were consumed, to become part of the bottom sediments.

The wet detention process results in good pollutant removal from small storm events. Runoff from larger storms will experience pollutant removal, but not with the same high efficiency levels as the runoff from smaller storms. Studies have shown that because of the frequency distribution of storm events, good control for more frequent small storms (wet detention's strength) is very important to long-term pollutant removal.

B.1.2 Infiltration

Infiltration is the movement of water into the soil surface. For a given storm event, the infiltration rate will tend to vary with time. At the beginning of the storm, the initial infiltration rate represents the maximum infiltration that can occur because the soil surface is typically dry and full of air spaces. The infiltration rate tends to gradually decrease as the storm event continues because the soil air spaces fill with water. For long-duration storms, the infiltration rate will eventually reach a constant value, or the minimum infiltration rate (the design infiltration rate). The infiltrated runoff helps recharge the groundwater and mitigate the impacts of development. Stormwater flows into an infiltration basin, pools on the ground surface, and gradually infiltrates into the soil bed. Pollutants are removed by adsorption, filtration, volatilization, ion exchange, and decomposition. Therefore, infiltration is one of a few BMPs that can reduce the amount of dissolved pollutant in stormwater. Infiltration BMP devices, such as porous pavements, infiltration trenches and basins, and rainwater gardens, can be utilized to promote a variety of water management objectives, including:

- Reduced downstream flooding
- Increased groundwater recharge
- Reduced peak stormwater discharges and volumes
- Improved stormwater quality

An infiltration basin collects and stores stormwater until it infiltrates the surrounding soil and evaporates into the atmosphere. Infiltration basins remove fine sediment, nutrients (including dissolved nutrients), trace metals, and organics through filtration by surface vegetation, and through infiltration through the subsurface soil. Deep-rooted vegetation can increase infiltration capacity by creating small conduits for water flow. Infiltration basins are designed as a grass-covered depression underlain with geotextile fabric and coarse gravel. A layer of topsoil is usually placed between the gravel layer and the grassed surface. Pretreatment is often required to remove any coarse particulates (leaves and debris), oil and grease, and soluble organics to reduce the potential of groundwater contamination and the likelihood of the soil pores being plugged. Infiltration can also be promoted in existing detention ponds by excavating excess sediments (typically the fines that have sealed the bottom of the pond) and exposing a granular sub-base (assuming one was present prior to the original construction of the detention pond).

Rainwater gardens (a form of bio-retention) are shallow, landscaped depressions that channel and collect runoff. To increase infiltration, the soil bed is sometimes amended with mulch or soils with greater infiltration capacity. Vegetation in the rainwater gardens take up nutrients, and stored runoff is reduced through evapotranspiration. Bio-retention is commonly located in parking lot islands, or within small pockets in residential areas, and is primarily designed to remove sediment, nutrients, metals, and oil and grease. Secondary benefits include flow attenuation; volume reduction; and removal of floatables, fecal coliform, and Biological Oxygen Demand (BOD).

B.1.3 Iron-Enhanced Sand Filtration

Iron-enhanced sand filtration is a stormwater BMP that incorporates iron into a filtration media to remove soluble phosphorus. In conditions with sufficient oxygen, the iron in the filter binds with dissolved constituents in stormwater, including dissolved phosphorus. If conditions within the filter media become anoxic, the bond between the phosphorus and iron can break down and the phosphorus can be re-released into the water. Because of the need to maintain an oxygenated filter media, iron-enhanced sand filters are most suitable to conditions with minimal groundwater intrusion or tailwater effects and should include underdrains to convey filtered water and to help aerate the filter bed between storms. Studies of iron enhanced sand filters have resulted in soluble phosphorus reductions ranging from 40 to 90 percent (City of Bellevue, Washington, 1999; Erickson et al. 2006; Erickson et al. 2009). A relatively short contact time (20 to 30 minutes) is required for the surface sorption to bind phosphorus to the iron oxide on the iron filings. Therefore, the filter must be drawn down within 48 hours of a rainfall event. This means that the BMP footprint is proportional to the volume of water to be treated. The estimated lifespan of the iron material is approximately 35 years, although this has not been confirmed in the field (Erickson et al. 2012). Simple, periodic maintenance activities are required, including inspection of inlet and outlet structures, cleanout of the underdrain system, and occasional addition of filtration media to maintain the design depth (i.e., contact time) of the material. Figure B.1 includes photographs of iron-enhanced sand filtration systems.

Construction of Beam Avenue iron-enhanced sand filtration system.

Iron-enhanced sand filtration system near Beam Avenue following a rainfall event.

Figure B.1 Photographs of iron-enhanced sand filtration system

The use of iron-enhanced filtration in stormwater management is recognized by the MPCA and included as a BMP in the *Minnesota Stormwater Manual* (MPCA, 2014). Monitoring data reported in this manual has shown promising results for the removal of both total and dissolved phosphorus. Total phosphorus removal through the system is approximately 71 percent (MPCA, 2014).

B.1.4 Vegetated Buffer Strips

Vegetative buffer strips are low, sloping areas designed to accommodate stormwater runoff traveling by overland sheet flow. Vegetated buffer strips perform several pollutant attenuation functions, mitigating the impact of development. Urban watershed development often involves disturbing natural vegetated buffers for the construction of homes, parking lots, and lawns. When natural vegetation is removed, pollutants are given a direct path to the lake; sediments cannot settle out, and nutrients and other pollutants cannot be removed. Additional problems resulting from removal of natural vegetation include streambank erosion and loss of valuable wildlife habitat (Rhode Island Department of Environmental Management, 1990).

The effectiveness of buffer strips is dependent on the width of the buffer, the slope of the site, and the type of vegetation present. Buffer strips should be 20 feet wide at a minimum; however, 50 to 75 feet is recommended. Many attractive native plant species can be planted in buffer strips to create aesthetically pleasing landscapes, as well as havens for wildlife and birds. When properly designed, buffer strips can remove 30 to 50 percent of TSS from lawn runoff. In addition, well-designed buffer strips will discourage waterfowl from nesting and feeding on shoreland lawns. Such waterfowl can be a significant source of phosphorus to ponds, by grazing turfed areas adjacent to the water and defecating in or near the water's edge where wash-off into the pond is probable.

B.1.5 Spent Lime Treatment

Spent lime consists of calcium and carbonate and is a byproduct of the drinking-water treatment process. Since this material is fresh (e.g., recently precipitated), it has properties that allow it to bind with phosphorus. When water with dissolved phosphorus contacts the lime material, calcium from the lime binds with phosphorus and forms calcium phosphate, which is a solid material and does not dissolve in the stormwater, thus remaining within the treatment system. Figure B.2 includes photographs of spent-lime treatment systems that have been constructed.

Although the use of spent lime in stormwater management is still an emerging technology, over two years of monitoring, a test spent-lime treatment system in Maplewood (2012 and 2013) has shown promising results for the removal of both total and dissolved phosphorus. Total phosphorus removal through the system is approximately 65 percent. However, for most monitored events, the dissolved phosphorus levels at the discharge were at laboratory detection limits, suggesting that dissolved phosphorus removal may be higher than the reported removal. Additionally, removal of TSS and heavy metals has been observed.

Spent-lime treatment system upstream of Wakefield Pond during construction before spent lime has been added.

Completed spent-lime treatment system upstream of Wakefield Pond.

Figure B.2 Photographs of spent-lime treatment system

Spent-lime treatment is a cost-effective BMP, using a waste byproduct of the drinking-water treatment system typically disposed of via agricultural land application. Because only a short contact time (5 to 10 minutes) is required for the chemical reaction to bind phosphorus to the calcium in the lime, a fairly small BMP footprint can be used to treat a significant volume of water. Additionally, the spent-lime material has a significant phosphorus-binding capacity and an estimated lifespan of 100-plus years (unconfirmed in the field). Routine maintenance is required, including inspection of inlet and outlet structures, annual mixing of the lime material to maintain its porosity and hydraulic conductivity, and occasional addition of spent-lime material to maintain the design depth (contact time) of the material.

B.1.6 Oil and Grit Separators

Oil-grit separators (e.g., StormCeptors) are concrete chambers designed to remove oil, sediments, and floatable debris from runoff, and are typically used in areas with heavy traffic or high potential for petroleum spills such as parking lots, gas stations, roads, and holding areas. A three-chamber design is common; the first chamber traps sediment, the second chamber separates oil, and a third chamber holds the overflow pipe. The three-chambered unit is enclosed in reinforced concrete. Oil-grit separators remove coarse particulates well, but soluble pollutants tend to pass through. To operate properly, the devices must be cleaned out regularly (at least twice a year). Oil-grit separators can be especially beneficial when used as pre-treatment for an infiltration basin or pond. They can also be incorporated into existing stormwater systems or included in underground vault detention systems when no available land exists for a surface detention basin. Only moderate removals of TSS can be expected; however, oil and floatable debris are effectively removed from properly designed oil- grit separators.

B.1.7 Alum Treatment Plants

In addition to the commonly installed structural BMPs discussed above, alum treatment plants are becoming an option for efficiently removing phosphorus from tributaries, rather than directly treating the lake with alum to remove phosphorus. Alum (aluminum sulfate) is commonly used as a flocculent in water treatment plants and as an in-lake treatment for phosphorus removal. To treat inflows in streams or storm sewers, part of the flow is diverted (e.g., 5 cfs) from the main flow and treated with alum. After the alum is injected in the diverted flow, it passes to a detention pond to allow the flocculent to settle out before the water enters the lake. Alum treatment has been shown to remove up to 90 percent of the soluble and particulate phosphorus from the inflows.

B.2 In-Lake Management Activities

B.2.1 Removal of Benthivorous (Bottom-Feeding) Fish

Benthivorous fish, such as carp and bullhead, can have a direct influence on the phosphorus concentration in a lake (LaMarra, 1975). These fish typically feed on decaying plant and animal matter and other organic particulates found at the sediment surface. The fish digest the organic matter, and excrete soluble nutrients, thereby transforming sediment phosphorus into soluble phosphorus available for uptake by algae at the lake surface. Depending on the number of benthivorous fish present, this process can occur at rates similar to watershed phosphorus loads.

Benthivorous fish can also cause resuspension of sediments in shallow ponds and lakes, causing reduced water clarity and poor aquatic plant growth, as well as high phosphorus concentrations (Cooke et al., 1993). In some cases, the water quality impairment caused by benthivorous fish can negate the positive effects of BMPs and lake restoration. Depending on the numbers of fish present, the removal of benthivorous fish may cause an immediate improvement in lake water quality. The predicted water quality improvement following removal of the bottom-feeding fish is difficult to estimate, and require permitting and guidance from the MDNR. In addition, using fish barriers to prevent benthivorous fish from spawning may adversely affect the spawning of game fish, such as northern pike.

B.2.2 Application of Alum (Aluminum Sulfate)

Internal loading due to release from the sediment can be a significant source of phosphorus loading to a lake. Sediment release of phosphorus to the lake occurs during the summer months, when the water overlying the sediments is depleted of oxygen. This internal load of phosphorus is transported to the entire lake during late summer or early fall, when the surface waters cool sufficiently for wind-mixing to mix the entire lake (often referred to as "fall turnover"). Phosphorus released from the sediments is typically in a dissolved form, which can be quickly utilized by algae, leading to intense algae blooms. Areal application of alum and related precipitants has proven to be a highly effective and long-lasting control of phosphorus release from the sediments, especially where an adequate dose has been delivered to the sediments and where watershed sediment and phosphorus loads have been minimized (Moore and Thorton, 1988). Alum will remove phosphorus from the water column as it settles and then forms a layer on the lake bottom that covers the sediments and prevents phosphorus from entering the lake as internal load. An application of alum to the lake sediments can decrease the internal phosphorus load by 80 percent (*Effectiveness and Longevity of Phosphorus Inactivation with Alum*, Welch and Cook, 1999) and will likely be effective for approximately seven to 10 years, depending on the control of watershed nutrient loads.

B.2.3 Application of Herbicides

Curlyleaf pondweed can be controlled by herbicide treatments applied from a barge or boat or by mechanical harvesting, or by a combination of these methods. Herbicide treatments are more effective at eradicating the plant, but MDNR regulations limit the extent of the lake that can be treated in a given year. Aquatic herbicides are among the most closely scrutinized compounds, and must be registered for use by both the U.S. Environmental Protection Agency and the State of Minnesota. Registration of an aquatic herbicide requires extensive testing. Consequently, all of the aquatic herbicides currently registered for use are characterized by excellent toxicology packages, are only bio-active for short periods of time, have relatively short-lived residuals, and are not bioconcentrated (*The Lake Association Leader's Aquatic Vegetation Management Guidance Manual*, Pullmann, 1992). Examples of two aquatic herbicides appropriate for use in controlling the curlyleaf pondweed growth in lakes are Reward (active ingredient = Diquat) and Aquathol-K (active ingredient = Endothall).

The use of low-level Sonar application has recently been found to selectively control exotic weed species such as Eurasian watermilfoil and curlyleaf pondweed (*Whole-Lake Applications of Sonar for Selective Control of Eurasian Watermilfoil*, Getsinger *et al*, 2001). Due to past history of Sonar applications and the limited research on the new low-level applications, the use of Sonar is not feasible at this time.

Both chemical and mechanical harvesting of macrophytes has been occurring in several of the lakes for several decades. Unless otherwise approved, the MDNR will currently only permit 15 percent of the littoral zone of a given lake be treated with herbicides.

B.2.4 Application of Copper Sulfate

Copper sulfate applications can be a highly effective algaecide in some cases, but these efforts are always temporary (days) and can have high annual costs. In addition, care must be taken to limit the impacts on non-target organisms, such as invertebrates, and possible sediment contamination with copper. The primary effects on algae include inhibition of photosynthesis and cell division as a result of the additional cupric ion, the form of copper toxic to algae, present in the water column (Cooke *et al*, 1993). Blue-green algae are particularly sensitive to copper sulfate treatments. As a result, after a copper sulfate treatment is made, the blue-green algae concentration is knocked back. However, after a few days, the green algae (fast growers) take control, and within a few weeks the chlorophyll *a* concentration can be back to pretreatment levels (Ed Swain, MPCA). As the algae die and settle out of the water column, they take with them the nutrients they used for growth. Therefore, copper sulfate application may temporarily reduce the total phosphorus concentration in a water body by removing the phosphorus that is associated with algal biomass. Once the algae have settled out of the water column and start to decompose, soluble phosphorus is released back into the water column that can be used for future algal growth. As a result, copper sulfate treatments are typically not considered a long-term solution to nutrient loading problems.

B.2.5 Mechanical Harvesting

Harvesting of lake macrophytes is typically used to remove plants that are interfering with uses such as boating, fishing, swimming, or aesthetic viewing. Mechanical control involves macrophyte removal via harvesting, hand pulling, hand digging, rotovation/cultivation, or diver-operated suction dredging. Small-scale harvesting may involve the use of the hand or hand-operated equipment such as rakes, cutting blades, or motorized trimmers. Individual residents frequently clear swimming areas via small-scale harvesting or hand pulling or hand digging.

Large-scale mechanical control often uses floating, motorized harvesting machines that cut the plants and remove them from the water onto land, where they can be disposed. Mechanical harvesters consist of a barge, a reciprocating mower in front of the barge that can cut up to a depth of roughly 8 feet, and an inclined porous conveyer system to collect the cuttings and bring them to the surface. Typically, a lake association or homeowner will contract a large-scale harvesting operation at an estimated cost of $500-plus per acre (McComas, 2007).

Removal of aquatic vegetation through mechanical harvesting has been shown to not be an effective nutrient control method (Cooke et al, 1993). However, none of this research was focused on the internal phosphorus load reduction due to mechanical harvesting of curlyleaf pondweed. Blue Water Science's 2000 *Orchard Lake Management Plan* suggests that there are up to 5.5 pounds of phosphorus per acre of curlyleaf pondweed. Additional research mentions that harvesting can reduce the extent of nuisance curlyleaf pondweed growth if harvesting occurs for several years and can reduce stem densities by up to 80 percent (McComas and Stuckert, 2000). Therefore, harvesting of curlyleaf pondweed may significantly reduce the phosphorus in the water column of a lake assuming enough biomass can be removed from the lake. This assumes that enough time and equipment is available to harvest the curlyleaf pondweed prior to die-back in early July.

While more acceptable to the MDNR than chemical methods, chemical harvesting still requires an MDNR permit, provides only temporary benefits, and must be repeated annually. The MDNR regulations state that the maximum area that can be harvested is 50 percent of the littoral zone.

B.2.6 Hypolimnetic Withdrawal

Hypolimnetic withdrawal involves discharging the nutrient-rich waters from the hypolimnion instead of surface waters. This typically results in a reduced hypolimnetic detention time, decreased chance for anaerobic conditions to develop, and reduced phosphorus availability for epilimnetic entrainment. The withdrawal is accomplished by extending a pipe from the lake's outlet along the lake bottom to the deepest part of the lake. This pipe can act as either a siphon, or water can be pumped at a predetermined rate. By discharging nutrient-rich water from the hypolimnion the internal phosphorus load available when stratification breakdowns can be reduced.

B.2.7 Hypolimnetic Aeration

Hypolimnetic aeration involves the oxygenation in the hypolimnion of a thermally stratified lake to raise the dissolved oxygen content within this layer of the lake without disrupting the stratification or temperature. By aerating the hypolimnion, the anoxic conditions that often develop along the sediment-water interface during the summer months in many thermally stratified lakes can be minimized, reducing the internal phosphorus loading from the lake sediments into the water column. Hypolimnetic aeration can be achieved through a variety of designs and setups, which can include mechanical agitation, injection of pure oxygen, and injection of air.

B.2.8 Iron Salt Applications

The application of iron salts (such as ferric chloride or ferric sulfate) can be used to reduce TP concentrations within a lake. In aerobic conditions, the iron salts can be used to precipitate and/or inactivate the TP associated with lake sediments. Application of iron salts alone has not been shown to be effective in the long term. However, when used in combination with hypolimnetic aeration, the results of the treatment have been more effective.

B.3 Non-Structural Practices

B.3.1 Public Education

Public education regarding proper lawn care practices, such as fertilizer use and disposal of lawn debris, can result in reduced organic matter and phosphorus loadings to the lake. A public information and education program may be implemented to teach residents within the lake watersheds how to protect and improve the quality of the lake. The program could include distribution of fliers to all residents in the watershed as well as placement of advertisements and articles in the city's newsletters and the local newspapers. Information could also be distributed through organizations such as lake associations, local schools, Girl Scouts and Boy Scouts, and other local service clubs.

Initiation of a stenciling program to educate the public about stormwater could help reduce loadings to the storm sewer system. Volunteers could place stenciled messages (i.e., "Dump No Waste, Drains to Lake") on all storm-sewer catch basins within the watershed.

B.3.2 City Ordinances

Fortunately, Minnesota already has a statewide phosphorus fertilizer ban in place that restricts the residential use of phosphorus fertilizer. In addition, pet waste ordinances are an important mechanism for further reducing a large source of phosphorus in residential watershed areas.

B.3.3 Street Sweeping

Most often, street sweeping is performed only in the spring, after the snow has melted, and in the fall, after the leaves have fallen, to reduce this potential source of phosphorus from entering the storm sewer. For most urban areas, street sweeping has relatively low effectiveness from late spring (after the streets are cleaned of accumulated loads) until early fall (prior to the onset of leaf fall) (Bannerman, 1983). The use of vacuum sweepers is preferred over the use of mechanical brush sweepers. The vacuum sweepers are more efficient at removing small phosphorus-bearing particles from impervious surfaces within the watershed. Fall street sweeping is particularly important in the watersheds directly tributary to the lakes, where treatment of stormwater is not available.

B.3.4 Deterrence of Waterfowl

The role of waterfowl in the transport of phosphorus to lakes is often not considered. However, when the waterfowl population of a lake is large relative to the lake size, a substantial portion of the total phosphorus load to the lake may be caused by waterfowl. Waterfowl tend to feed primarily on plant material in or near a lake; the digestive processes alters the form of phosphorus in the food from particulate to dissolved. Waterfowl feces deposited in or near a lake may result in an elevated load of dissolved phosphorus to the lake. One recent study estimated that one Canada goose might produce 82 grams of feces per day (dry weight) while a mallard may produce 27 grams of feces per day (dry weight) (Scherer et al., 2002). Waterfowl prefer to feed and rest on areas of short grass adjacent to a lake or pond. Therefore, shoreline lawns that extend to the water's edge will attract waterfowl. The practice of feeding bread and scraps to waterfowl at the lakeshore not only adds nutrients to the lake, but attracts more waterfowl to the lake and encourages migratory waterfowl to remain at the lake longer in the fall.

Two practices often recommended to deter waterfowl are construction of vegetated buffer strips, and prohibiting the feeding of waterfowl on public shoreline property. As stated above, vegetated strips along a shoreline will discourage geese and ducks from feeding and nesting on lawns adjacent to the lake, and may decrease the waterfowl population.

Appendix C

Water Quality Monitoring Data Tables

Duck Lake Water Quality Data Table

Parameters	1971	1975	1978	1981	1984	1988	1990	1993	1996	2002	2004	2005	2008	2009	2011	2012	2013	2014	2015
Algae, blue-green density															X	X	X		
Alkalinity															X	X	X	X	X
Calcium																X			
Chla	X	X	X	X	X	X	X	X	X	X		X	X	X	X				
Chla phenophytin adjusted															X	X	X	X	X
C-Phycocyanin															X	X	X		
Chloride																		X	X
DO								X	X	X		X			X	X	X	X	X
NH3-N															X				
Nitrogen, ammonia as N (field)															X			X	X
Nitrogen, ammonia as N (Lab)															X	X	X		
Nitrogen, Nitrate + Nitrite, as N										X					X	X	X	X	X
ORP															X			X	X
Ortho-P								X		X					X	X	X	X	X
pH								X		X					X	X	X	X	X
Photosynthetically available radiation (PAR)															X	X	X		
Plankton				X	X	X	X	X		X									
Plant Survey										X	X			X		X			
Redox (oxidation potential)															X	X	X		
SC								X		X					X	X	X	X	X
Secchi	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Sediment P Fractionation												X				X			
Sulfate																X			
Temperature								X	X	X		X			X	X	X	X	X
TKN								X		X					X			X	X
Total Depth									X			X							
TP	X	X	X	X	X		X	X	X	X		X	X	X	X	X	X	X	X
TSS																		X	X
Turbidity										X									

Idlewild Lake Water Quality Data Table

Parameters	2014	2015
Alkalinity	X	X
Chla phenophytin adjusted	X	X
Chloride	X	X
DO	X	X
Nitrogen, ammonia as N (field)	X	X
Nitrogen, Nitrate + Nitrite, as N	X	X
ORP	X	X
Ortho-P	X	X
pH	X	X
Plant Survey	X	X
SC	X	X
Secchi	X	X
Temperature	X	X
TKN	X	X
TP	X	X
TSS	X	X

Lotus Lake Water Quality Data Table

Parameters	1972	1975	1978	1979	1980	1981	1984	1985	1988	1989	1990	1991	1994	1999	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Algae, blue-green density																						X				X		
Alkalinity																						X				X	X	X
Chl a,b,c																					X							
Chla	X	X	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Chla phenophytin adjusted																X	X	X	X	X	X		X	X	X	X	X	X
Chl-b																			X	X	X	X	X	X				
Chl-c																			X	X	X	X	X	X				
Cloudiness																											X	X
C-Phycocyanin																					X	X				X	X	X
DO								X			X			X	X		X				X	X				X	X	X
Fish Data													X	X														
Inlet Water Elevation																							X					
Iron																						X						
Manganese																						X						
mercury																						X						
Nitrogen, ammonia as N (field)																						X						
Nitrogen, ammonia as N (Lab)																					X	X				X	X	X
Nitrogen, Nitrate + Nitrite, as N																	X					X				X	X	X
Nitrogen, Nitrate as N																					X							
Nitrogen, Nitrite as N																					X							
ORP																					X	X						
Ortho-P														X			X				X	X				X	X	X
Outlet Water Elevation																							X	X				
pH								X						X	X		X				X	X				X	X	X
phenophytin a																X	X	X	X	X	X	X	X	X				
Photosynthetically available radiation (PAR)																					X	X				X	X	X
Plankton														X			X				X	X						
Plants														X												X	X	
Redox (oxidation potential)																					X	X				X	X	X
SC								X			X			X	X		X				X	X				X	X	X
Secchi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sediment % Solids																					X							
Sediment Ammonia																					X							
Sediment Calcium																					X							
Sediment Iron																					X							
Sediment Lead																					X							
Sediment Magnesium																					X							
Sediment Manganese																					X							
Sediment Mercury																					X							
Sediment Nitrate + Nitrite																					X							
Sediment Ortho P																					X							
Sediment P Fractionation																		X										
Sediment Sulfur																					X							
Sediment TKN																					X							
Sediment TP																					X							
SOD																					X							
Sulfur																						X						
Temperature								X			X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TKN				X	X			X			X			X	X	X	X	X	X	X	X	X	X	X				
Total Depth														X			X											
Total Nitrogen														X														
TP	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Turbidity														X			X											

Mitchell Lake Water Quality Data Table

Parameters	1972	1975	1978	1981	1984	1988	1991	1993	1995	1996	1997	1999	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Algae, blue-green density																				X	X	X				
Alkalinity																				X				X		
Cadmium																				X						
Carbon																				X						
Chl a,b,c																			X							
Chla	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Chla phenophytin adjusted														X	X	X	X	X	X	X	X	X	X			
Chl-b																	X	X	X	X	X	X				
Chl-c																	X	X	X	X	X	X				
Chloride														X											X	X
Cobalt																				X						
Copper																				X						
C-Phycocyanin																			X	X	X	X				
Curlyleaf Pondweed Assessment																									X	
DO								X		X		X				X			X	X	X	X			X	X
Invasive Species																								X		
Iron																				X						
Lead																				X						
Manganese																				X						
mercury																				X						
Methyl Mercury																				X						
Nitrogen, ammonia as N																								X	X	X
Nitrogen, ammonia as N (Lab)																			X	X	X	X				
Nitrogen, Nitrate + Nitrite, as N																X				X				X	X	X
Nitrogen, Nitrate as N																			X							
Nitrogen, Nitrite as N																			X							
ORP																			X	X	X				X	X
Ortho-P								X		X						X			X	X				X	X	X
pH								X	X	X		X	X	X		X			X	X	X	X			X	X
phenophytin a														X	X	X	X	X	X	X	X	X				
Photosynthetically available radiation (PAR)																			X	X	X	X				
Plankton									X	X		X				X		X	X	X						
Plant Survey												X			X			X				X		X		
Redox (oxidation potential)													X	X					X	X	X	X				
SC								X		X		X				X			X	X	X	X			X	X
Secchi	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sediment % Solids																			X							
Sediment Ammonia																			X							
Sediment Calcium																			X							
Sediment Core (Paleolimnological)																				X						
Sediment Iron																			X							
Sediment Lead																			X							
Sediment Magnesium																			X							
Sediment Manganese																			X							
Sediment Mercury																			X							
Sediment Nitrate + Nitrite																			X							
Sediment Ortho P																			X							
Sediment P Fractionation																X										
Sediment Sulfur																			X							
Sediment TKN																			X							
Sediment TP																			X							
SOD																			X							
Soluble Reactive Phosphorus												X														
Sulfur																				X						
Temperature								X	X	X		X	X	X	X	X	X	X	X	X	X	X	X			
TKN								X	X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Total Depth										X						X				X						
Total Nitrogen										X		X														
TP	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TSS																								X	X	X
Turbidity												X		X		X										
Zinc																				X						

Red Rock Lake Water Quality Data Table

Parameters	1972	1975	1978	1981	1984	1988	1991	1993	1996	1999	2000	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Algae, blue-green density																				X	X	X		
Alkalinity																				X	X	X	X	X
Calcium																					X			
Chla	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X				
Chla phenophytin adjusted												X	X		X					X	X	X	X	X
Chl-b															X					X				
Chl-c															X					X				
Cloudiness																							X	X
C-Phycocyanin																				X	X	X	X	X
DO									X	X	X	X	X	X	X					X	X	X	X	X
Fish Survey										X														
Invasive Species																						X		
NH3-N																				X				
Nitrogen, ammonia as N (Lab)																				X	X	X	X	X
Nitrogen, Nitrate + Nitrite, as N														X						X	X	X	X	X
ORP																				X				
Ortho-P									X	X				X						X	X	X	X	X
Perfluorobutane sulfonate																X								
Perfluorobutanoic acid																X								
Perfluorodecanoic acid																X								
Perfluorohexane sulfonate																X								
Perfluorohexanoic acid																X								
Perfluorolauric acid																X								
Perfluorononanoic acid																X								
Perfluorooctane sulfonate																X								
Perfluorooctanesulfonamide																X								
Perfluorooctanoic acid																X								
Perfluoroundecanoic acid																X								
Perfluorovaleric acid																X								
pH									X	X	X	X	X	X	X				X	X	X	X	X	X
phenophytin a												X	X		X					X				
Photosynthetically available radiation (PAR)																				X	X	X	X	X
Plankton										X										X				
Plants										X			X	X				X	X					
Redox (oxidation potential)											X	X	X		X					X	X	X	X	X
SC									X	X	X	X	X	X	X				X	X	X	X	X	X
Secchi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sediment P Fractionation												X		X							X			
Sulfate																					X			
Temperature								X	X	X	X	X	X	X	X					X	X	X	X	X
TKN										X	X	X	X	X	X					X				
Total Depth									X	X				X										
Total Nitrogen									X	X														
TP	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Tridecafluoroheptanoic acid																X								
Turbidity										X		X	X	X	X									

Round Lake Water Quality Data Table

Parameters	1972	1975	1978	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1991	1992	1993	1996	1997	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Algae, blue-green density																											X	X	X			
Alkalinity																											X	X		X	X	X
BOD																												X				
Calcium																												X		X		
Chl a,b,c																										X						
Chla	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X		X	X	X	X	X		X	X	X
Chla phenophytin adjusted																										X		X				
Chloride																															X	X
COD																												X				
C-Phycocyanin																										X	X	X	X			
DO		X	X														X	X	X			X				X	X	X	X	X		X
e. coli																											X					
Fish Survey															X																	
Invasive Species																														X		
iron																											X	X				
Manganese																											X	X				
mercury																											X					
Methyl Mercury																												X				
Nitrogen, ammonia as N																														X	X	X
Nitrogen, ammonia as N (Lab)																										X	X	X	X			
Nitrogen, Nitrate + Nitrite, as N																			X			X					X	X		X	X	X
Nitrogen, Nitrate as N																										X						
Nitrogen, Nitrite as N																										X						
ORP																										X	X	X	X			
Ortho-P																			X		X	X				X	X	X		X	X	X
pH																	X	X	X	X	X	X				X	X	X	X	X		X
Photosynthetically available radiation (PAR)																										X	X	X	X			
Plankton																		X	X		X	X				X	X					
Plants																X		X		X						X	X	X			X	X
Redox (oxidation potential)																										X	X	X	X			X
SC		X															X	X	X	X	X	X				X	X	X	X			X
Secchi	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X		X		X	X	X	X	X	X	X
Sediment % Solids																										X						
Sediment Ammonia																										X						
Sediment Calcium																										X						
Sediment Core (Paleolimnological)																											X					
Sediment Iron																										X						
Sediment Lead																										X						
Sediment Magnesium																										X						
Sediment Manganese																										X						
Sediment Mercury																										X						
Sediment Nitrate + Nitrite																										X						
Sediment Ortho P																										X						
Sediment P Fractionation																							X									
Sediment Sulfur																										X						
Sediment TKN																										X						
Sediment TP																										X						
SOD																										X						
Soluble Reactive Phosphorus																	X	X														
Sulfate																												X		X		
Sulfide																												X				
Sulfur																											X					
Temperature		X	X														X	X	X	X	X	X				X	X	X	X	X		X
TKN																			X			X				X	X	X		X	X	X
Total Depth																	X	X	X	X	X	X										
Total Nitrogen																	X	X			X											
TP	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X		X	X	X
TSS																														X	X	X
Turbidity																			X	X	X	X										

Silver Lake Water Quality Data Table

Parameters	1996	2000	2005	2010	2011	2012	2013	2014	2015
Algae, blue-green density					X	X	X		
Alkalinity					X	X	X	X	X
Calcium						X			
Chla	X	X	X		X				
Chla phenophytin adjusted					X	X	X	X	X
Cloudiness								X	X
C-Phycocyanin					X	X	X	X	X
DO	X	X	X		X	X	X	X	X
NH3-N					X				
Nitrogen, ammonia as N (Lab)					X	X	X	X	X
Nitrogen, Nitrate + Nitrite, as N		X	X		X	X	X	X	X
ORP					X				
Ortho-P	X	X	X		X	X	X	X	X
pH	X	X	X		X	X	X	X	X
Photosynthetically available radiation (PAR)					X	X	X	X	X
Plankton	X	X							
Plants	X	X							
Redox (oxidation potential)					X	X	X	X	X
SC	X	X	X		X	X	X	X	X
Secchi	X	X	X		X	X	X	X	X
Sediment P Fractionation			X						
Sulfate						X			
Temperature	X	X	X		X	X	X	X	X
TKN	X	X	X		X				
Total Depth	X	X	X						
Total Nitrogen	X	X							
TP	X	X	X		X	X	X	X	X
Turbidity		X	X						

Starring Lake Water Quality Data Table

Parameters	1971	1975	1978	1980	1981	1982	1983	1984	1985	1986	1987	1988	1991	1993	1995	1996	1999	2001	2002	2004	2005	2006	2008	2009	2010	2011	2012	2013	2014	2015
Algae, blue-green density																									X	X	X	X		
Alkalinity																										X	X	X	X	X
Aluminum				X																										
Arsenic				X																										
Barium				X																										
BOD																									X					
Boron				X																										
Cadmium				X																										
Calcium																											X			
Chla	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
Chla phenophytin adjusted																		X		X		X			X	X	X	X	X	X
Chl-b																						X								
Chl-c																						X								
Chloride				X																X		X								
Chromium				X																										
Cloudiness																													X	X
COD																									X					
Copper				X																										
C-Phycocyanin																									X	X	X	X	X	X
DO				X					X						X	X	X	X	X	X	X	X			X	X	X	X	X	X
Invasive Species																											X			
Iron				X																					X	X				
Lead				X																										
Manganese				X																					X					
mercury				X																										
NH3-N																										X				
Nickel				X																										
Nitrogen, ammonia as N																										X				
Nitrogen, ammonia as N (Field)																									X	X				
Nitrogen, ammonia as N (Lab)																									X	X	X	X	X	X
Nitrogen, Nitrate + Nitrite, as N				X					X										X		X				X	X	X	X	X	X
ORP																									X	X	X	X		
Ortho-P																X			X		X				X	X	X	X	X	X
Perfluorobutane sulfonate																							X							
Perfluorobutanoic acid																							X							
Perfluorodecanoic acid																							X							
Perfluorohexane sulfonate																							X							
Perfluorohexanoic acid																							X							
Perfluorolauric acid																							X							
Perfluorononanoic acid																							X							
Perfluorooctane sulfonate																							X							
Perfluorooctanesulfonamide																							X							
Perfluorooctanoic acid																							X							
Perfluoroundecanoic acid																							X							
Perfluorovaleric acid																							X							
pH				X					X						X	X	X	X	X	X	X	X			X	X	X	X	X	X
Pheophytin a																		X		X		X								
Photosynthetically available radiation (PAR)																									X	X	X	X	X	X
Plankton																									X	X				
Plants																				X				X		X				
Redox (oxidation potential)																									X	X	X	X	X	X
SC				X					X						X	X	X	X	X	X	X	X			X	X	X	X	X	X
Secchi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sediment P Fractionation																					X									
Sulfate																											X			
Temperature				X					X						X	X	X	X	X	X	X	X			X	X	X	X	X	X
TKN				X					X						X		X	X	X	X	X	X			X	X				
Total Depth																X			X		X									
Total Nitrogen														X																
TP	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Tridecafluoroheptanoic acid																							X							
TSS				X																						X				
Turbidity				X															X	X	X	X								
Volatile suspended solids				X																										

Purgatory Creek Water Quality Data Table

Parameters	2004	2005	2006	2008	2009	2010	2011	2012	2013	2014
Storm Composite Samples	X	X	X							X
Continuous Data	X	X	X							X
Grab Samples	X	X	X	X	X	X	X	X	X	X
a-Chlorophylltrichromatic	X	X	X							X
Alkalinity	X	X	X	X						X
Cadmium	X	X	X							
Calcium										X
Chl a,b,c				X						
Chla phenophytin adjusted	X	X	X	X						X
Chloride Ion	X	X	X							X
Chlorophyllpheophytin	X	X	X							X
Chromium	X	X	X							
COD	X	X	X							X
Copper	X	X	X							
Depth										X
Dissolved P	X	X	X							
DO					X	X	X	X	X	X
Fecal coliform	X	X	X							X
Fish Survey					X	X				
Flow	X	X	X		X	X	X	X	X	X
Habitat Assessment						X	X			
Hardness	X	X	X							X
Lead	X	X	X							
Macroinvertebrates						X	X			
magnesium										X
Nickel	X	X	X							
Nitrogen, ammonia as N	X	X	X	X						X
Nitrogen, Nitrate as N	X	X	X	X						X
Nitrogen, Nitrite as N	X	X	X	X						X
Ortho P	X	X	X							X
pH				X	X	X	X	X	X	X
Physical Characteristics						X	X			
Redox (oxidation potential)					X	X	X	X	X	X
SC	X	X	X							X
Stream width										X
Sulfate	X	X	X							X
TBOD 5-day	X	X	X							
Temperature										X
Temperature					X	X	X	X	X	
TKN	X	X	X	X	X	X				X
TOC	X	X	X							X
Total P	X	X	X		X	X	X	X	X	X
TSS	X	X	X		X	X	X	X	X	X
Turbidity	X	X	X							X
Turbidity	X	X	X		X	X	X	X	X	X
Velocity					X	X	X	X	X	X
VSS	X	X	X							X
Zinc	X	X	X							

Appendix D

In-Lake Model Parameter Selection and Calibration

Appendix D: Watershed and Lake Modeling Methodology

D.1 P8 Watershed Modeling

Water quality modeling was conducted using the P8 Urban Catchment Model (Program for Predicting Polluting Particle Passage thru Pits, Puddles, and Ponds). P8 is a model used for predicting the generation and transport of stormwater runoff and pollutants in urban watersheds. The model tracks the movement of particulate matter (fine sand, dust, soil particles, etc.) as it is carried along by stormwater runoff traveling over land and pavement. Particle deposition in ponds/infiltration practices are tracked in order to estimate the amount of pollutants that eventually reach a water body. P8 is a diagnostic tool used for evaluating and designing watershed improvements and BMPs. P8 version 3.4 was used for all model development.

When evaluating the results of the modeling, it is important to consider that the results provided are more accurate in terms of relative differences than in absolute results. The model will predict the percent difference in phosphorus reduction between various BMP options in the watershed fairly accurately. It also provides a realistic estimate of the relative differences in phosphorus and water loadings from the various subwatersheds and major inflow points to the lake. However, since runoff quality is highly variable with time and location, the phosphorus loadings estimated by the model for a specific watershed may not necessarily reflect the actual loadings, in absolute terms. Various site-specific factors, such as lawn care practices, illicit point discharges, and erosion due to construction, are not accounted for in the model. The model provides values that are considered to be typical of the region, given the watershed's respective land uses.

D.1.1 Watershed boundaries

Watershed boundaries were delineated for each lake. Watersheds were delineated to existing BMPs, wetlands, other waterbodies, or large section of stormsewer. Each BMP was delineated with its own subwatershed. Existing subwatersheds from the city of Eden Prairie and previous P8 models were reviewed and updated when appropriate based on 2011 MDNR LiDAR topographic data, storm sewer data, record drawings, and other information provided by the RPBCWD as well as the cities.

D.1.1.1 Staring Lake Watersheds

The total watershed area of Staring lake is over 10,000 acres. P8 has a limit of 76 devices that can be placed into one model. Therefore the P8 model for Staring Lake was divided into two models. The first model covered areas contributing to the Purgatory Creek Recreational Wetland (PCR model). The second model covered areas directly contributing to Staring Lake. All upstream lakes (Duck Lake, Silver Lake, Lotus Lake, Round Lake, Mitchell Lake and Red Rock Lake) were modeled independently from Staring Lake. The PCR model was divided into two sections above and below the intersection of Purgatory Creek and Valley View Road. A single watershed represents the contributing areas to Purgatory Creek north of the Purgatory Creek Valley View Road intersection (Valley View Watershed). South of this intersection watershed are drawn to individual BMPs. Flow and TP from the Valley View watershed were calibrated to flow and TP concentrations measured at the Valley View WOMP station.

A single infiltration device was created to collect flow from the Valley View watershed. Parameters of the infiltration basin were calibrated to match the flows and TP loads leaving this watershed. Water infiltration through percolation from the watershed and the infiltration basin were accumulated in an aquifer device and rerouted back as an outflow to account for baseflow conditions of Purgatory Creek. Modeled flow and TP loads exiting the device were compared with flow measurement recorded and composite storm TP concentrations recorded at the Purgatory Creek Valley View station. The calibration was conducted between June 3, 2015 and September 30, 2015. Over the calibration period the total measured flow was recorded as 1763 acre-ft. The modeled flows were calculated as 1773 acre-ft. Event mean TP concentrations (EMC) were also compared for 6 events. Table D.1 shows the comparison between the measured and modeled EMC values.

Table 0.1 Comparison between measured and modeled TP EMC values at Purgatory Creek Valley View Station

date	Measured TP EMC (mg/l)	P8 modeled TP EMC (mg/l)
6/22/2015	0.244	0.228
6/30/2015	0.173	0.186
7/6/2015	0.233	0.203
7/13/2015	0.195	0.201
8/18/2015	0.254	0.178
9/17/2015	0.246	0.255

D.1.2 Land Use

Land use data was obtained to estimate both the percentage of directly and indirectly connected imperviousness within each watershed. The directly-connected impervious fraction consists of the impervious surfaces that are "connected" directly to stormwater conveyance systems, meaning that flows do not cross over pervious areas. The indirectly connected impervious fraction represents impervious areas that flow over pervious areas before reaching the stormwater conveyance system. Percent imperviousness was calculated 2010 land use data from the Metropolitan Council. Table D.2 shows the 2010 land use categories with the assigned percent impervious and percent directly connected impervious areas.

Table 0.2 Impervious Assumption by 2010 Land Use Category

2010 Land Use Categories	Total Percent Impervious	Percent Directly Connected Impervious
Agricultural	5	1
Airport	5	1
Retail and Other Commercial	86	85
Mixed use commercial	86	85
Golf course	6	5
Manufactured Housing Parks	68	50
Major highway	50	50
Railway	65	65
Office	73	72
Industrial and Utility	73	72
Mixed use industrial	73	72
Mixed use residential	59	37
Institutional	49	40
Single family detached	35	20
Multifamily	59	37
Single family attached	50	30
Seasonal/Vacation	30	20
Park, Recreational, or Preserve	6	5
Undeveloped	3	0
Open Water	100	100
Extractive	60	50
Farmstead	25	12

D.1.3 Curve Numbers

The pervious curve number (a measure of how easily water can percolate into the soil) was determined for each P8 drainage basin. Data from the 2015 gridded soil survey geographic (gSSURGO) database (Soil Survey Staff, 2015) were used to determine the hydrologic soils group (HSG) in each watershed. The HSG serves as an indicatory of a soils infiltration capacity. Hydrologic soils groups range from type A soils that are well drained with high infiltration capacities to HSG type D soils that are poorly drained with the lowest infiltration capacities. Some areas in the county soil surveys are not defined. For these areas a HSG of type B was assumed. Using the curve number classifications, a composite pervious area curve number was calculated for each of the subwatersheds. Curve numbers were assigned based on soil type (Table D.3) and an area weighted average curve number for each subwatershed was calculated.

Table 0.3: Pervious area curve number classification by HSG soil type

HSG Soil Type	Curve Number
A	39
B	61
C	74
A/D	80
B/D	80
C/D	80
D	80

D.1.4 Drainage Patterns

Drainage patterns were reviewed and updated from previous P8 models where appropriate or determined based on 2011 MDNR LiDAR topographic data, storm sewer data, record drawings, and other information provided by the RPBCWD as well as the cities. Development plans submitted as part of the RPBCWD permit review process for projects implemented after the original UAA was completed were also used as a data source.

D.1.5 Pollutant Removal Device Information

The P8 water quality model can predict pollutant removal efficiency for a variety of treatment practices such as detention ponds and infiltration basins. The model can also be used to simulate pollutant removal from alternative BMPs such as underground treatment devices. The modeled treatment practices are referred to in the P8 model as pollutant removal 'devices'.

Inputs for the ponds and wetlands included in the previously developed models were reviewed and adjusted if more current data were available. Pond outlets were checked against the GIS storm-sewer and as-built data from the cities of Chanhassen and Eden Prairie. The water volumes below the pond outlet (i.e., dead storage) were checked against field survey data and as-built plans. Pond live storage was adjusted using volumes calculated from the MNDNR's 2011 LiDAR data. In some cases, there were existing ponds that were not included in the original P8 modeling without readily available data to develop the pond inputs. In these cases, the pond removal efficiencies were calculated using the ratio of the contributing watershed impervious area to the pond surface area and an assumed pond depth following the method described in the document Phosphorus Removal by Urban Runoff Detention Basins (Walker, 1987). The new ponds and wetland areas included in the updated P8 model were developed using the same data sources listed above. In cases where no data was available, the new ponds, without available as-built or survey data, were assumed to be built to NURP specifications.

D.1.6 Other Model Parameters

- **Time Steps Per Hour (Integer) = 20.** Modified from original UAA P8 model to eliminate continuity errors greater than 2%.

- **Minimum Inter-Event Time (Hours) = 10.** Preserved from the original UAA P8 model. Similar to the original model calibration year of 1998, during 2014 frequent storms were noted during the summer. Use of this parameter resulted in a good fit between the observed and modeled lake volumes and was preserved from the original model. It should be noted that the average minimum inter-event time in the Minneapolis area is 6 hours.

- **Snowmelt Melt Coef (Inches/Day-Deg-F) = 0.06**. Preserved from the original UAA P8 model. This selection was based on the snowmelt rate that provided the best match between observed and predicted snowmelt in the original UAA.

- **Snowmelt Scale Factor for Max Abstraction = 1**. This factor controls the quantity of snowmelt runoff (i.e., controls losses due to infiltration). Selection was based upon the factor that resulted in the closest fit between modeled and observed runoff volumes, based on the original Lake Riley P8 model calibration. Preserved from the original UAA P8 model.

- **Growing Season Antecedent Moisture Conditions AMC-II = 0 and AMC-III = 0**. Selection of this factor was based upon the observation that the model accurately predicted runoff water volumes from monitored watersheds when the Antecedent Moisture Condition III was selected (i.e., curve numbers selected by the model are based upon antecedent moisture conditions). Modeled water volumes were less than observed volumes when Antecedent Moisture Condition I or II was selected. The selected parameters tell the model to only use Antecedent Moisture Condition III. Preserved from the original UAA P8 model.

- **Particle Scale Factor for TP = 1.** The particle scale factor determines the total phosphorus load generated by the particles predicted by the model in watershed runoff. Modified from the original UAA P8 model (1.42) in order to reduce the loading to the lakes and produce a better fit to observed lake data.

- **Particle File = NURP50.PAR.** The NURP 50 particle file was found to most accurately predict phosphorus loading to Round Lake. Preserved from the original UAA P8 model.

- **Precipitation File Selection = MSP_FC4915_Corr.pcp.** For the 2008-2014 climatic conditions, a continuous hourly precipitation file was developed based on data from the Flying Cloud Airport weather station. For any gaps in the local precipitation record, the hourly data from the Minneapolis-St. Paul International Airport NWS stations (MSP) was used and adjusted based on comparison of the daily precipitation amounts at MSP to the daily data collected at the Chanhassen NWS station.

- **Air Temperature File Selection MSP_FC4915.tmp.** For the 2008-2014 climatic conditions, a continuous daily average temperature file was developed based on data from the Flying Cloud Airport weather station.

- **Particle Removal Scale Factor. = 0.3** for ponds less than 2 feet deep and 1 for all ponds 3 feet deep or greater. The particle removal factor for watershed devices determines particle removal by devices. The factor was selected to match observed phosphorus loads and modeled loads. Insufficient information was available to say with certainty the particle removal scale factor for ponds 2 to 3 feet deep. A factor of 0.6 was used for all ponds of this depth. Preserved from the original UAA P8 model.

- **Swept/Not Swept. =** An "Unswept" assumption was made for the entire impervious watershed area. A Sweeping Frequency of 0 was selected. Selected parameters were placed in the "Swept" column since a sweeping frequency of 0 was selected. Preserved from the original UAA P8 model.

- **Impervious Depression Storage = 0.0065.** Preserved from the original UAA P8 model.

- **Impervious Runoff Coefficient = 1.** Preserved from the original UAA P8 model.

D.2 In-Lake Water Quality Mass Balance Modeling

For the majority of Minnesota lakes, phosphorus is the limiting nutrient for algae, and an increase in phosphorus results in an increase in chlorophyll *a* concentrations and a decrease in water clarity. Eutrophic lakes can be restored by reducing phosphorus concentrations. An in-lake mass balance model for phosphorus was developed for each lake in order to quantify phosphorus source loads to the lake. In-lake modeling for each lake was accomplished through the creation of a daily time-step mass balance model that tracked the flow of water and phosphorus through the lake over the range of observed climatic conditions. The following sections discuss the methodology used for the in-lake water quality mass balance modeling that first includes the development of a water balance model followed by the development of a phosphorus mass balance model.

D.2.1 Lake Model Water Balance

The first step of the in-lake water quality mass balance modeling is to develop and calibrate the water balance portion of the model. The water balance is a daily time-step model that tracks the inflows to and outflow from the lake system. Typical inflows of water to a lake include direct precipitation and watershed runoff (as generated by the watershed model), and can also include inflows from upstream lakes and/or inflows from groundwater (depending on the lake system). Losses from a lake include evaporation from the lake surface and discharge through the outlet (if applicable), and can also include losses to the groundwater (depending on the lake system). By estimating the change in storage in the lake on a daily time step, the model can be used to predict lake levels, which can then be compared to observed lake levels, which can then be used to estimate groundwater exchange and verify the estimated watershed model runoff volumes.

The lake water balance calculated the total lake water volume through the simulated daily gains and losses into the lake. The water balance is represented by the following equation:

$$V_i = V_{i-1} + (I_W + I_{LC}) + P * A_S - E * A_{S,(i-1)} - O + G$$

Where:

V = Lake volume (acre-ft)
i = Daily time step
I_W = Inflow from modeled lake's direct watershed (acre-ft/day)
I_{LC} = Total daily inflow from upstream lake (acre-ft/day)
P = Daily precipitation depth (ft/day)
E = Daily evaporation depth (ft/day)
A_S = Lake surface area (acres)
O = Outflow (acre-ft/day)
G = Groundwater flow (acre-ft/day)

Key input parameters into the lake models include lake depth recorded every 15 minutes while the level sensor is in place during ice free period, lake volume estimated using a relationship between lake elevation and lake cumulative volume (Tables D.4 – D.11), daily inflow rate from the direct watershed calculated using the P8 watershed model, daily inflow rate from upstream lakes, daily outflow rates estimated using lake water elevation data with the creation of outflow rating curves (Tables D.4 – D.11), daily precipitation data recorded at the Flying Cloud airport weather station over the lakes surface area, and evaporation calculated using the Lake Hefner equation (Marciano and Harbeck, 1954) described below:

$$E = 0.00177u(e_o - e_a)$$

$$e_0 = 6.11 * 10^{\frac{7.5*T_W}{237.7+T_W}}$$

$$e_a = 6.11 * 10^{\frac{7.5*T_A}{237.7+T_A}}$$

Where:

E = evaporation (inches)
U = wind speed (mph)
e_o = vapor pressure of the saturates area at the temperature of the water surface
e_a = vapor pressure of the air
T_W = surface water temperature in (°C)
T_A = air temperature in (°C)

Climate data (wind speed, air temperature, and relative humidity) were obtained from the Minneapolis-St. Paul International Airport. Surface water temperatures (TW) were obtained from lake monitoring data.

Groundwater flows were not available for the study lakes. Net groundwater flows were estimated for the study lakes such that model predicted changes in lake volume agreed with observed changes in lake volume.

Table 0.4 Staring Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acres-ft)	Outflow (cfs)
798.6	0.00	0.00	0.00
799.6	9.03	4.52	0.00
804.6	42.35	132.97	0.00
809.6	106.10	504.08	0.00
813.9	159.26	1077.27	0.03
814.0	160.50	1090.60	0.27
814.5	164.06	1174.41	9.25
815.0	167.62	1258.22	20.40
816.0	174.74	1425.84	62.13
817.0	190.55	1616.39	140.36
818.0	206.37	1806.95	263.25

Table 0.5 Lotus Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
864.6	0.00	0.00	0.00
870.6	2.80	8.42	0.00
875.6	16.59	56.89	0.00
880.6	63.25	256.48	0.00
885.6	127.89	734.31	0.00
890.6	176.72	1495.84	0.00
895.0	233.76	2427.43	0.00
895.4	238.95	2512.12	0.00
895.5	240.24	2533.29	1.15
896.0	246.73	2639.15	14.77
897.0	262.96	2902.12	18.55
898.0	279.20	3165.08	21.05

Table 0.6 Duck Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
906	0.00	0.00	0.00
909.3	6.74	11.23	0.00
914	40.61	121.79	0.00
914.4	41.28	138.70	0.00
914.5	41.45	142.93	0.06
915	42.29	164.08	1.06
915.5	43.13	185.22	2.55
916	43.96	206.36	4.19
916.5	44.74	229.12	9.40

Table 0.7 Silver Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
885	0.00	0.00	0.00
886	0.01	0.00	0.00
887	0.12	0.07	0.00
888	0.37	0.31	0.00
889	0.74	0.87	0.00
890	1.18	1.83	0.00
891	1.78	3.31	0.00
892	3.17	5.78	0.00
893	6.84	10.79	0.00
894	19.45	23.93	0.00
895	29.83	48.57	0.00
896	41.08	84.02	0.00
897	58.39	133.76	0.00
898	67.93	196.92	0.00
898.5	69.11	232.06	0.00
898.6	69.34	239.09	0.12
899	70.28	267.20	3.04
899.5	71.46	302.34	8.52
900	72.64	337.48	9.59
900.5	74.11	375.28	10.10
901	75.58	413.07	10.53
902	78.52	488.65	11.35

Table 0.8 Mitchell Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
851.2	100	0.00	0.00
856.2	148,322	8.52	0.00
861.2	462,113	43.55	0.00
866.2	2,286,894	201.32	0.00
868.3	3,778,643	376.64	0.00
868.5	3,920,714	393.34	0.12
869	4,275,893	435.08	0.63
869.5	4,631,071	476.82	0.92
870	4,986,249	518.56	1.15
871	5,223,038	638.47	1.52
872	5,459,828	758.37	5.08
873	5,599,480	886.92	15.97
874	5,739,133	1015.47	23.35

Table 0.9 Red Rock Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
821.55	0.00	0.00	0.00
825	0.41	0.75	0.00
830	3.87	11.45	0.00
835	51.11	148.90	0.00
837.8	88.05	370.44	0.01
838	90.89	387.49	0.11
838.5	98.00	430.09	0.57
839	105.10	472.70	0.87
839.5	112.20	515.30	1.10
840	119.31	557.90	1.30
841	123.43	681.34	9.32
842	127.56	804.77	17.54
843	130.50	935.27	21.72
844	133.43	1065.77	24.69

Table 0.10 Round Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
841.7	0.00	0.00	0.00
843.8	0.26	0.28	0.00
848.8	2.13	6.27	0.00
853.8	5.39	25.08	0.00
858.8	7.47	57.21	0.00
863.8	9.45	99.51	0.00
868.8	11.76	152.54	0.00
873.8	14.61	218.45	0.00
878	29.40	310.87	0.00
879	30.56	341.44	0.00
879.1	30.68	344.49	0.02
879.5	31.15	356.72	0.38
880	31.73	372.00	1.14
880.5	32.65	388.79	4.00
881	33.57	405.57	5.33
881.5	34.50	422.36	5.91
882	35.42	439.15	6.46
883	38.80	477.95	7.40

Table 0.11 Idelwild Lake Bathymetry and Outflow

Water Elevation (ft)	Surface Area (acres)	Cumulative Volume (acre-ft)	Outflow (cfs)
845.8	0.00	0.00	0.00
847	0.80	0.48	0.00
848	2.66	2.21	0.00
849	5.63	6.36	0.00
850	7.61	12.98	0.00
851	9.20	21.38	0.00
853.5	12.08	48.70	0.00
853.6	12.19	49.79	0.03
854	12.65	54.16	1.23
854.5	13.18	61.02	2.66
855	13.71	67.88	3.03
855.5	14.24	74.73	3.43
856	14.77	81.59	3.65
857	15.27	96.86	4.12
857.5	15.53	104.50	4.34

D.2.2 Lake Model Total Phosphorus Balance

While the watershed model is a useful tool for evaluating runoff volumes and pollutant concentrations from a watershed, another method is needed to predict the in-lake phosphorus concentrations that are likely to result from the various phosphorus loads. In-lake phosphorus modeling was accomplished through the creation of a daily time-step mass balance model that tracked the flow of water and phosphorus through the lake over a range of climatic conditions. A daily time-step model was chosen because of the high variability in the nutrient-related water quality parameters. Using a daily time-step model (instead of an annual model, e.g., Bathtub), allowed for the determination of the critical components (i.e., internal vs. external phosphorus sources), causing water quality standard exceedance as well as allowing for lake response modeling of management methods during the periods of standard exceedance. Once calibrated, the models could be used predictively to evaluate the lake phosphorus concentrations under a variety of scenarios, including future land-use conditions, and following the implementation of remedial watershed BMPs and in-lake management strategies.

The lake phosphorus budgets are based on the Vollenweider (1969) mass balance equation:

$$TP = (L + L_{int})/(\bar{Z} * (\rho + \sigma))$$

Where:

- $\bar{Z}$ = average lake depth in meters
- ρ = flushing rate in yr^{-1}
- σ = sedimentation rate in yr^{-1}
- L = areal loading rate in $mg/(m^2*yr)$
- L_{int} = internal loading rate in $mg/(m^2*yr)$

A difference between Vollenweider's equation and the model used for this study is that the parameters in the above equation were used on a daily timestep as opposed to an annual basis. Also, the magnitude of the net internal phosphorus load to the lake surface was determined by comparing the observed water quality in the lake to the water quality predicted by the in-lake model under existing conditions.

The in-lake phosphorus mass balance model assumed a fully mixed lake volume, i.e. the phosphorus concentration is uniform throughout the lake volume. The change in the total phosphorus mass within the lake was calculated with the following mass balance equation:

Δ Phosphorus Mass = Watershed Inputs + Direct Deposition to Lake Surface + Internal Loading – Surface Outflow – Groundwater Outflow – Settling of In-Lake Phosphorus

Key input parameters in the lake phosphorus budget include phosphorus loads from upstream lakes, atmospheric deposition and from the direct watershed; internal loading from the lake sediments; loading or losses from groundwater depending if the groundwater is flowing into or out of the lake; and loses through settling and outflow.

The loading from upstream lakes was calculated using existing daily in-lake models for the lake upstream if available. This method was used for Staring Lake and Lake Riley. If an existing model was not available upstream loads were calculated using inflow rates estimated from the upstream lake's water surface elevation and rating curve combined with the surface phosphorus concentration recorded in the lake. This method was used for Lake Susan. The phosphorus load from the lakes direct watersheds was calculated using the P8 modeling results. Atmospheric deposition of phosphorus onto the lakes water surfaces was calculated by using the estimated statewide phosphorus atmospheric deposition rate of 0.17 kg/ha/year (Barr, 2004) combined with the lakes water surface areas based on the current water elevation. Groundwater loads were either a source or a sink for phosphorus depending on if water was flowing into or out of the lake respectively. If the net daily groundwater flow was into the lake, the load of phosphorus was calculated using the groundwater flow rate and an estimate for groundwater phosphorus concentration of 0.035 mg/l. If the net flow was out of the lake then the loss of phosphorus was estimated using the flow rate and the average lake phosphorus concentration. The loss of phosphorus through outflow from the lakes was calculated using the measured surface concentrations of total phosphorus and the outflow rate calculated in the water balance.

The final two parameters, settling and internal loading, were used to calibrate the model to the recorded lake concentrations. Lake mixing and anoxic conditions can create an environment in the lake that is conducive to internal loads at times. At other times, the lake does not experience a significant internal load (generally spring and fall). Monitoring data (phosphorus, temperature, and dissolved oxygen profiles) provided useful information in determining when the lake is susceptible to internal loading from the sediment. Dissolved oxygen data was used to determine when anoxic conditions were present what area was under anoxic conditions. When the dissolved oxygen concentration was below 1 mg/l the sediments at that depth were considered to be anoxic resulting in internal loading of iron-bound phosphorus. The rate of phosphorus loading was calibrated for each year to match the measured data.

The sedimentation rates for the lakes were calibrated using in-lake TP monitoring data from well mixed periods without the conditions necessary for internal phosphorus loading. At these times (generally in spring and fall after turnover) phosphorus concentration in the surface waters of the lake is only affected by sedimentation, flushing, and incoming external loads of phosphorus from the watershed and atmosphere. This was accomplished by setting the internal loading rate (L_{int}) in the above equation by Vollenweider to zero and adjusting the settling rate so that the calculated, in-lake phosphorus concentration matched the monitored phosphorus during the spring period.

D.2.3 Lake Surface Model Concentration

Surface water phosphorus concentration are required to determine if a lake is meeting or exceeding the phosphorus standard. Therefore, the volumetric average lake models were further divided into two completely mixed models representing the lake epilimnion and hypolimnion for lakes that displayed persistent stratification throughout the summer (Lotus, Round, Red Rock, and Mitchell). All parameters in the volumetric model remained the same in the lake surface models. The main change between the two approaches was the internal loading and groundwater sources were only applied to the hypolimnion and all other phosphorus sources (atmospheric, direct watershed, and upstream lake inflows) were applied to the epilimnion. Mixing between the hypolimnion and the epilimnion were determined based on temperature profiles. The point of the maximum temperature gradient was used as the dividing depth between the two layers. Temperature profiles taken during open water periods were used to calculate the thermocline depth. As this depth moved up or down in the lake water was mixed between the two layers appropriately. The parameters were then applied to the whole lake volumetric model to check that they produced a reasonable result in this analysis as well.

D.2.4 Lotus Lake Model Calibration

The Lotus Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 – September 2015). The Lotus Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation. Both the epilimnion and hypolimnion total phosphorus concentrations were modeled in Lotus Lake due to its thermally stratifying during the growing season. Dividing the lake model into these separate layers enabled a more accurate estimate of internal loading. The Lotus Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure D.1 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic total phosphorus concentrations. Figure D.2 shows the comparison between the modeled, monitored surface and monitored epilimnetic volumetric averaged total phosphorus concentrations over the course of the 2015 water year.

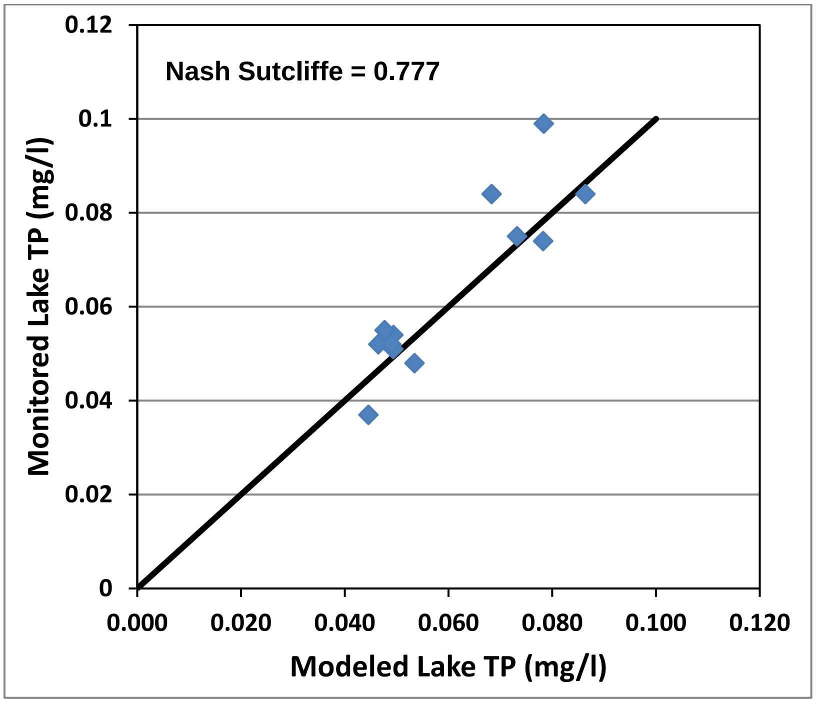

Figure D.1 Lotus Lake comparison between modeled volumetric average TP concentration and measured concentrations

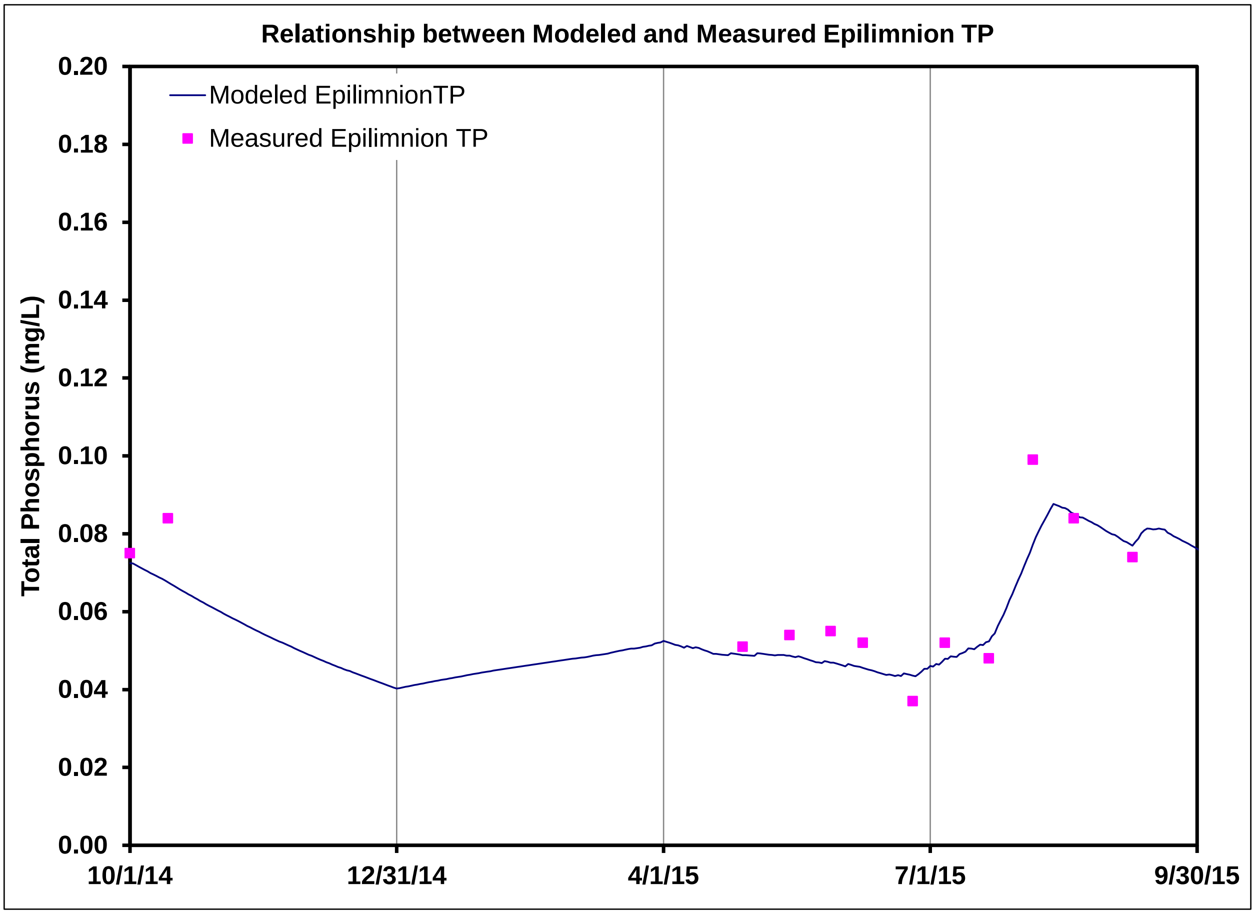

Figure D.2 **Lotus Lake time series comparison between modeled and measured surface water TP concentrations.**

D.2.5 Staring Lake Model Calibration

The Staring Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 – September 2015). The Staring Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater outflows were used to match the observed water surface elevation throughout the year. Total phosphorus concentrations were balanced on a whole lake basis since Staring Lake does not have a stable thermal stratification during the growing season. The Staring Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity. Inflows from upstream lakes were entered based on in-lake models constructed for Red Rock Lake, Duck Lake, Lotus Lake and Silver Lake as part of the ongoing Purgatory Creek Watershed Assessment. Inflows from Red Rock Lake were adjusted based on modeled removal efficiencies of downstream ponds including Lake McCoy before it enters Staring Lake.

Figure D.3 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged total phosphorus concentrations for the entire water column. Figure D.4 shows the comparison between the modeled, monitored surface and monitored volumetric averaged total phosphorus concentrations over the course of the 2015 water year.

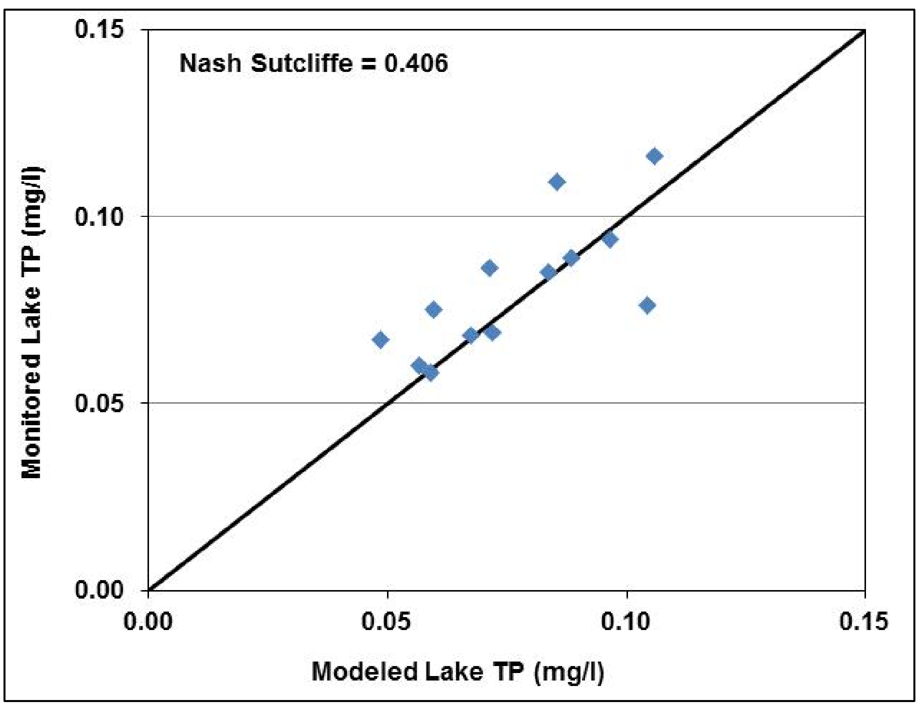

Figure D.3 **Staring Lake comparison between modeled volumetric average TP concentration and measured concentrations**

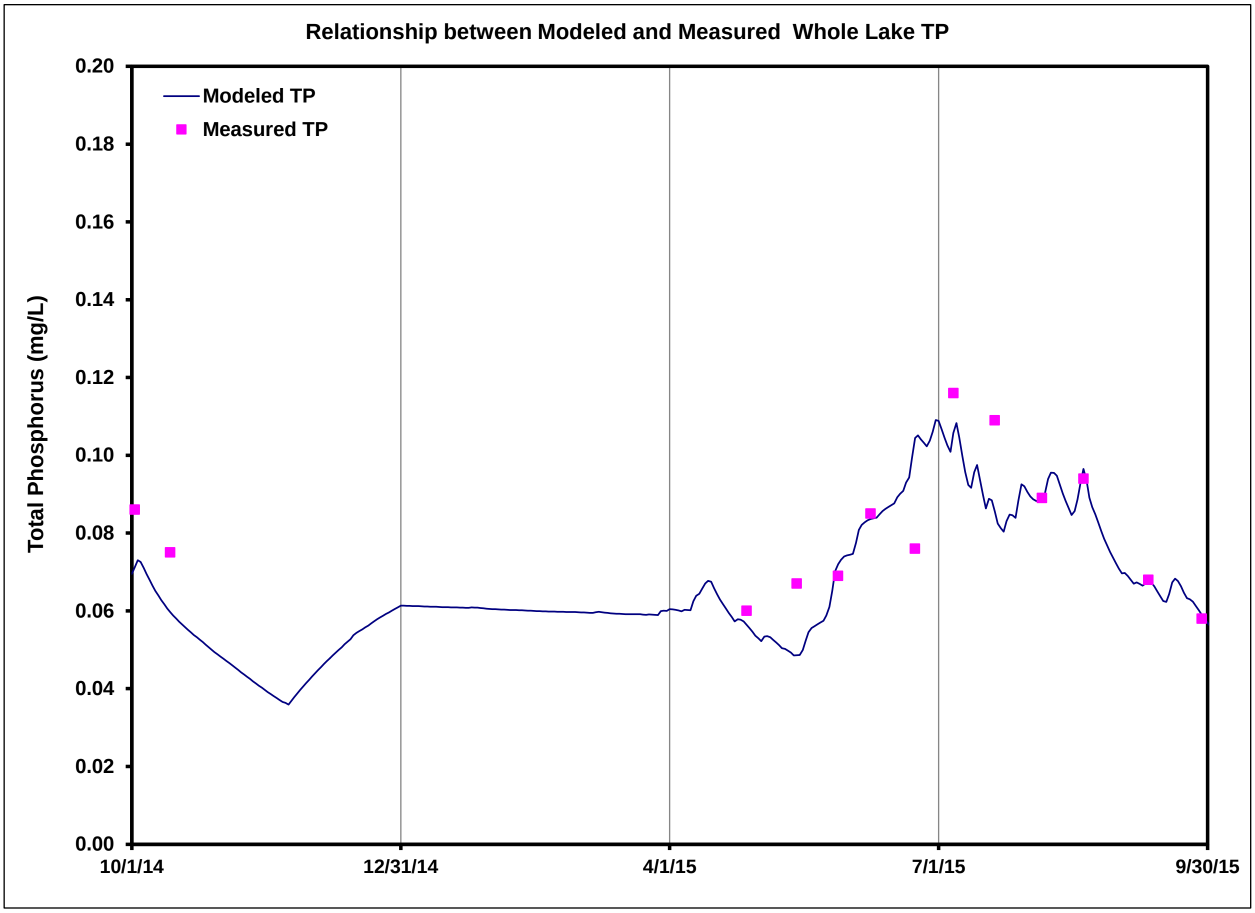

Figure D.4 **Staring Lake time series comparison between modeled and measured whole lake TP concentrations.**

D.2.6 Duck Lake Model Calibration

The Duck Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 – September 2015). The Duck Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation Total phosphorus concentrations were balanced on a whole lake basis since Staring Lake does not have a stable thermal stratification during the growing season. The Duck Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure D.5 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged total phosphorus concentrations. Figure D.6 shows the comparison between the modeled, monitored volumetric averaged total phosphorus concentrations over the course of the 2015 water year.

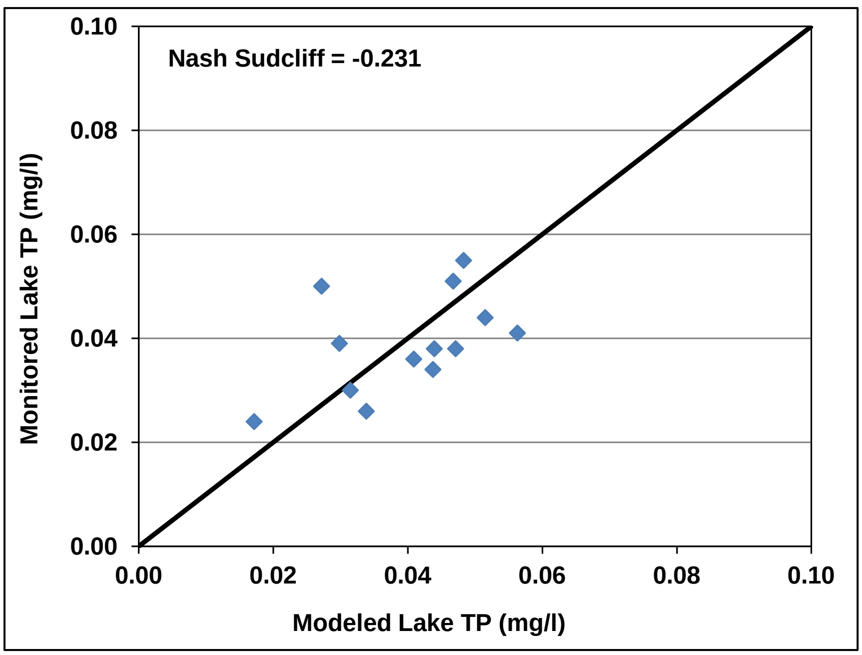

Figure D.5 **Duck Lake comparison between modeled volumetric average TP concentration and measured concentrations**

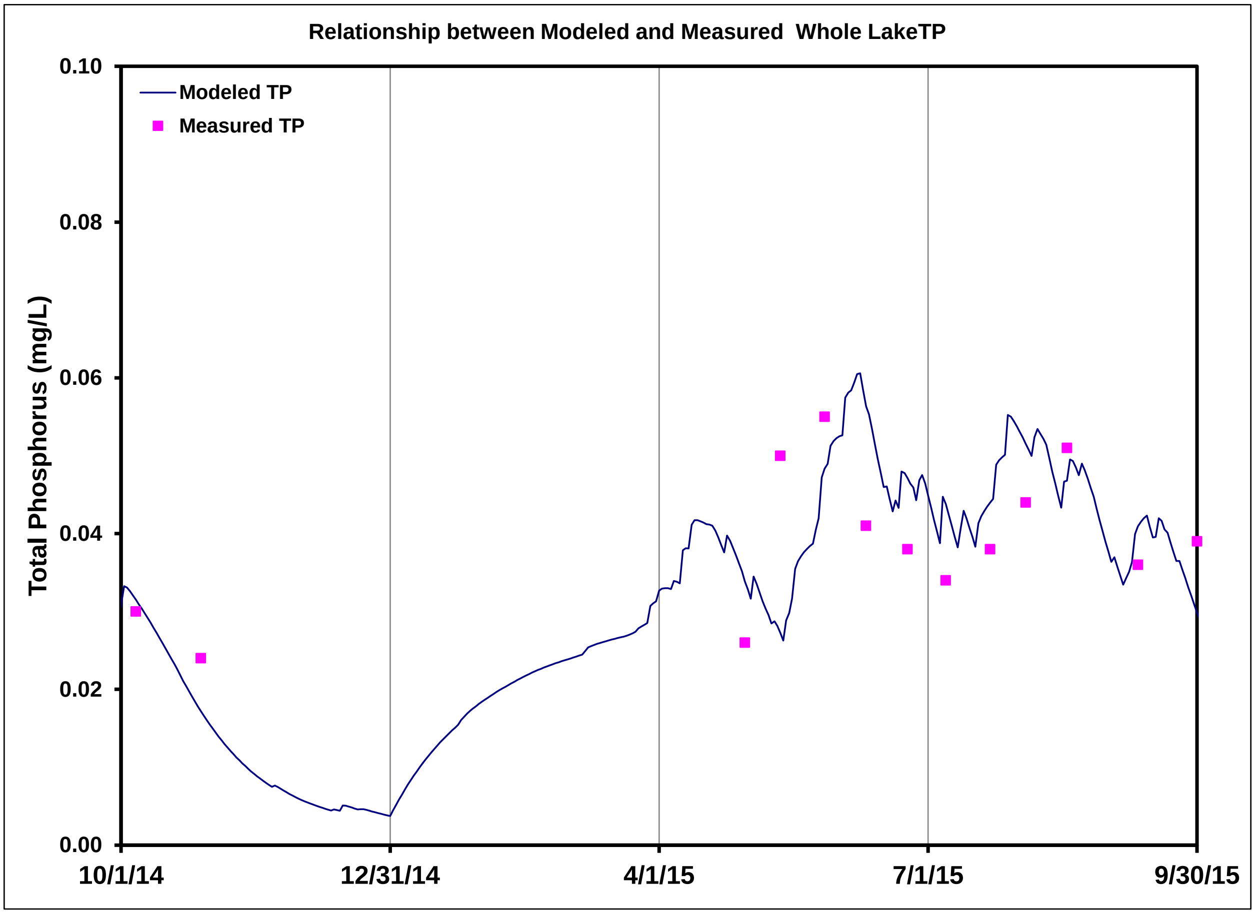

Figure D.6 **Duck Lake time series comparison between modeled and measured whole lake TP concentrations.**

D.2.7 Idelwild Lake Model Calibration

The Idelwild Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 – September 2015). Data was only available starting in May 2015. The Idelwild Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation Total phosphorus concentrations were balanced on a whole lake basis since Idlewild Lake does not have a stable thermal stratification during the growing season. The Idelwild Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure D.7 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged total phosphorus concentrations. Figure D.8 shows the comparison between the modeled, monitored volumetric averaged total phosphorus concentrations over the course of the 2015 water year.

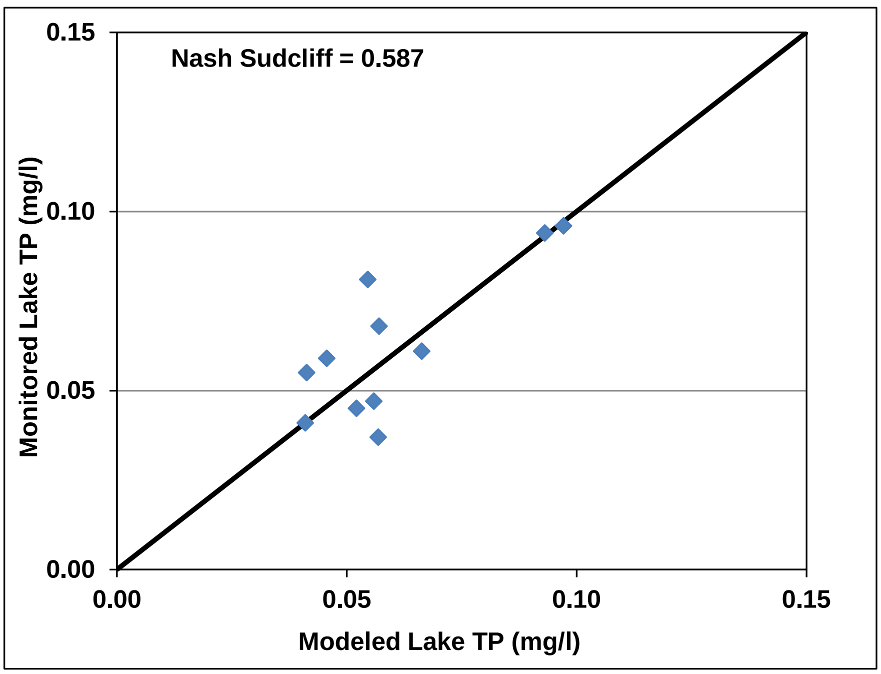

Figure D.7 **Idelwild Lake comparison between modeled volumetric average TP concentration and measured concentrations**

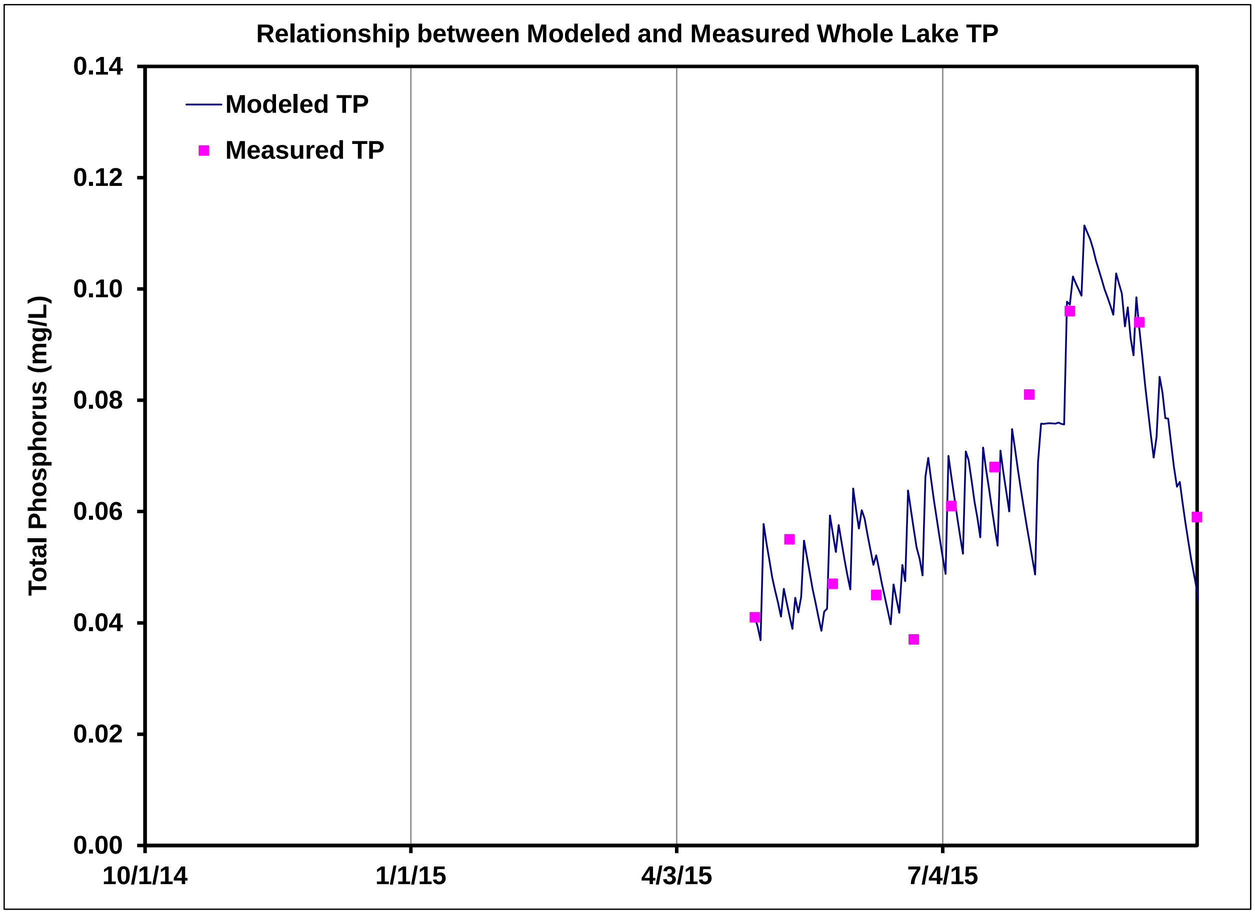

Figure D.8 **Idelwild Lake time series comparison between modeled and measured whole lake TP concentrations.**

D.2.8 Mitchell Lake Model Calibration

The Mitchell Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 – September 2015). The Mitchell Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation. Both the epilimnion and hypolimnion total phosphorus concentrations were modeled in Mitchell Lake due to its thermally stratifying during the growing season. Dividing the lake model into these separate layers enabled a more accurate estimate of internal loading and provided results for the lakes surface waters which are used to determine conformance with water quality goals. The Mitchell Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure D.9 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic total phosphorus concentrations. Figure D.10 shows the comparison between the modeled, monitored surface and monitored epilimnetic volumetric averaged total phosphorus concentrations over the course of the 2015 water year.

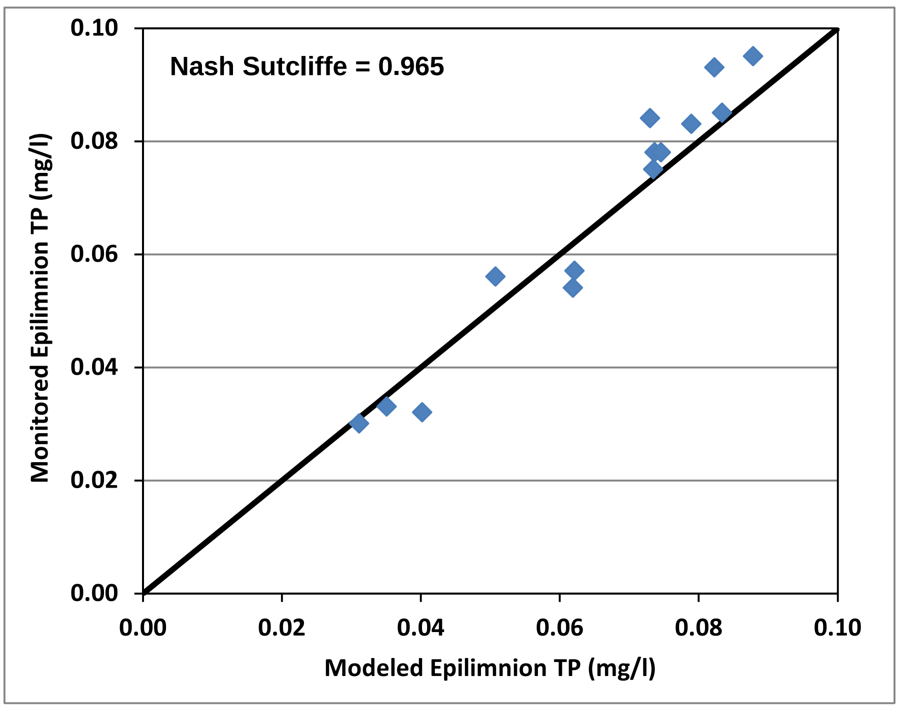

Figure D.9 Mitchell Lake comparison between modeled volumetric average TP concentration and measured concentrations in the epilimnion.

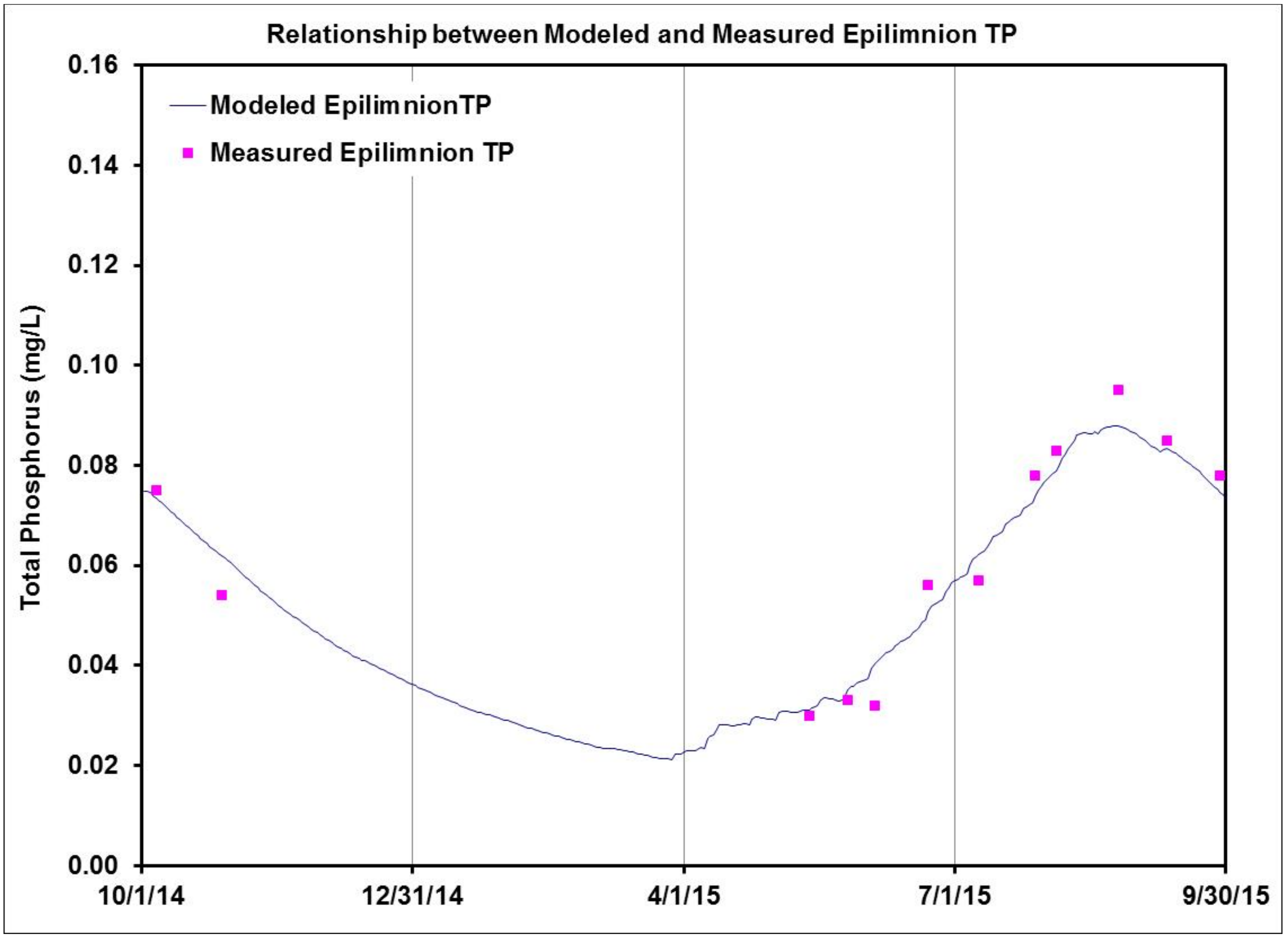

Figure D.10 **Mitchell Lake time series comparison between modeled and measured surface water TP concentrations.**

D.2.9 Red Rock Lake Model Calibration

The Red Rock Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 – September 2015). The Red Rock Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation. Both the epilimnion and hypolimnion total phosphorus concentrations were modeled in Red Rock Lake due to its thermally stratifying during the growing season. Dividing the lake model into these separate layers enabled a more accurate estimate of internal loading and provided results for the lakes surface waters which are used to determine conformance with water quality goals. The Red Rock Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure D.11 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic total phosphorus concentrations. Figure D.12 shows the comparison between the modeled, monitored surface and monitored epilimnetic volumetric averaged total phosphorus concentrations over the course of the 2015 water year.

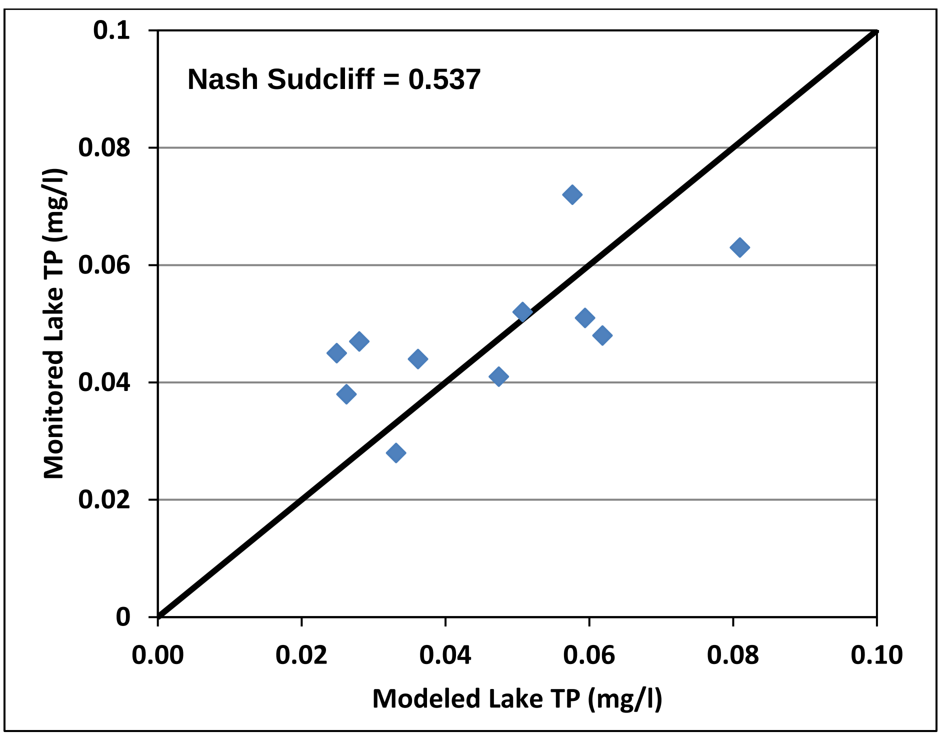

Figure D.11 Red Rock Lake comparison between modeled volumetric average TP concentration and measured concentrations

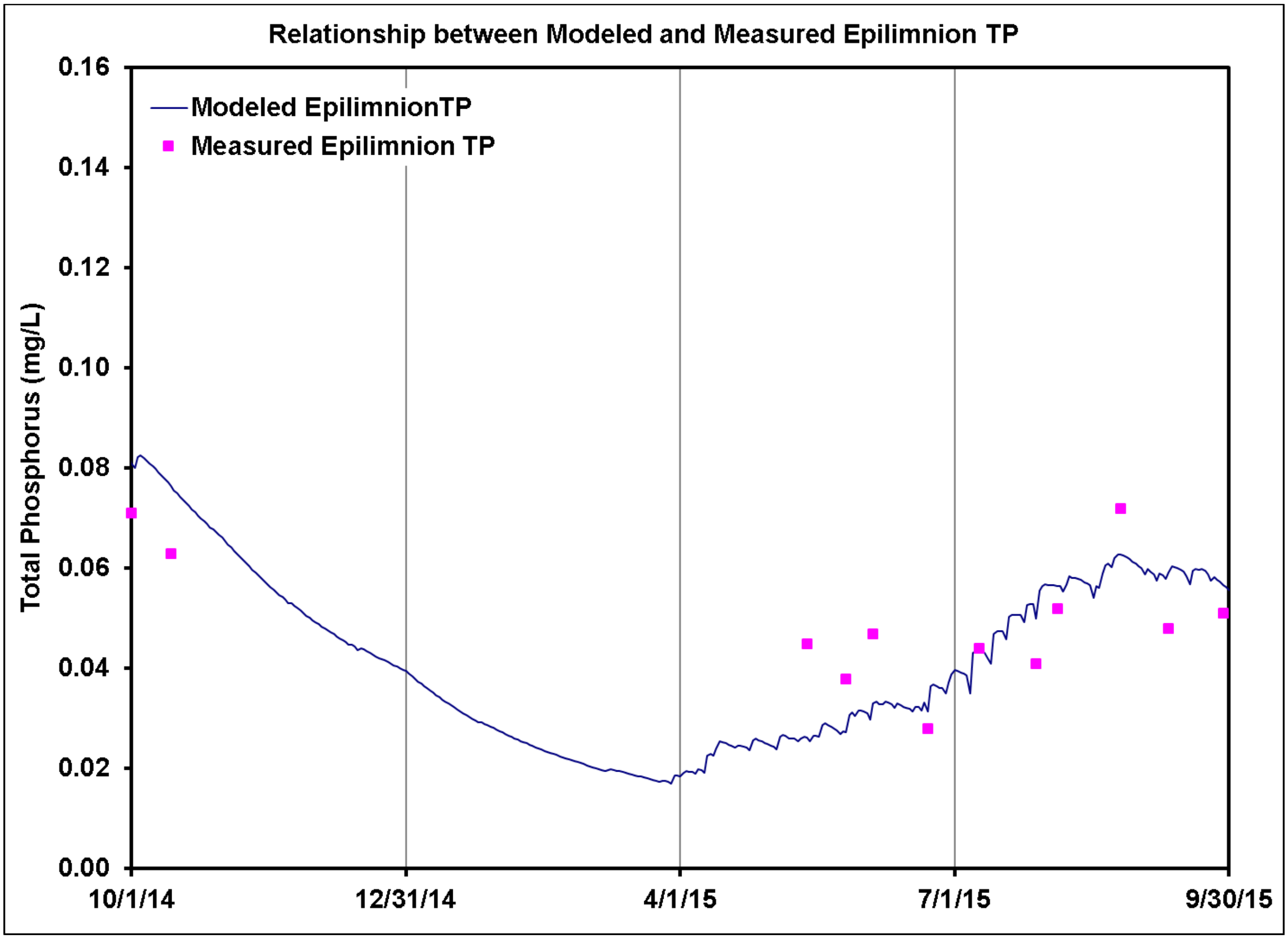

Figure D.12 **Red Rock Lake time series comparison between modeled and measured surface water TP concentrations.**

D.2.10 Round Lake Model Calibration

The Round Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 – September 2015). The Round Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation. Both the epilimnion and hypolimnion total phosphorus concentrations were modeled in Round Lake due to its thermally stratifying during the growing season. Dividing the lake model into these separate layers enabled a more accurate estimate of internal loading and provided results for the lakes surface waters which are used to determine conformance with water quality goals. The Round Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure D.13 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic total phosphorus concentrations. Figure D.14 shows the comparison between the modeled, monitored surface and monitored epilimnetic volumetric averaged total phosphorus concentrations over the course of the 2015 water year.

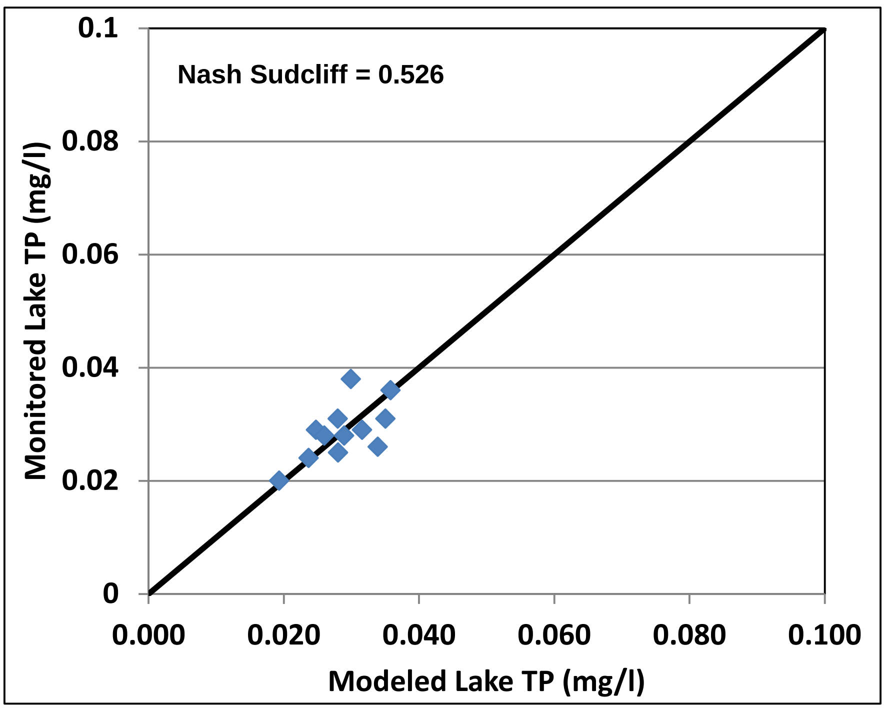

Figure D.13 Round Lake comparison between modeled volumetric average TP concentration and measured concentrations

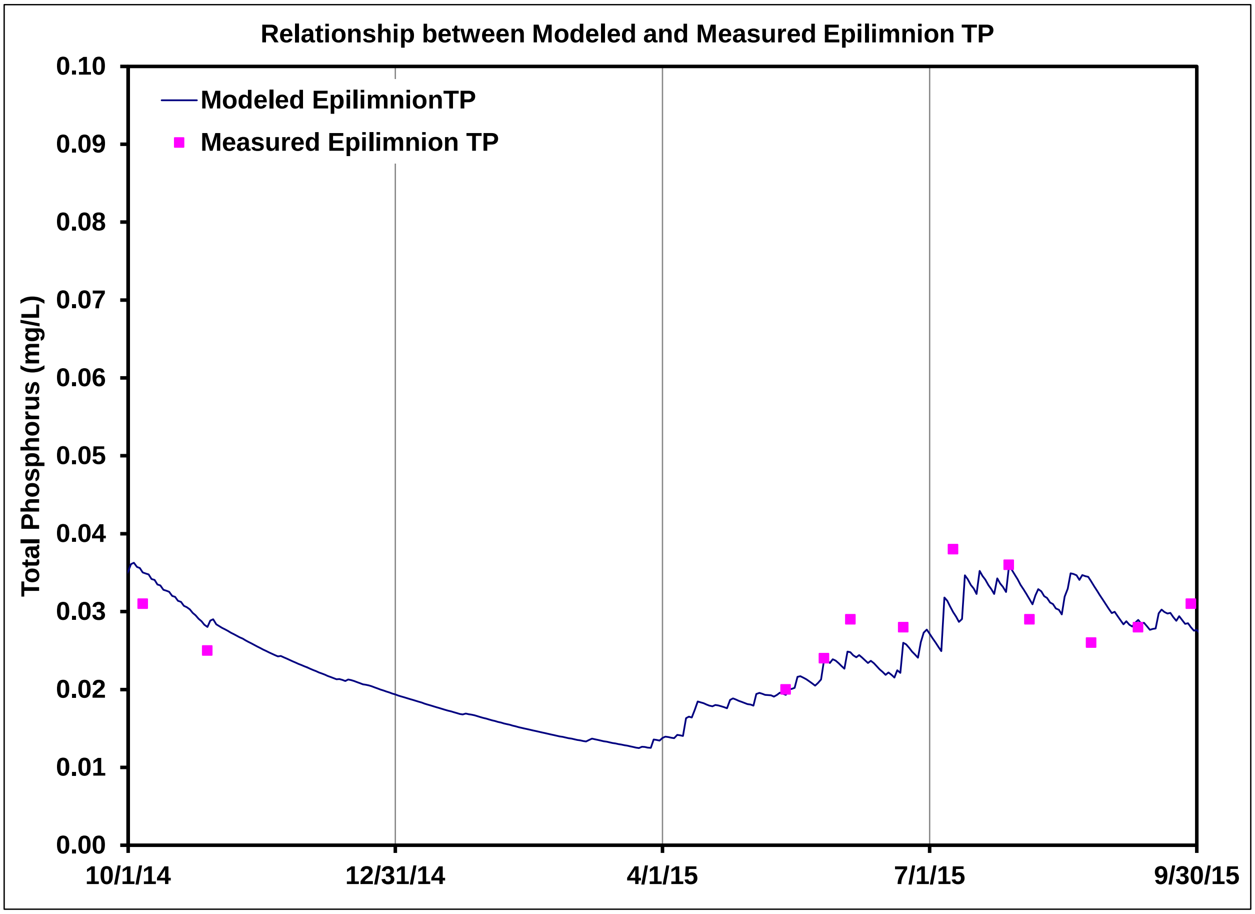

Figure D.14 **Round Lake time series comparison between modeled and measured surface water TP concentrations.**

D.2.11 Silver Lake Model Calibration

The Silver Lake water and TP balance portion of the in lake model were calibrated for the 2015 water year (October 2014 – September 2015). The Silver Lake daily water balance was adjusted using the "groundwater" calibration parameter. Groundwater inflows were used to match the observed spring water surface elevation Total phosphorus concentrations were balanced on a whole lake basis since Silver Lake does not have a stable thermal stratification during the growing season. The Silver Lake model was calibrated by adjusting the sediment phosphorus release rate and phosphorus settling velocity.

Figure D.15 shows the results of the Nash Sutcliffe statistical comparison between the 2015 modeled and measured volumetric averaged epilimnetic total phosphorus concentrations. Figure D.16 shows the comparison between the modeled, monitored surface and monitored epilimnetic volumetric averaged total phosphorus concentrations over the course of the 2015 water year.

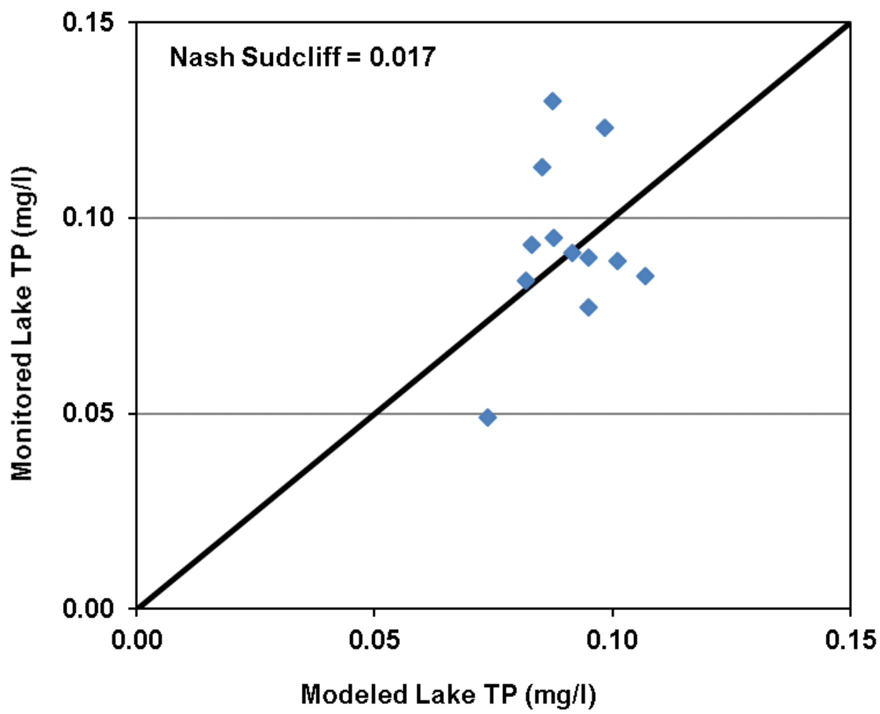

Figure D.15 Silver Lake comparison between modeled volumetric average TP concentration and measured concentrations

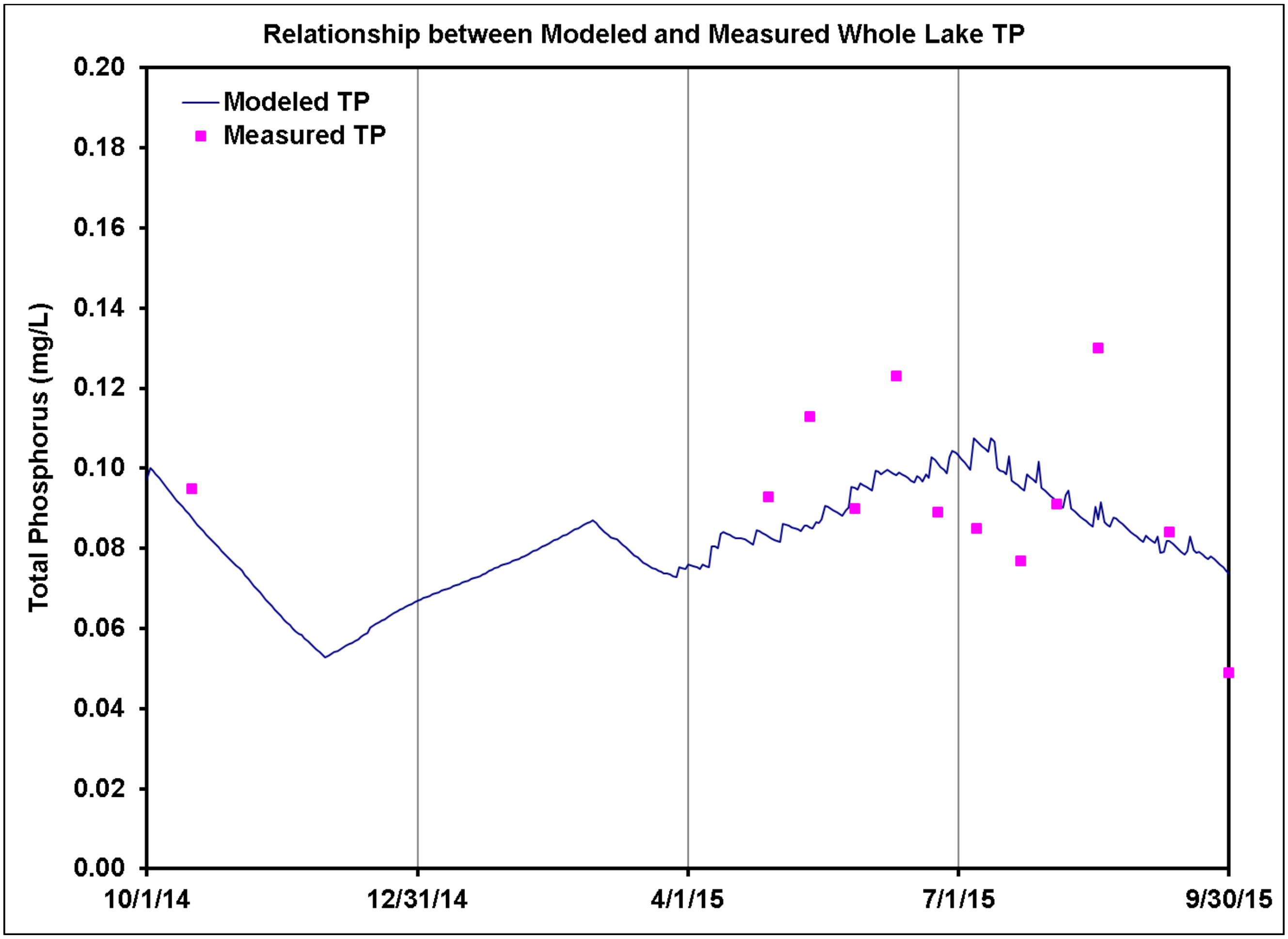

Figure D.16 **Silver Lake time series comparison between modeled and measured whole lake TP concentrations.**

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References

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Appendix E

Planning Level Opinion of Costs

Appendix E: BMP Cost Methodology

E.1 Cost estimates for sized, structural BMPs

Engineer's opinions of probable costs for design, permitting, and construction were developed for each BMP. These opinions of costs, project reserves, contingency, documentation and discussion are intended to provide background information for feasibility alternatives assessment, analysis purposes and budget authorization by the RPBCWD. The cost of time escalation is not included in the opinions of probable cost. All costs are presented in 2016 US dollars.

Quantities were estimated with calculations based on available information presented in previous sections. Dimensions, areas, and volumes for construction were determined using 2011 MDNR LiDAR data (MDNR, 2011).

Unit costs are based on recent bid prices, published construction cost index resources, and similar stormwater BMP projects. Unit process were developed and compared to similar project prices. Costs associated with Base Planning Engineering and Design (PED) are based on percentages of estimated construction cost and are within a range similar to those used in past projects designed by Barr. Costs associated with Construction Management (CM) are based on estimated costs to manage the construction process, based on Barr's experience with similar projects, but may change depending on the services that are provided during construction. The estimates also include Permitting and Regulatory Approvals, which is intended to account for additional planning, coordination, and mitigation costs that are likely to be incurred as the project is permitted with environmental agencies.

The opinions of cost include tasks and items related to engineering and design, permitting, and constructing each conceptual design. The opinions of cost do not include other tasks following construction of each alternative presented such as monitoring. Operation and maintenance is included separately as 2% of the opinion of cost.

Contingency used in these opinions of probable cost are intended to help identify an estimated construction cost amount for the minor items included in the current Project scope, but have not yet been quantified or estimated directly during the feasibility evaluation. Stated another way, contingency is the resultant of the pluses and minuses that cannot be estimated at the level of project definition that exists. The contingency includes the cost of ancillary items not currently itemized in the quantity summaries but commonly identified in more detailed design and required for completeness of the work. For this project, the contingency is captured in the cost range, which is described below, and not as a separate line item.

Industry resources for cost estimating provide guidance on cost uncertainty, depending on the level of project design developed (American Society for Testing and Materials, 2006) and (Association for the Advancement of Cost Estimating, 2005). The opinion of probable cost for the alternatives evaluated generally corresponds to a Class 4 estimate characterized by completion of limited engineering and use of deterministic estimating methods. As the level of design detail increases, the level of uncertainty is reduced. Figure E-1 provides a graphic representation of how uncertainty (or accuracy) of cost estimates can be expected to improve as more detailed design is developed.

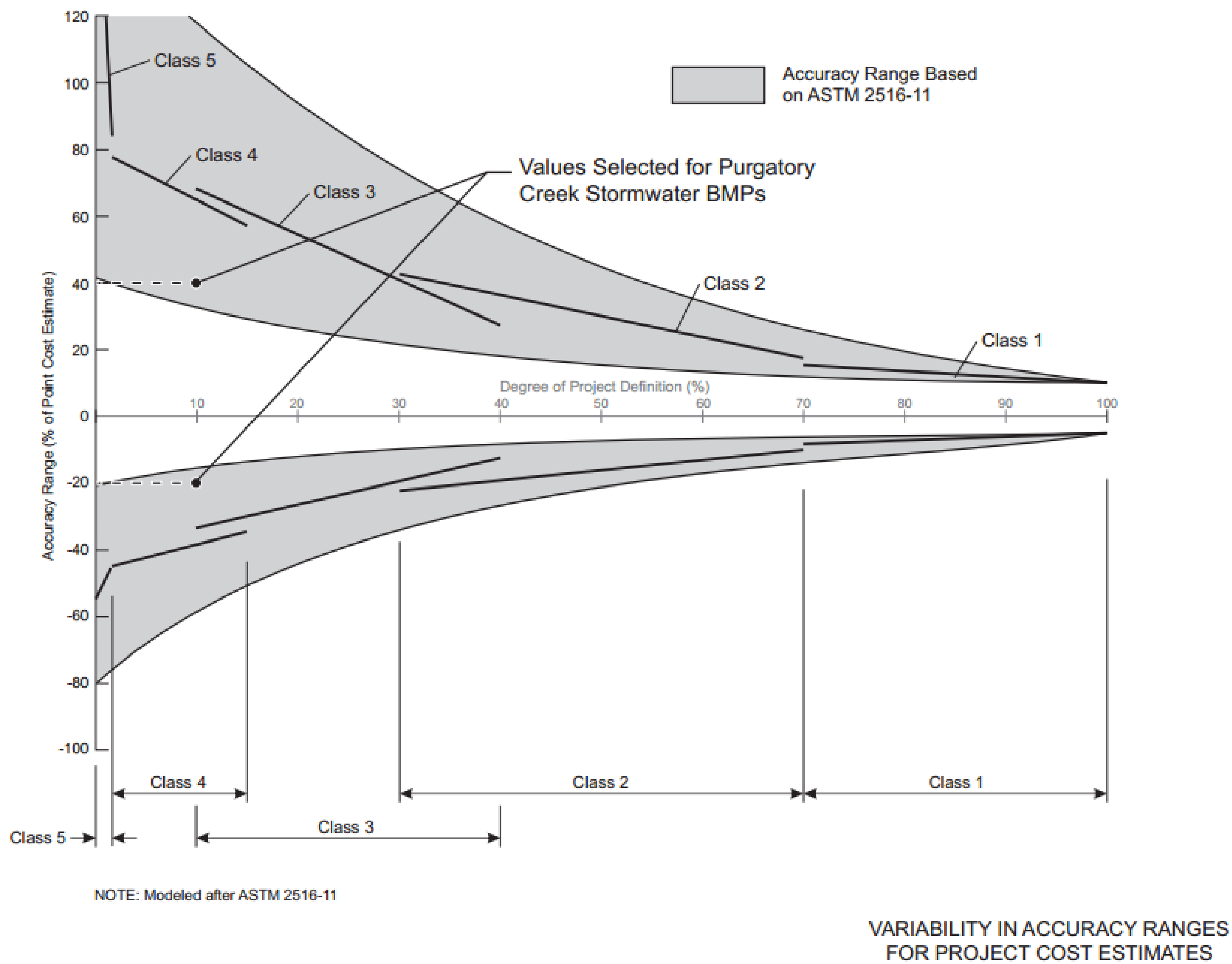


Figure E-1 Relationship between Cost Accuracy and Degree of Project Definition

At this early stage of design, the range of uncertainty of total project cost is high. Due to the early stage of design, it is standard practice to place a broad accuracy range around the point cost estimate.

The accuracy range is based on professional judgment considering the level of design completed, the complexity of the project, and the uncertainties in the project scope; the accuracy range does not include costs for future scope changes that are not part of the project as currently defined. The estimated accuracy range for this point estimate is -20% to +40%.

The opinion of probable cost provided in this memorandum is made on the basis of Barr Engineering's experience and qualifications and represents our best judgment as experienced and qualified professionals familiar with the project. It is acknowledged that additional investigations and additional site specific information that becomes available in the next stage of design may result in changes to the proposed configuration, cost and functioning of project features. This opinion is based on project-related information available to Barr Engineering at this time and includes a conceptual-level feasibility design of the project. The opinion of cost may change as more information becomes available and further design is completed. In addition, because we have no control over the eventual cost of labor, materials, equipment or services furnished by others, or over the contractor's methods of determining prices, or over competitive bidding or market conditions, Barr Engineering cannot and does not guarantee that proposals, bids, or actual costs will not vary from the opinion of probable cost presented in this memorandum. If the RPBCWD wishes greater assurance as to the probable project cost, the RPBCWD should authorize further investigation and design of selected BMPs.

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: LL_1, Lotus Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	12000.00	12000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
ACCESS TRAIL REPAIRS	LS	1	12000.00	12000.00
SILT FENCE	LN FT	330	3.50	1155.00
SILTATION LOG	LN FT	450	5.50	2475.00
TREE PROTECTION	LN FT	50	3.00	150.00
EROSION CONTROL BLANKET	SQ YD	1742	2.50	4355.00
CLEAR AND GRUBBING	AC	0.6	7500.00	4500.00
TREE REMOVAL	EACH	6	350.00	2100.00
POND EXCAVATION	CU YD	2200	4.00	8800.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	1000	12.00	12000.00
IMPORT AGGREGATE	CU YD	800	25.00	20000.00
CONSTRUCT BERM	CU YD	2000	5.00	10000.00
36" RCP INLET	LN FT	80	118.00	9440.00
36" RCP FLARED END SECTION	EACH	1	3625.00	3625.00
36" RCP OUTLET	LN FT	50	118.00	5900.00
36" RCP FLARED END SECTION	EACH	1	3625.00	3625.00
RIPRAP CLASS 2	TON	48	74.00	3552.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2440.00	2440.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
IMPORT TOP SOIL	CU YD	194	20.00	3880.00
SITE RESTORATION	AC	0.75	2500.00	1875.00
			SUB TOTAL =	$ 133,079.00
ENGINEERING AND DESIGN 15%				$ 19,961.85
CONSTRUCTION MANAGEMENT 15%				$ 19,961.85
LEGAL 5%				$ 6,653.95
PERMITTING 5%				$ 6,653.95
			TOTAL =	$ 186,310.60

PROBABLE RANGE -20% to +40% ($149,000) to ($261,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER PONDS
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: LL_2, Lotus Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	6000.00	6000.00
CONSTRUCTION ENTRANCE	EACH	2	2500.00	5000.00
SILT FENCE	LN FT	250	3.50	875.00
SILTATION LOG	LN FT	100	5.50	550.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	1064	2.50	2660.00
CLEAR AND GRUBBING	AC	0.3	7500.00	2250.00
TREE REMOVAL	EACH	4	350.00	1400.00
POND EXCAVATION	CU YD	600	4.00	2400.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	600	12.00	7200.00
2 - 15" RCP INLET	LN FT	40	40.00	1600.00
15" RCP FLARED END SECTION	EACH	2	1081.00	2162.00
2 - 18" RCP OUTLET	LN FT	100	47.00	4700.00
18" RCP FLARED END SECTION	EACH	4	1238.00	4952.00
RIPRAP CLASS 2	TON	72	74.00	5328.00
2 - 60" DIA. PRECAST RC MANHOLE	LN FT	14	499.00	6986.00
60" CONE GRATE TRASHRACK	EACH	2	1880.00	3760.00
FLOW CONTROL WEIR AND PIPING	LS	2	2000.00	4000.00
SITE RESTORATION	AC	0.4	2500.00	1000.00
			SUB TOTAL =	$ 63,273.00
ENGINEERING AND DESIGN 15%				$ 9,490.95
CONSTRUCTION MANAGEMENT 15%				$ 9,490.95
LEGAL 5%				$ 3,163.65
PERMITTING 5%				$ 3,163.65
			TOTAL =	$ 88,582.20

PROBABLE RANGE -20% to +40% ($71,000) to ($124,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BASIN
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: LL_3, Lotus Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	25000.00	25000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
ACCESS TRAIL REPAIRS	LS	1	8000.00	8000.00
SILT FENCE	LN FT	360	3.50	1260.00
SILTATION LOG	LN FT	180	5.50	990.00
TREE PROTECTION	LN FT	230	3.00	690.00
EROSION CONTROL BLANKET	SQ YD	7744	2.50	19360.00
TREE REMOVAL	EACH	20	350.00	7000.00
POND EXCAVATION	CU YD	1000	4.00	4000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	1000	12.00	12000.00
12" RCP INLET	LN FT	20	36.00	720.00
12" RCP FLARED END SECTION	EACH	1	951.00	951.00
33" RCP INLET	LN FT	20	109.00	2180.00
33" RCP FLARED END SECTION	EACH	1	3063.00	3063.00
48" RCP INLET	LN FT	20	208.00	4160.00
48" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
60" RCP OUTLET	LN FT	60	304.00	18240.00
60" RCP FLARED END SECTION	EACH	1	7856.00	7856.00
RIPRAP CLASS 2	TON	74	74.00	5476.00
96" DIA. PRECAST RC MANHOLE	LN FT	7	1218.00	8526.00
96" CONE GRATE TRASHRACK	EACH	1	4023.00	4023.00
FLOW CONTROL WEIR AND PIPING	LS	1	8500.00	8500.00
TILL EXISTING SOIL	SQ YD	7405	5.00	37025.00
FILTRATION SAND	CU YD	2468	25.00	61700.00
FILTRATION TOP SOIL	CU YD	821	30.00	24630.00
SITE RESTORATION	AC	2	2500.00	5000.00
			SUB TOTAL =	$ 278,338.00
ENGINEERING AND DESIGN 15%				$ 41,750.70
CONSTRUCTION MANAGEMENT 15%				$ 41,750.70
LEGAL 5%				$ 13,916.90
PERMITTING 5%				$ 13,916.90
			TOTAL =	$ 389,673.20

PROBABLE RANGE -20% to +40% ($312,000) to ($546,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

UNDERGROUND STORAGE
PRELIMINARY ENGINEERS OPINION OF COST 3/7/2016
LOCATION: LL_5, Lotus Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	120000.00	120000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	400	3.50	1400.00
SILTATION LOG	LN FT	200	5.50	1100.00
TREE PROTECTION	LN FT	275	3.00	825.00
EROSION CONTROL BLANKET	SQ YD	2420	2.50	6050.00
TREE REMOVAL	EACH	0	350.00	0.00
EXCAVATION	CU YD	6000	4.00	24000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	2000	12.00	24000.00
REINFORCED CONCRETE STRUCTURE	CU YD	1300	800.00	1040000.00
18" RCP INLET	LN FT	75	47.00	3525.00
18" RCP OUTLET	LN FT	75	47.00	3525.00
48" DIA. PRECAST RC MANHOLE	LN FT	14	307.00	4298.00
60" DIA. PRECAST RC CONTROL MANHOLE	LN FT	7	499.00	3493.00
CASTING ASEMBLY STORM SEWER	EACH	5	550.00	2750.00
SITE RESTORATION	AC	0.5	5000.00	2500.00
			SUB TOTAL =	$ 1,240,966.00
ENGINEERING AND DESIGN 15%				$ 186,144.90
CONSTRUCTION MANAGEMENT 15%				$ 186,144.90
LEGAL 5%				$ 62,048.30
PERMITTING 5%				$ 62,048.30
			TOTAL =	$ 1,737,352.40

PROBABLE RANGE -20% to +40% ($1,390,000) to ($2,432,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

IRON ENHANCED SAND FILTER
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: LL_7, Lotus Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	40000.00	40000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
ACCESS	LS	1	4500.00	4500.00
SILT FENCE	LN FT	1200	3.50	4200.00
SILTATION LOG	LN FT	300	5.50	1650.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	1342	2.50	3355.00
TREE REMOVAL	EACH	10	350.00	3500.00
EXCAVATION	CU YD	3388	4.00	13552.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	3388	12.00	40656.00
18" RCP INLET	LN FT	100	47.00	4700.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
33" RCP INLET	LN FT	30	40.00	1200.00
30" RCP OUTLET	LN FT	50	118.00	5900.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2444.00	2444.00
DRAIN TILE PIPING W/CO's	LS	1	5500.00	5500.00
HDPE 40 MIL LINER	SQ YD	4000	4.50	18000.00
IRON ENHANCED FILTRATION SAND	CU YD	2500	96.00	240000.00
FILTRATION TOP SOIL	CU YD	452	30.00	13560.00
SITE RESTORATION	AC	1.25	5000.00	6250.00
			SUB TOTAL =	$ 418,362.00
ENGINEERING AND DESIGN 15%				$ 62,754.30
CONSTRUCTION MANAGEMENT 15%				$ 62,754.30
LEGAL 5%				$ 20,918.10
PERMITTING 5%				$ 20,918.10
			TOTAL =	$ 585,706.80

PROBABLE RANGE -20% to +40% ($469,000) to ($820,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: LL_8, Lotus Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	11000.00	11000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	400	3.50	1400.00
SILTATION LOG	LN FT	100	5.50	550.00
TREE PROTECTION	LN FT	250	3.00	750.00
EROSION CONTROL BLANKET	SQ YD	544	2.50	1360.00
CLEAR AND GRUBBING	AC	0.5	7500.00	3750.00
TREE REMOVAL	EACH	20	350.00	7000.00
POND EXCAVATION	CU YD	2900	4.00	11600.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	2900	12.00	34800.00
24" RCP INLET	LN FT	30	59.00	1770.00
24" RCP FLARED END SECTION	EACH	1	2271.00	2271.00
44" SPAN RCP OUTLET	LN FT	30	158.00	4740.00
44" SPAN RCP FLARED END SECTION	EACH	1	3625.00	3625.00
RIPRAP CLASS 2	TON	48	74.00	3552.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2444.00	2444.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
SITE RESTORATION	AC	0.75	2500.00	1875.00
			SUB TOTAL =	$ 101,694.00
ENGINEERING AND DESIGN 15%				$ 15,254.10
CONSTRUCTION MANAGEMENT 15%				$ 15,254.10
LEGAL 5%				$ 5,084.70
PERMITTING 5%				$ 5,084.70
			TOTAL =	$ 142,371.60

PROBABLE RANGE -20% to +40% ($114,000) to ($199,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: LL_9, Lotus Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	41000.00	41000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	960	3.50	3360.00
SILTATION LOG	LN FT	200	5.50	1100.00
TREE PROTECTION	LN FT	250	3.00	750.00
EROSION CONTROL BLANKET	SQ YD	1984	2.50	4960.00
REMOVE CONCRETE APPRON	EACH	1	750.00	750.00
CLEAR AND GRUBBING	AC	1.5	7500.00	11250.00
TREE REMOVAL	EACH	25	350.00	8750.00
POND EXCAVATION	CU YD	15000	4.00	60000.00
REMOVE CONCRETE CURB AND GUTTER	LN FT	40	12.00	480.00
REMOVE CONCRETE APPRON	EACH	1	750.00	750.00
SAW CUT BITUMINOUS PAVEMENT	LN FT	180	7.50	1350.00
REMOVE BITUMINOUS PAVEMENT	SQ YD	250	11.00	2750.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	15000	12.00	180000.00
24" RCP INLET	LN FT	330	59.00	19470.00
24" RCP FLARED END SECTION	EACH	1	2271.00	2271.00
30" RCP OUTLET	LN FT	20	91.00	1820.00
30" RCP FLARED END SECTION	EACH	1	2607.00	2607.00
RIPRAP CLASS 2	TON	36	74.00	2664.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	499.00	3493.00
72" CONE GRATE TRASHRACK	EACH	1	1880.00	1880.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
REPLACE CONCRETE CURB AND GUTTER	LN FT	40	38.00	1520.00
REPLACE CONCRETE APPRON	EACH	1	3500.00	3500.00
CLASS 5 AGGREGATE BASE	CU YD	45	35.00	1575.00
REPLACE BITUMINOUS PAVEMENT	SQ YD	250	120.00	30000.00
SITE RESTORATION	AC	1.7	2500.00	4250.00
			SUB TOTAL =	$ 397,300.00
ENGINEERING AND DESIGN 15%				$ 59,595.00
CONSTRUCTION MANAGEMENT 15%				$ 59,595.00
LEGAL 5%				$ 19,865.00
PERMITTING 5%				$ 19,865.00
			TOTAL =	$ 556,220.00

PROBABLE RANGE -20% to +40% ($445,000) to ($779,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER FILTERING STRUCTURE
PRELIMINARY ENGINEERS OPINION OF COST 7/25/2016
LOCATION: SiL_1, Sliver Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	60000.00	60000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	300	3.50	1050.00
SILTATION LOG	LN FT	250	5.50	1375.00
TREE PROTECTION	LN FT	250	3.00	750.00
EROSION CONTROL BLANKET	SQ YD	564	2.50	1410.00
CLEAR AND GRUBBING	AC	0.1	7500.00	750.00
TREE REMOVAL	EACH	4	350.00	1400.00
EXCAVATION	CU YD	6272	4.00	25088.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	1829	12.00	21948.00
BACKFILL AND COMPACTION	CU YD	4443	8.50	37765.50
12' X 12' PRECAST CONCRETE BOX CULVER	LN FT	252	1400.00	352800.00
36" RCP INLET	LN FT	30	118.00	3540.00
48" DIA. PRECAST RC MANHOLE	LN FT	15	307.00	4605.00
2 - 60" DIA. PRECAST RC MANHOLE	LN FT	28	499.00	13972.00
PRETREATMENT SYSTEM STRUCTURE	LS	1	15000.00	15000.00
36" RCP OUTLET	LN FT	30	118.00	3540.00
CASTING ASEMBLY STORM SEWER	EACH	9	550.00	4950.00
DRAIN TILE PIPING W/CO's	LS	1	8500.00	8500.00
FILTRATION SAND	CU YD	662	25.00	16550.00
SITE RESTORATION	AC	0.12	5000.00	600.00
			SUB TOTAL =	$ 579,093.50
ENGINEERING AND DESIGN 15%				$ 86,864.03
CONSTRUCTION MANAGEMENT 15%				$ 86,864.03
LEGAL 5%				$ 28,954.68
PERMITTING 5%				$ 28,954.68
			TOTAL =	$ 810,730.90

PROBABLE RANGE -20% to +40% ($649,000) to ($1,135,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

SAND FILTER
PRELIMINARY ENGINEERS OPINION OF COST 7/25/2016
LOCATION: SiL_2, Silver Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	39000.00	39000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	450	3.50	1575.00
SILTATION LOG	LN FT	250	5.50	1375.00
TREE PROTECTION	LN FT	400	3.00	1200.00
EROSION CONTROL BLANKET	SQ YD	1936	2.50	4840.00
CLEAR AND GRUBBING	AC	0.8	7500.00	6000.00
TREE REMOVAL	EACH	46	350.00	16100.00
CONSTRUCT ACCESS ROAD	LS	1	3500.00	3500.00
REMOVE BITUMINOUS CURB AND GUTTER	LN FT	350	12.00	4200.00
SAW CUT BITUMINOUS PAVEMENT	LN FT	390	7.50	2925.00
REMOVE BITUMINOUS PAVEMENT	SQ YD	778	11.00	8558.00
POND EXCAVATION	CU YD	1150	4.00	4600.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	942	12.00	11304.00
CONSTRUCT BERM	CU YD	208	12.00	2496.00
18" RCP INLET	LN FT	170	47.00	7990.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
18" RCP INLET	LN FT	48	47.00	2256.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
27" RCP OUTLET	LN FT	50	80.00	4000.00
27" RCP FLARED END SECTION	EACH	1	2251.00	2251.00
CURB INLET STRUCTURE	EACH	2	4500.00	9000.00
48" DIA. PRECAST RC MANHOLE	LN FT	36	307.00	11052.00
CASTING ASEMBLY STORM SEWER	EACH	2	550.00	1100.00
48" SAFFLE BAFFLE	EACH	2	4200.00	8400.00
RIPRAP CLASS 2	TON	48	74.00	3552.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2440.00	2440.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
TILL EXISTING SOIL	SQ YD	2275	5.00	11375.00
FILTRATION SAND	CU YD	3033	25.00	75825.00
FILTRATION TOP SOIL	CU YD	252	30.00	7560.00
CONCRETE CURB AND GUTTER	LN FT	350	38.00	13300.00
CLASS 5 AGGREGATE BASE	CU YD	174	35.00	6090.00
REPLACE BITUMINOUS PAVEMENT	SQ YD	778	120.00	93360.00
SITE RESTORATION	AC	0.8	2500.00	2000.00
			SUB TOTAL =	$ 381,907.00
ENGINEERING AND DESIGN 15%				$ 57,286.05
CONSTRUCTION MANAGEMENT 15%				$ 57,286.05
LEGAL 5%				$ 19,095.35
PERMITTING 5%				$ 19,095.35
			TOTAL =	$ 534,669.80

PROBABLE RANGE -20% to +40% ($428,000) to ($749,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: DL_1, Duck Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	13000.00	13000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	300	3.50	1050.00
SILTATION LOG	LN FT	80	5.50	440.00
FLOATATION SILT CURTAIN	LN FT	360	10.50	3780.00
TREE PROTECTION	LN FT	100	3.00	300.00
EROSION CONTROL BLANKET	SQ YD	1500	2.50	3750.00
CLEAR AND GRUBBING	AC	0.2	7500.00	1500.00
TREE REMOVAL	EACH	6	350.00	2100.00
POND EXCAVATION	CU YD	1000	4.00	4000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	500	12.00	6000.00
IMPORT AGGREGATE	CU YD	2000	25.00	50000.00
CONSTRUCT BERM	CU YD	2500	5.00	12500.00
2 -24" RCP INLET	LN FT	120	59.00	7080.00
24" RCP FLARED END SECTION	EACH	2	2271.00	4542.00
36" RCP OUTLET	LN FT	50	118.00	5900.00
36" RCP FLARED END SECTION	EACH	2	3625.00	7250.00
RIPRAP CLASS 2	TON	64	74.00	4736.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2440.00	2440.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
IMPORT TOP SOIL	CU YD	250	20.00	5000.00
SITE RESTORATION	AC	0.25	2500.00	625.00
			SUB TOTAL =	$ 145,200.00
ENGINEERING AND DESIGN 15%				$ 21,780.00
CONSTRUCTION MANAGEMENT 15%				$ 21,780.00
LEGAL 5%				$ 7,260.00
PERMITTING 5%				$ 7,260.00
			TOTAL =	$ 203,280.00

PROBABLE RANGE -20% to +40% ($163,000) to ($285,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

RAINWATER GARDENS (6 small)
PRELIMINARY ENGINEERS OPINION OF COST 8/25/2016
LOCATION: DL_3, Duck Lake, Prarie View Elementary School

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	16000.00	16000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	947	3.50	3314.50
SILTATION LOG	LN FT	527	5.50	2898.50
REMOVE & SALVAGE TREES	EACH	2	400.00	800.00
REMOVE TREES	EACH	6	350.00	2100.00
TREE PROTECTION	LN FT	350	3.00	1050.00
REMOVE RIPRAP	CU YD	35	10.00	350.00
REMOVE AND REPLACE SCHOOL SIGN	L. S.	1	2000.00	2000.00
EROSION CONTROL BLANKET	SQ YD	2479	2.50	6197.50
POND EXCAVATION	CU YD	1563	4.00	6252.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	1563	12.00	18756.00
MODULAR CONC. BLOCK RETAINING WALL	SQ FT	650	28.00	18200.00
DROP STEEPED INLET STRUCTURES	EACH	8	1500.00	12000.00
18" RCP	LN FT	24	47.00	1128.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
RIPRAP CLASS 2	TON	12	74.00	888.00
TILL EXISTING SOIL	SQ YD	1236	5.00	6180.00
FILTRATION SAND	CU YD	462	25.00	11550.00
FILTRATION TOP SOIL	CU YD	231	30.00	6930.00
REPLANT SALVAGED TREES	EACH	2	200.00	400.00
REPLACE REMOVED TREES	EACH	6	400.00	2400.00
SHRUBS	EACH	306	40.00	12240.00
SOD	SQ YD	1800	7.00	12600.00
EDUCATIONAL SIGNAGE & AMENITIES	L. S.	1	2000.00	2000.00
SITE RESTORATION	AC	0.59	2500.00	1475.00
			SUB TOTAL =	$ 152,447.50
ENGINEERING AND DESIGN 15%				$ 22,867.13
CONSTRUCTION MANAGEMENT 15%				$ 22,867.13
LEGAL 5%				$ 7,622.38
PERMITTING 5%				$ 7,622.38
			TOTAL =	$ 213,426.50

PROBABLE RANGE -20% to +40% ($171,000) to ($299,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BASIN
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: RL_1, Round Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	8000.00	8000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	150	3.50	525.00
SILTATION LOG	LN FT	200	5.50	1100.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	1936	2.50	4840.00
TREE REMOVAL	EACH	8	350.00	2800.00
POND EXCAVATION	CU YD	650	4.00	2600.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	650	12.00	7800.00
15" RCP INLET	LN FT	48	40.00	1920.00
15" RCP FLARED END SECTION	EACH	1	1081.00	1081.00
18" RCP OUTLET	LN FT	50	47.00	2350.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
RIPRAP CLASS 2	TON	24	74.00	1776.00
60" DIA. PRECAST RC MANHOLE	LN FT	7	499.00	3493.00
60" CONE GRATE TRASHRACK	EACH	1	1880.00	1880.00
FLOW CONTROL WEIR AND PIPING	LS	1	2000.00	2000.00
TILL EXISTING SOIL	SQ YD	1250	5.00	6250.00
FILTRATION SAND	CU YD	968	25.00	24200.00
FILTRATION TOP SOIL	CU YD	215	30.00	6450.00
SITE RESTORATION	AC	0.5	2500.00	1250.00
			SUB TOTAL =	$ 84,503.00
ENGINEERING AND DESIGN 15%				$ 12,675.45
CONSTRUCTION MANAGEMENT 15%				$ 12,675.45
LEGAL 5%				$ 4,225.15
PERMITTING 5%				$ 4,225.15
			TOTAL =	$ 118,304.20

PROBABLE RANGE -20% to +40% ($95,000) to ($166,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION CHAMBER
PRELIMINARY ENGINEERS OPINION OF COST 7/25/2016
LOCATION: RL_2, Round Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	18000.00	18000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	200	3.50	700.00
SILTATION LOG	LN FT	80	5.50	440.00
TREE PROTECTION	LN FT	180	3.00	540.00
EROSION CONTROL BLANKET	SQ YD	1200	2.50	3000.00
TREE REMOVAL	EACH	6	350.00	2100.00
POND EXCAVATION	CU YD	2133	4.00	8532.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	2133	12.00	25596.00
42" RCP INLET	LN FT	48	170.00	8160.00
42" RCP FLARED END SECTION	EACH	1	4612.00	4612.00
42" RCP OUTLET	LN FT	50	170.00	8500.00
42" RCP FLARED END SECTION	EACH	1	4612.00	4612.00
RIPRAP CLASS 2	TON	36	74.00	2664.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2440.00	2440.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
STEP WEIRS	EACH	7	4000.00	28000.00
TILL EXISTING SOIL	SQ YD	1600	5.00	8000.00
FILTRATION SAND	CU YD	1100	25.00	27500.00
FILTRATION TOP SOIL	CU YD	357	30.00	10710.00
SITE RESTORATION	AC	0.35	2500.00	875.00
			SUB TOTAL =	$ 175,188.00
ENGINEERING AND DESIGN 15%				$ 26,278.20
CONSTRUCTION MANAGEMENT 15%				$ 26,278.20
LEGAL 5%				$ 8,759.40
PERMITTING 5%				$ 8,759.40
			TOTAL =	$ 245,263.20

PROBABLE RANGE -20% to +40% ($196,000) to ($343,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BASIN
PRELIMINARY ENGINEERS OPINION OF COST — 7/25/2016
LOCATION: RL_4, Round Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	27000.00	27000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	220	3.50	770.00
SILTATION LOG	LN FT	100	5.50	550.00
TREE PROTECTION	LN FT	50	3.00	150.00
EROSION CONTROL BLANKET	SQ YD	906	2.50	2265.00
TREE REMOVAL	EACH	0	350.00	0.00
POND EXCAVATION	CU YD	1990	4.00	7960.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	1990	12.00	23880.00
30" RCP INLET	LN FT	16	91.00	1456.00
30" RCP FLARED END SECTION	EACH	1	2607.00	2607.00
42" RCP INLET	LN FT	16	170.00	2720.00
42" RCP FLARED END SECTION	EACH	1	4612.00	4612.00
36" RCP OUTLET	LN FT	50	118.00	5900.00
36" RCP FLARED END SECTION	EACH	1	3625.00	3625.00
RIPRAP CLASS 2	TON	36	74.00	2664.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2440.00	2440.00
FLOW CONTROL WEIR AND PIPING	LS	1	3000.00	3000.00
TILL EXISTING SOIL	SQ YD	1600	5.00	8000.00
DRAIN TILE SYSTEM	LS	1	4500.00	4500.00
FILTRATION SAND	CU YD	5307	25.00	132675.00
FILTRATION TOP SOIL	CU YD	442	30.00	13260.00
SITE RESTORATION	AC	0.25	2500.00	625.00
			SUB TOTAL =	$ 258,366.00
ENGINEERING AND DESIGN 15%				$ 38,754.90
CONSTRUCTION MANAGEMENT 15%				$ 38,754.90
LEGAL 5%				$ 12,918.30
PERMITTING 5%				$ 12,918.30
			TOTAL =	$ 361,712.40

PROBABLE RANGE -20% to +40% ($289,000) to ($506,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: ML_1, Mitchell Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	9000.00	9000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	375	3.50	1312.50
SILTATION LOG	LN FT	120	5.50	660.00
TREE PROTECTION	LN FT	100	3.00	300.00
EROSION CONTROL BLANKET	SQ YD	2420	2.50	6050.00
CLEAR AND GRUBBING	AC	1	7500.00	7500.00
TREE REMOVAL	EACH	10	350.00	3500.00
POND EXCAVATION	CU YD	2200	4.00	8800.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	2200	12.00	26400.00
12" RCP INLET	LN FT	20	36.00	720.00
12" RCP FLARED END SECTION	EACH	1	951.00	951.00
15" RCP INLET	LN FT	20	40.00	800.00
15" RCP FLARED END SECTION	EACH	1	1081.00	1081.00
33" RCP INLET	LN FT	20	109.00	2180.00
33" RCP FLARED END SECTION	EACH	1	3063.00	3063.00
30" RCP OUTLET	LN FT	20	91.00	1820.00
30" RCP FLARED END SECTION	EACH	1	2607.00	2607.00
RIPRAP CLASS 2	TON	48	74.00	3552.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2440.00	2440.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
SITE RESTORATION	AC	1.2	2500.00	3000.00
			SUB TOTAL =	$ 94,943.50
ENGINEERING AND DESIGN 15%				$ 14,241.53
CONSTRUCTION MANAGEMENT 15%				$ 14,241.53
LEGAL 5%				$ 4,747.18
PERMITTING 5%				$ 4,747.18
			TOTAL =	$ 132,920.90

PROBABLE RANGE -20% to +40% ($106,000) to ($186,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

IRON ENHANCED SAND FILTER

PRELIMINARY ENGINEERS OPINION OF COST 7/25/2016

LOCATION: ML_3, Mitchell Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	40000.00	40000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
ACCESS	LS	1	4500.00	4500.00
SILT FENCE	LN FT	500	3.50	1750.00
SILTATION LOG	LN FT	300	5.50	1650.00
TREE PROTECTION	LN FT	350	3.00	1050.00
EROSION CONTROL BLANKET	SQ YD	1701	2.50	4252.50
CLEAR AND GRUBBING	AC	0.35	7500.00	2625.00
TREE REMOVAL	EACH	26	350.00	9100.00
EXCAVATION	CU YD	3970	4.00	15880.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	3970	12.00	47640.00
48" RCP INLET	LN FT	50	208.00	10400.00
48" RCP FLARED END SECTION	EACH	2	5488.00	10976.00
48" RCP OUTLET	LN FT	24	208.00	4992.00
48" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
RIPRAP CLASS 2	TON	60	74.00	4440.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2444.00	2444.00
DRAIN TILE PIPING W/CO's	LS	1	5500.00	5500.00
HDPE 40 MIL LINER	SQ YD	1700	4.50	7650.00
IRON ENHANCED FILTRATION SAND	CU YD	2268	96.00	217728.00
FILTRATION TOP SOIL	CU YD	189	30.00	5670.00
SITE RESTORATION	AC	0.4	5000.00	2000.00
			SUB TOTAL =	$ 413,442.50
ENGINEERING AND DESIGN 15%				$ 62,016.38
CONSTRUCTION MANAGEMENT 15%				$ 62,016.38
LEGAL 5%				$ 20,672.13
PERMITTING 5%				$ 20,672.13
			TOTAL =	$ 578,819.50

PROBABLE RANGE -20% to +40% ($463,000) to ($810,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

UNDERGROUND INFILTRATION
PRELIMINARY ENGINEERS OPINION OF COST — 7/25/2016
LOCATION: ML_4, Mitchell Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	23000.00	23000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	250	3.50	875.00
SILTATION LOG	LN FT	150	5.50	825.00
TREE PROTECTION	LN FT	0	3.00	0.00
EROSION CONTROL BLANKET	SQ YD	0	2.50	0.00
REMOVE CONCRETE CURB AND GUTTER	LN FT	220	12.00	2640.00
SAW CUT BITUMINOUS PAVEMENT	LN FT	260	7.50	1950.00
REMOVE BITUMINOUS PAVEMENT	SQ YD	489	11.00	5379.00
EXCAVATION	CU YD	2252	4.00	9008.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	351	12.00	4212.00
BACKFILL AND COMPACTION	CU YD	1901	6.50	12356.50
STORMWATER STORAGE CHAMBER	LN FT	190	110.00	20900.00
FILTER ROCK	CU YD	180	40.00	7200.00
FILTER FABRIC	SQ YD	488	2.50	1220.00
24" RCP INLET	LN FT	48	170.00	8160.00
24" RCP OUTLET	LN FT	50	170.00	8500.00
48" DIA. PRECAST RC MANHOLE	LN FT	32	307.00	9824.00
PRETREATMENT STRUCTURE	L S	1	20000.00	20000.00
CASTING ASEMBLY STORM SEWER	EACH	4	550.00	2200.00
INSPECTION PORTS	EACH	2	3500.00	7000.00
REPLACE CONCRETE CURB AND GUTTER	LN FT	220	38.00	8360.00
CLASS 5 AGGREGATE BASE	CU YD	110	35.00	3850.00
REPLACE BITUMINOUS PAVEMENT	SQ YD	489	120.00	58680.00
SITE RESTORATION	L S	1	5000.00	5000.00
			SUB TOTAL =	$ 224,639.50
ENGINEERING AND DESIGN 15%				$ 33,695.93
CONSTRUCTION MANAGEMENT 15%				$ 33,695.93
LEGAL 5%				$ 11,231.98
PERMITTING 5%				$ 11,231.98
			TOTAL =	$ 314,495.30

PROBABLE RANGE -20% to +40% ($252,000) to ($440,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: RRL_1, Red Rock Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	20000.00	20000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
ACCESS TRAIL REPAIRS	LS	1	3000.00	3000.00
SILT FENCE	LN FT	350	3.50	1225.00
SILTATION LOG	LN FT	100	5.50	550.00
TREE PROTECTION	LN FT	50	3.00	150.00
EROSION CONTROL BLANKET	SQ YD	1064	2.50	2660.00
CLEAR AND GRUBBING	AC	0	7500.00	0.00
TREE REMOVAL	EACH	0	350.00	0.00
POND EXCAVATION	CU YD	7200	4.00	28800.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	7200	12.00	86400.00
12" RCP INLET	LN FT	85	36.00	3060.00
12" RCP FLARED END SECTION	EACH	1	951.00	951.00
30" RCP INLET	LN FT	60	91.00	5460.00
30" RCP FLARED END SECTION	EACH	1	2607.00	2607.00
48" RCP INLET	LN FT	60	208.00	12480.00
48" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	665.00	4655.00
60" RCP OUTLET	LN FT	30	208.00	6240.00
60" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
RIPRAP CLASS 2	TON	64	74.00	4736.00
96" DIA. PRECAST RC MANHOLE	LN FT	7	1218.00	8526.00
96" CONE GRATE TRASHRACK	EACH	1	4023.00	4023.00
FLOW CONTROL WEIR AND PIPING	LS	1	4500.00	4500.00
SITE RESTORATION	AC	2	2500.00	5000.00
			SUB TOTAL =	$ 218,499.00
ENGINEERING AND DESIGN 15%				$ 32,774.85
CONSTRUCTION MANAGEMENT 15%				$ 32,774.85
LEGAL 5%				$ 10,924.95
PERMITTING 5%				$ 10,924.95
			TOTAL =	$ 305,898.60

PROBABLE RANGE -20% to +40% ($245,000) to ($428,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BASIN
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: RRL_2, Red Rock Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	6000.00	6000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	250	3.50	875.00
SILTATION LOG	LN FT	180	5.50	990.00
TREE PROTECTION	LN FT	300	3.00	900.00
EROSION CONTROL BLANKET	SQ YD	968	2.50	2420.00
TREE REMOVAL	EACH	12	350.00	4200.00
POND EXCAVATION	CU YD	780	4.00	3120.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	730	12.00	8760.00
12" RCP INLET	LN FT	20	36.00	720.00
12" RCP FLARED END SECTION	EACH	1	951.00	951.00
15" RCP INLET	LN FT	30	40.00	1200.00
15" RCP FLARED END SECTION	EACH	1	1081.00	1081.00
18" RCP OUTLET	LN FT	50	47.00	2350.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
RIPRAP CLASS 2	TON	36	74.00	2664.00
60" DIA. PRECAST RC MANHOLE	LN FT	7	499.00	3493.00
60" CONE GRATE TRASHRACK	EACH	1	1880.00	1880.00
FLOW CONTROL WEIR AND PIPING	LS	1	2000.00	2000.00
TILL EXISTING SOIL	SQ YD	968	5.00	4840.00
FILTRATION SAND	CU YD	322	25.00	8050.00
FILTRATION TOP SOIL	CU YD	108	30.00	3240.00
SITE RESTORATION	AC	0.25	2500.00	625.00
			SUB TOTAL =	$ 64,097.00
ENGINEERING AND DESIGN 15%				$ 9,614.55
CONSTRUCTION MANAGEMENT 15%				$ 9,614.55
LEGAL 5%				$ 3,204.85
PERMITTING 5%				$ 3,204.85
			TOTAL =	$ 89,735.80

PROBABLE RANGE -20% to +40% ($72,000) to ($126,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: RRL_3, Red Rock Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	7000.00	7000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	650	3.50	2275.00
SILTATION LOG	LN FT	350	5.50	1925.00
TREE PROTECTION	LN FT	340	3.00	1020.00
EROSION CONTROL BLANKET	SQ YD	1210	2.50	3025.00
CLEAR AND GRUBBING	AC	1	7500.00	7500.00
TREE REMOVAL	EACH	60	350.00	21000.00
POND EXCAVATION	CU YD	1000	4.00	4000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	1000	12.00	12000.00
18" RCP INLET	LN FT	30	47.00	1410.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
18" RCP OUTLET	LN FT	40	47.00	1880.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
RIPRAP CLASS 2	TON	24	74.00	1776.00
60" DIA. PRECAST RC MANHOLE	LN FT	7	499.00	3493.00
60" CONE GRATE TRASHRACK	EACH	1	1880.00	1880.00
FLOW CONTROL WEIR AND PIPING	LS	1	2000.00	2000.00
SITE RESTORATION	AC	1.2	2500.00	3000.00
			SUB TOTAL =	$ 80,160.00
ENGINEERING AND DESIGN 15%				$ 12,024.00
CONSTRUCTION MANAGEMENT 15%				$ 12,024.00
LEGAL 5%				$ 4,008.00
PERMITTING 5%				$ 4,008.00
			TOTAL =	$ 112,224.00

PROBABLE RANGE -20% to +40% ($90,000) to ($157,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

SAND FILTER TRENCH 1000' x 100'

PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016

LOCATION: RRL_4, Red Rock Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	70000.00	70000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	900	3.50	3150.00
SILTATION LOG	LN FT	400	5.50	2200.00
TREE PROTECTION	LN FT	400	3.00	1200.00
EROSION CONTROL BLANKET	SQ YD	1900	2.50	4750.00
CLEAR AND GRUBBING	AC	1	7500.00	7500.00
TREE REMOVAL	EACH	10	350.00	3500.00
EXCAVATION	CU YD	2300	4.00	9200.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	2300	12.00	27600.00
CONCRETE STRUCTURE	CU YD	600	800.00	480000.00
36" RCP INLET	LN FT	40	118.00	4720.00
48" RCP OUTLET	LN FT	30	208.00	6240.00
48" DIA. PRECAST RC MANHOLE	LN FT	18	307.00	5526.00
CASTING ASEMBLY STORM SEWER	EACH	4	550.00	2200.00
DRAIN TILE PIPING W/CO's	LS	1	6500.00	6500.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
60" CONE GRATE TRASHRACK	EACH	1	2444.00	2444.00
FLOW CONTROL WEIR AND PIPING	LS	1	1000.00	1000.00
IRON ENHANCED FILTRATION SAND	CU YD	400	96.00	38400.00
FILTRATION TOP SOIL	CU YD	200	30.00	6000.00
SITE RESTORATION	AC	2	5000.00	10000.00
			SUB TOTAL =	$ 699,837.00
ENGINEERING AND DESIGN 15%				$ 104,975.55
CONSTRUCTION MANAGEMENT 15%				$ 104,975.55
LEGAL 5%				$ 34,991.85
PERMITTING 5%				$ 34,991.85
			TOTAL =	$ 979,771.80

PROBABLE RANGE -20% to +40% ($784,000) to ($1,372,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: RRL_5, Red Rock Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	11000.00	11000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	300	3.50	1050.00
SILTATION LOG	LN FT	150	5.50	825.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	620	2.50	1550.00
CLEAR AND GRUBBING	AC	0.5	7500.00	3750.00
TREE REMOVAL	EACH	0	350.00	0.00
POND EXCAVATION	CU YD	5000	4.00	20000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	5000	12.00	60000.00
18" RCP INLET	LN FT	30	47.00	1410.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
18" RCP OUTLET	LN FT	40	47.00	1880.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
RIPRAP CLASS 2	TON	24	74.00	1776.00
60" DIA. PRECAST RC MANHOLE	LN FT	7	499.00	3493.00
60" CONE GRATE TRASHRACK	EACH	1	1880.00	1880.00
FLOW CONTROL WEIR AND PIPING	LS	1	2000.00	2000.00
SITE RESTORATION	AC	0.6	2500.00	1500.00
			SUB TOTAL =	$ 117,540.00
ENGINEERING AND DESIGN 15%				$ 17,631.00
CONSTRUCTION MANAGEMENT 15%				$ 17,631.00
LEGAL 5%				$ 5,877.00
PERMITTING 5%				$ 5,877.00
			TOTAL =	$ 164,556.00

PROBABLE RANGE -20% to +40% ($132,000) to ($230,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

EXPAND EXISTING STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 8/25/2016
LOCATION: RRL_6, Red Rock Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST		TOTAL COST
MOBLIZATION	EACH	1	15000.00		15000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00		2500.00
ACCESS ROAD	L S	1	12000.00		12000.00
SILT FENCE	LN FT	680	3.50		2380.00
SILTATION LOG	LN FT	250	5.50		1375.00
TREE PROTECTION	LN FT	550	3.00		1650.00
EROSION CONTROL BLANKET	SQ YD	300	2.50		750.00
CLEAR AND GRUBBING	AC	0.5	7500.00		3750.00
TREE REMOVAL	EACH	5	350.00		1750.00
REMOVE 48" RCP FLARED END SECTION	EACH	0	1200.00		0.00
BULKHEAD 48" RCP	L S	0	650.00		0.00
CONTROL OF WATER	L S	1	5000.00		5000.00
POND EXCAVATION	CU YD	5077	4.00		20308.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	5077	12.00		60924.00
48" RCP INLET	LN FT	0	208.00		0.00
48" RCP FLARED END SECTION	EACH	0	5488.00		0.00
RIPRAP CLASS 2	TON	36	74.00		2664.00
OUTLET CONTROL STRUCTURE	LS	0	25000.00		0.00
GRATE TRASHRACK	EACH	0	8000.00		0.00
FLOW CONTROL WEIR AND PIPING	LS	0	3500.00		0.00
MODULAR CONC. BLOCK RETAINING WALL	SQ FT	0	28.00		0.00
48" CHAIN LINK FENCE	LN FT	400	15.00		6000.00
SITE RESTORATION	AC	1	2500.00		2500.00
			SUB TOTAL =	$	138,551.00
ENGINEERING AND DESIGN 15%				$	20,782.65
CONSTRUCTION MANAGEMENT 15%				$	20,782.65
LEGAL 5%				$	6,927.55
PERMITTING 5%				$	6,927.55
			TOTAL =	$	193,971.40

PROBABLE RANGE -20% to +40% ($155,000) to ($272,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

IRON ENHANCED SAND FILTER BENCHES
PRELIMINARY ENGINEERS OPINION OF COST 8/25/2016
LOCATION: RRL_7, Red Rock Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	30000.00	30000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
ACCESS	LS	1	4500.00	4500.00
SILT FENCE	LN FT	780	3.50	2730.00
SILTATION LOG	LN FT	340	5.50	1870.00
TREE PROTECTION	LN FT	180	3.00	540.00
EROSION CONTROL BLANKET	SQ YD	4627	2.50	11567.50
CLEAR AND GRUBBING	AC	0.90	7500.00	6750.00
TREE REMOVAL	EACH	9	350.00	3150.00
CONTROL OF WATER	L S	1	3500.00	3500.00
EXCAVATION	CU YD	2198	4.00	8792.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	2198	12.00	26376.00
18" RCP INLET	LN FT	40	208.00	8320.00
18" RCP FLARED END SECTION	EACH	4	5488.00	21952.00
18" RCP OUTLET	LN FT	20	118.00	2360.00
18" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
RIPRAP CLASS 2	TON	60	74.00	4440.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2444.00	2444.00
HDPE 40 MIL LINER	SQ YD	1157	4.50	5206.50
IRON ENHANCED FILTRATION SAND	CU YD	1542	96.00	148032.00
FILTRATION TOP SOIL	CU YD	130	30.00	3900.00
SITE RESTORATION	AC	1	5000.00	5000.00
			SUB TOTAL =	$ 314,625.00
ENGINEERING AND DESIGN 15%				$ 47,193.75
CONSTRUCTION MANAGEMENT 15%				$ 47,193.75
LEGAL 5%				$ 15,731.25
PERMITTING 5%				$ 15,731.25
			TOTAL =	$ 440,475.00

PROBABLE RANGE -20% to +40% ($352,000) to ($617,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

EXPAND AND DREDGE EXISTING STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 8/25/2016
LOCATION: RRL_8, Red Rock Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	48000.00	48000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	680	3.50	2380.00
SILTATION LOG	LN FT	340	5.50	1870.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	5112	2.50	12780.00
CLEAR AND GRUBBING	AC	0.28	7500.00	2100.00
TREE REMOVAL	EACH	14	350.00	4900.00
REMOVE 18" RCP FLARED END SECTION	EACH	1	350.00	350.00
BULKHEAD 18" RCP	L S	1	200.00	200.00
REMOVE CONCRETE SIDEWALK	SQ FT	1100	3.50	3850.00
REMOVE CONCRETE CURB AND GUTTER	LN FT	80	12.00	960.00
SAW CUT BITUMINOUS PAVEMENT	LN FT	220	7.50	1650.00
REMOVE BITUMINOUS PAVEMENT	SQ YD	164	11.00	1804.00
CONTROL OF WATER	L S	1	5000.00	5000.00
DREDGE SEDIMENT FROM EXISTING PONE	CU YD	1672	6.00	10032.00
DISPOSAL OF DREDGED MATERIAL	CU YD	1672	16.00	26752.00
POND EXCAVATION	CU YD	13176	5.00	65880.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	13176	12.00	158112.00
21" RCP INLET	LN FT	312	54.00	16848.00
21" RCP FLARED END SECTION	EACH	1	1625.00	1625.00
48" DIA. PRECAST RC MANHOLE	LN FT	42	307.00	12894.00
CASTING ASEMBLY STORM SEWER	EACH	4	550.00	2200.00
RIPRAP CLASS 2	TON	24	74.00	1776.00
OUTLET CONTROL STRUCTURE	LS	1	25000.00	25000.00
GRATE TRASHRACK	EACH	1	8000.00	8000.00
FLOW CONTROL WEIR AND PIPING	LS	1	3500.00	3500.00
REPLACE CONCRETE SIDEWALK	SQ FT	1100	5.50	6050.00
REPLACE CONCRETE CURB AND GUTTER	LN FT	80	38.00	3040.00
CLASS 5 AGGREGATE BASE	CU YD	37	35.00	1295.00
REPLACE BITUMINOUS PAVEMENT	SQ YD	164	120.00	19680.00
TRAFFIC CONTROL	LS	1	2500.00	2500.00
SOD	SQ YD	1200	7.50	9000.00
SITE RESTORATION	AC	1	2500.00	2500.00
			SUB TOTAL =	$ 465,478.00
ENGINEERING AND DESIGN 15%				$ 69,821.70
CONSTRUCTION MANAGEMENT 15%				$ 69,821.70
LEGAL 5%				$ 23,273.90
PERMITTING 5%				$ 23,273.90
			TOTAL =	$ 651,669.20

PROBABLE RANGE -20% to +40% ($521,000) to ($912,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BASIN
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: StL_2, Staring Lake via the Recreation Area

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	16000.00	16000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	950	3.50	3325.00
SILTATION LOG	LN FT	300	5.50	1650.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	2952	2.50	7380.00
CLEAR AND GRUBBING	AC	0.4	7500.00	3000.00
TREE REMOVAL	EACH	6	350.00	2100.00
EXCAVATION	CU YD	3500	4.00	14000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	3500	12.00	42000.00
24" RCP INLET	LN FT	40	59.00	2360.00
24" RCP FLARED END SECTION	EACH	2	2271.00	4542.00
33" RCP INLET	LN FT	60	109.00	6540.00
33" RCP FLARED END SECTION	EACH	1	3063.00	3063.00
36" RCP OUTLET	LN FT	20	118.00	2360.00
36" RCP FLARED END SECTION	EACH	1	3625.00	3625.00
RIPRAP CLASS 2	TON	56	74.00	4144.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2444.00	2444.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
TILL EXISTING SOIL	SQ YD	1333	5.00	6665.00
FILTRATION SAND	CU YD	889	25.00	22225.00
FILTRATION TOP SOIL	CU YD	222	30.00	6660.00
LANDSCAPING/BUILDING SIGNS	LS	1	7500.00	7500.00
SOD	SQ YD	1333	6.00	7998.00
SITE RESTORATION	AC	0.6	2500.00	1500.00
			SUB TOTAL =	$ 180,738.00
ENGINEERING AND DESIGN 15%				$ 27,110.70
CONSTRUCTION MANAGEMENT 15%				$ 27,110.70
LEGAL 5%				$ 9,036.90
PERMITTING 5%				$ 9,036.90
			TOTAL =	$ 253,033.20

PROBABLE RANGE -20% to +40% ($202,000) to ($354,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: StL_3, Staring Lake via the Recreation Area

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	18000.00	18000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	350	3.50	1225.00
SILTATION LOG	LN FT	200	5.50	1100.00
TREE PROTECTION	LN FT	50	3.00	150.00
EROSION CONTROL BLANKET	SQ YD	1005	2.50	2512.50
CLEAR AND GRUBBING	AC	0.8	7500.00	6000.00
TREE REMOVAL	EACH	0	350.00	0.00
POND EXCAVATION	CU YD	8000	4.00	32000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	8000	12.00	96000.00
24" RCP INLET	LN FT	60	59.00	3540.00
24" RCP FLARED END SECTION	EACH	1	2271.00	2271.00
24" RCP INLET	LN FT	60	59.00	3540.00
24" RCP FLARED END SECTION	EACH	1	2271.00	2271.00
24" RCP OUTLET	LN FT	60	59.00	3540.00
24" RCP FLARED END SECTION	EACH	2	2271.00	4542.00
RIPRAP CLASS 2	TON	48	74.00	3552.00
60" DIA. PRECAST RC MANHOLE	LN FT	7	499.00	3493.00
60" CONE GRATE TRASHRACK	EACH	1	1880.00	1880.00
FLOW CONTROL WEIR AND PIPING	LS	1	2000.00	2000.00
SITE RESTORATION	AC	1	2500.00	2500.00
			SUB TOTAL =	$ 192,616.50
ENGINEERING AND DESIGN 15%				$ 28,892.48
CONSTRUCTION MANAGEMENT 15%				$ 28,892.48
LEGAL 5%				$ 9,630.83
PERMITTING 5%				$ 9,630.83
			TOTAL =	$ 269,663.10

PROBABLE RANGE -20% to +40% ($216,000) to ($378,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: StL_4, Staring Lake via the Recreation Area

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	13000.00	13000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	250	3.50	875.00
SILTATION LOG	LN FT	160	5.50	880.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	944	2.50	2360.00
CLEAR AND GRUBBING	AC	0.5	7500.00	3750.00
TREE REMOVAL	EACH	20	350.00	7000.00
POND EXCAVATION	CU YD	5000	4.00	20000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	5000	12.00	60000.00
15" RCP INLET	LN FT	60	40.00	2400.00
15" RCP FLARED END SECTION	EACH	2	1081.00	2162.00
18" RCP OUTLET	LN FT	40	47.00	1880.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
RIPRAP CLASS 2	TON	36	74.00	2664.00
60" DIA. PRECAST RC MANHOLE	LN FT	7	499.00	3493.00
60" CONE GRATE TRASHRACK	EACH	1	1880.00	1880.00
FLOW CONTROL WEIR AND PIPING	LS	1	2000.00	2000.00
REPAIR PRIVATE DRIVE AND PARKING LOT	LS	1	15000.00	15000.00
SITE RESTORATION	AC	0.7	2500.00	1750.00
			SUB TOTAL =	$ 145,282.00
ENGINEERING AND DESIGN 15%				$ 21,792.30
CONSTRUCTION MANAGEMENT 15%				$ 21,792.30
LEGAL 5%				$ 7,264.10
PERMITTING 5%				$ 7,264.10
			TOTAL =	$ 203,394.80

PROBABLE RANGE -20% to +40% ($163,000) to ($285,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: StL_5, Staring Lake via the Recreation Area

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	60000.00	60000.00
CONSTRUCTION ENTRANCE	EACH	2	2500.00	5000.00
SILT FENCE	LN FT	2300	3.50	8050.00
SILTATION LOG	LN FT	800	5.50	4400.00
TREE PROTECTION	LN FT	50	3.00	150.00
EROSION CONTROL BLANKET	SQ YD	6462	2.50	16155.00
CLEAR AND GRUBBING	AC	5	7500.00	37500.00
TREE REMOVAL	EACH	100	350.00	35000.00
POND EXCAVATION	CU YD	25000	4.00	100000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	25000	12.00	300000.00
12" RCP INLET	LN FT	60	36.00	2160.00
12" RCP FLARED END SECTION	EACH	3	951.00	2853.00
15" RCP INLET	LN FT	60	40.00	2400.00
15" RCP FLARED END SECTION	EACH	3	1081.00	3243.00
18" RCP INLET	LN FT	20	47.00	940.00
18" RCP FLARED END SECTION	EACH	7	1238.00	8666.00
48" RCP INLET	LN FT	20	208.00	4160.00
48" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
54" RCP INLET	LN FT	20	256.00	5120.00
54" RCP FLARED END SECTION	EACH	1	7206.00	7206.00
RIPRAP CLASS 2	TON	84	74.00	6216.00
OUTLET CONTROL STRUCTURE	LS	1	15000.00	15000.00
GRATE TRASHRACK	EACH	1	8000.00	8000.00
FLOW CONTROL WEIR AND PIPING	LS	1	3500.00	3500.00
WORK AROUND H.V. TRANMISSION TOWEI	LS	1	5000.00	5000.00
SITE RESTORATION	AC	6	2500.00	15000.00
			SUB TOTAL =	$ 661,207.00
ENGINEERING AND DESIGN 15%				$ 99,181.05
CONSTRUCTION MANAGEMENT 15%				$ 99,181.05
LEGAL 5%				$ 33,060.35
PERMITTING 5%				$ 33,060.35
			TOTAL =	$ 925,689.80

PROBABLE RANGE -20% to +40% ($741,000) to ($1,296,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: StL_7, Staring Lake via the Recreation Area

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	15000.00	15000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	1500	3.50	5250.00
SILTATION LOG	LN FT	600	5.50	3300.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	5300	2.50	13250.00
CLEAR AND GRUBBING	AC	0.4	7500.00	3000.00
TREE REMOVAL	EACH	10	350.00	3500.00
POND EXCAVATION	CU YD	1500	4.00	6000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	1500	12.00	18000.00
15" RCP INLET	LN FT	30	40.00	1200.00
15" RCP FLARED END SECTION	EACH	1	1081.00	1081.00
18" RCP INLET	LN FT	30	47.00	1410.00
18" RCP FLARED END SECTION	EACH	1	1238.00	1238.00
36" RCP INLET	LN FT	30	118.00	3540.00
36" RCP FLARED END SECTION	EACH	1	3625.00	3625.00
60" RCP INLET	LN FT	20	304.00	6080.00
60" RCP FLARED END SECTION	EACH	1	7856.00	7856.00
RIPRAP CLASS 2	TON	104	74.00	7696.00
OUTLET CONTROL STRUCTURE	LS	1	25000.00	25000.00
GRATE TRASHRACK	EACH	1	8000.00	8000.00
FLOW CONTROL WEIR AND PIPING	LS	1	3500.00	3500.00
WORK AROUND H.V. TRANMISSION TOWEI	LS	1	5000.00	5000.00
SITE RESTORATION	AC	1	2500.00	2500.00
			SUB TOTAL =	$ 147,976.00
ENGINEERING AND DESIGN 15%				$ 22,196.40
CONSTRUCTION MANAGEMENT 15%				$ 22,196.40
LEGAL 5%				$ 7,398.80
PERMITTING 5%				$ 7,398.80
			TOTAL =	$ 207,166.40

PROBABLE RANGE -20% to +40% ($166,000) to ($290,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BASIN
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: StL_14, Staring Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	72000.00	72000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	450	3.50	1575.00
SILTATION LOG	LN FT	250	5.50	1375.00
TREE PROTECTION	LN FT	50	3.00	150.00
EROSION CONTROL BLANKET	SQ YD	2468	2.50	6170.00
CLEAR AND GRUBBING	AC	1.5	7500.00	11250.00
TREE REMOVAL	EACH	25	350.00	8750.00
EXCAVATION	CU YD	20000	4.00	80000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	20000	12.00	240000.00
CONCRETE STRUCTURE	CU YD	200	800.00	160000.00
36" RCP INLET	LN FT	60	118.00	7080.00
36" RCP FLARED END SECTION	EACH	1	3625.00	3625.00
24" RCP OUTLET	LN FT	20	59.00	1180.00
24" RCP FLARED END SECTION	EACH	2	2271.00	4542.00
RIPRAP CLASS 2	TON	36	74.00	2664.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2444.00	2444.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
TILL EXISTING SOIL	SQ YD	4500	5.00	22500.00
FILTRATION SAND	CU YD	1646	25.00	41150.00
FILTRATION TOP SOIL	CU YD	548	30.00	16440.00
SITE RESTORATION	AC	2	2500.00	5000.00
			SUB TOTAL =	$ 697,102.00
ENGINEERING AND DESIGN 15%				$ 104,565.30
CONSTRUCTION MANAGEMENT 15%				$ 104,565.30
LEGAL 5%				$ 34,855.10
PERMITTING 5%				$ 34,855.10
			TOTAL =	$ 975,942.80

PROBABLE RANGE -20% to +40% ($781,000) to ($1,366,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BASINS
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: StL_15, Staring Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	66000.00	66000.00
CONSTRUCTION ENTRANCE	EACH	2	2500.00	5000.00
SILT FENCE	LN FT	500	3.50	1750.00
SILTATION LOG	LN FT	150	5.50	825.00
TREE PROTECTION	LN FT	200	3.00	600.00
EROSION CONTROL BLANKET	SQ YD	3630	2.50	9075.00
CLEAR AND GRUBBING	AC	0.55	7500.00	4125.00
TREE REMOVAL	EACH	21	350.00	7350.00
REMOVE CONCRETE CURB AND GUTTER	LN FT	60	12.00	720.00
SAW CUT BITUMINOUS PAVEMENT	LN FT	220	7.50	1650.00
REMOVE BITUMINOUS PAVEMENT	SQ YD	220	11.00	2420.00
POND EXCAVATION	CU YD	1000	4.00	4000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	1000	12.00	12000.00
CONCRETE STRUCTURE	CU YD	400	800.00	320000.00
CONC. MODULAR BLOCK RETAINING WALL	SQ FT	2720	30.00	81600.00
15" RCP INLET	LN FT	60	40.00	2400.00
15" RCP FLARED END SECTION	EACH	2	1081.00	2162.00
18" RCP OUTLET	LN FT	180	47.00	8460.00
18" RCP FLARED END SECTION	EACH	3	1238.00	3714.00
48" DIA. PRECAST RC MANHOLE	LN FT	28	307.00	8596.00
CASTING ASEMBLY STORM SEWER	EACH	4	550.00	2200.00
RIPRAP CLASS 2	TON	60	74.00	4440.00
60" DIA. PRECAST RC MANHOLE	LN FT	14	499.00	6986.00
60" CONE GRATE TRASHRACK	EACH	2	1880.00	3760.00
FLOW CONTROL WEIR AND PIPING	LS	2	2000.00	4000.00
TILL EXISTING SOIL	SQ YD	2565	5.00	12825.00
FILTRATION SAND	CU YD	855	25.00	21375.00
FILTRATION TOP SOIL	CU YD	285	30.00	8550.00
REPLACE CONCRETE CURB AND GUTTER	LN FT	60	38.00	2280.00
CLASS 5 AGGREGATE BASE	CU YD	50	35.00	1750.00
REPLACE BITUMINOUS PAVEMENT	SQ YD	220	120.00	26400.00
SITE RESTORATION	AC	0.75	2500.00	1875.00
			SUB TOTAL =	$ 638,888.00
ENGINEERING AND DESIGN 15%				$ 95,833.20
CONSTRUCTION MANAGEMENT 15%				$ 95,833.20
LEGAL 5%				$ 31,944.40
PERMITTING 5%				$ 31,944.40
			TOTAL =	$ 894,443.20

PROBABLE RANGE -20% to +40% ($716,000) to ($1,252,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER POND
PRELIMINARY ENGINEERS OPINION OF COST 7/11/2016
LOCATION: StL_16, Staring Lake

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	37000.00	37000.00
CONSTRUCTION ENTRANCE	EACH	1	2500.00	2500.00
SILT FENCE	LN FT	350	3.50	1225.00
SILTATION LOG	LN FT	150	5.50	825.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	726	2.50	1815.00
CLEAR AND GRUBBING	AC	1	7500.00	7500.00
TREE REMOVAL	EACH	60	350.00	21000.00
POND EXCAVATION	CU YD	8000	4.00	32000.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	8000	12.00	96000.00
CONC. MODULAR BLOCK RETAINING WALL	SQ FT	4200	30.00	126000.00
36" RCP INLET	LN FT	60	118.00	7080.00
36" RCP FLARED END SECTION	EACH	1	3625.00	3625.00
36" RCP OUTLET	LN FT	20	47.00	940.00
36" RCP FLARED END SECTION	EACH	2	1238.00	2476.00
RIPRAP CLASS 2	TON	48	74.00	3552.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2444.00	2444.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
SITE RESTORATION	AC	1.5	2500.00	3750.00
			SUB TOTAL =	$ 356,889.00
ENGINEERING AND DESIGN 15%				$ 53,533.35
CONSTRUCTION MANAGEMENT 15%				$ 53,533.35
LEGAL 5%				$ 17,844.45
PERMITTING 5%				$ 17,844.45
			TOTAL =	$ 499,644.60

PROBABLE RANGE -20% to +40% ($400,000) to ($700,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BENCH
PRELIMINARY ENGINEERS OPINION OF COST 7/25/2016
LOCATION: StL_19, Staring Lake via the Recreation Area

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	20000.00	20000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	350	3.50	1225.00
SILTATION LOG	LN FT	180	5.50	990.00
TREE PROTECTION	LN FT	150	3.00	450.00
EROSION CONTROL BLANKET	SQ YD	2356	2.50	5890.00
CLEAR AND GRUBBING	AC	0.56	7500.00	4200.00
TREE REMOVAL	EACH	24	350.00	8400.00
POND EXCAVATION	CU YD	4428	4.00	17712.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	3925	12.00	47100.00
CONSTRUCT BERM	CU YD	503	6.00	3018.00
48" RCP INLET	LN FT	150	208.00	31200.00
48" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
48" RCP OUTLET	LN FT	30	208.00	6240.00
48" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
RIPRAP CLASS 2	TON	36	74.00	2664.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2440.00	2440.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
TILL EXISTING SOIL	SQ YD	707	5.00	3535.00
FILTRATION SAND	CU YD	471	25.00	11775.00
FILTRATION TOP SOIL	CU YD	78	30.00	2340.00
TRM OVERFLOW	SQ YD	80	18.00	1440.00
SITE RESTORATION	AC	0.56	2500.00	1400.00
			SUB TOTAL =	$ 193,202.00
ENGINEERING AND DESIGN 15%				$ 28,980.30
CONSTRUCTION MANAGEMENT 15%				$ 28,980.30
LEGAL 5%				$ 9,660.10
PERMITTING 5%				$ 9,660.10
			TOTAL =	$ 270,482.80

PROBABLE RANGE -20% to +40% ($216,000) to ($379,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

STORMWATER INFILTRATION BENCH
PRELIMINARY ENGINEERS OPINION OF COST 7/25/2016
LOCATION: StL_20, Staring Lake via the Recreation Area

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	28000.00	28000.00
CONSTRUCTION ENTRANCE	EACH	1	3500.00	3500.00
SILT FENCE	LN FT	450	3.50	1575.00
SILTATION LOG	LN FT	220	5.50	1210.00
TREE PROTECTION	LN FT	40	3.00	120.00
EROSION CONTROL BLANKET	SQ YD	2356	2.50	5890.00
CLEAR AND GRUBBING	AC	1.19	7500.00	8925.00
TREE REMOVAL	EACH	2	350.00	700.00
POND EXCAVATION	CU YD	7133	4.00	28532.00
REMOVAL OF EXCAVATED MATERIAL	CU YD	6422	12.00	77064.00
CONSTRUCT BERM	CU YD	711	6.00	4266.00
48" RCP INLET	LN FT	180	208.00	37440.00
48" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
48" RCP OUTLET	LN FT	30	208.00	6240.00
48" RCP FLARED END SECTION	EACH	1	5488.00	5488.00
RIPRAP CLASS 2	TON	36	74.00	2664.00
72" DIA. PRECAST RC MANHOLE	LN FT	7	601.00	4207.00
72" CONE GRATE TRASHRACK	EACH	1	2440.00	2440.00
FLOW CONTROL WEIR AND PIPING	LS	1	2500.00	2500.00
TILL EXISTING SOIL	SQ YD	1000	5.00	5000.00
FILTRATION SAND	CU YD	1333	25.00	33325.00
FILTRATION TOP SOIL	CU YD	111	30.00	3330.00
TRM OVERFLOW	SQ YD	86	18.00	1548.00
SITE RESTORATION	AC	1.2	2500.00	3000.00
			SUB TOTAL =	$ 272,452.00
ENGINEERING AND DESIGN 15%				$ 40,867.80
CONSTRUCTION MANAGEMENT 15%				$ 40,867.80
LEGAL 5%				$ 13,622.60
PERMITTING 5%				$ 13,622.60
			TOTAL =	$ 381,432.80

PROBABLE RANGE -20% to +40% ($305,000) to ($534,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

Streambank Stabilization at 10 Sites (Group 1) Identified in 2015 Wenck Technical Memo
PRELIMINARY ENGINEERS OPINION OF COST 10/15/2016
LOCATION: Lower Valley Purgatory Creek

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST	TOTAL COST
MOBLIZATION	EACH	1	15000.00	15000.00
TEMPORARY EROSION CONTROL	LS	1	7500.00	7500.00
EROSION CONTROL BLANKET	SY	5000	3.00	15000.00
CLEAR AND GRUBBING	LS	1	30000.00	30000.00
SITE GRADING	LS	1	20000.00	20000.00
ROLANKA BIOD-NET 40	SY	5000	5.00	25000.00
STREET SWEEPER (W/ PICKUP BROOM)	HR	20	125.00	2500.00
CLASS 3 RIP RAP	TON	20	120.00	2400.00
24" TO 36" FIELDSTONE BOULDER TOE	TON	110	120.00	13200.00
NATIVE SEED - MN MIX 33-262	SY	5000	1.00	5000.00
GEOTEXTILE FABRIC MN DOT TYPE 5	SY	50	5.00	250.00
SITE RESTORATION	LS	1	10000.00	10000.00
30% CONTINGENCY				43755.00
			SUB TOTAL =	$ 189,605.00
ENGINEERING AND DESIGN 15%				$ 28,440.75
CONSTRUCTION MANAGEMENT 15%				$ 28,440.75
LEGAL 5%				$ 9,480.25
PERMITTING 5%				$ 9,480.25
			TOTAL =	$ 265,447.00

PROBABLE RANGE -50% to +100% ($133,000) to ($531,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION
LINE ITEMS, UNIT COSTS, AND AMOUNTS COME FROM THE CITY OF EDEN PRAIRIE'S LOCAL SURFACE WATER MANAGEMENT PLAN (WENCK ASSOCIATES, 2016).

PURGATORY CREEK WATERSHED RESTORATION
Riley Purgatory Bluff Creek Watershed District
Eden Prairie, Minnesota

Streambank Stabilization at 6 Sites (Group 2) Identified in 2015 Wenck Technical Memo
PRELIMINARY ENGINEERS OPINION OF COST 10/15/2016
LOCATION: Lower Valley Purgatory Creek

ITEM DESCRIPTION	UNIT	AMOUNT	UNIT COST		TOTAL COST
MOBLIZATION	EACH	1	10000.00		10000.00
TEMPORARY EROSION CONTROL	LS	1	7500.00		7500.00
EROSION CONTROL BLANKET	SY	2000	3.00		6000.00
CLEAR AND GRUBBING	LS	1	20000.00		20000.00
SITE GRADING	LS	1	10000.00		10000.00
ROLANKA BIOD-NET 40	SY	2000	5.00		10000.00
STREET SWEEPER (W/ PICKUP BROOM)	HR	10	125.00		1250.00
24" TO 36" FIELDSTONE BOULDER TOE	TON	200	120.00		24000.00
NATIVE SEED - MN MIX 33-262	SY	2000	1.00		2000.00
GEOTEXTILE FABRIC MN DOT TYPE 5	SY	200	5.00		1000.00
SITE RESTORATION	LS	1	10000.00		10000.00
30% CONTINGENCY					30525.00
			SUB TOTAL =	$	132,275.00
ENGINEERING AND DESIGN 15%				$	19,841.25
CONSTRUCTION MANAGEMENT 15%				$	19,841.25
LEGAL 5%				$	6,613.75
PERMITTING 5%				$	6,613.75
			TOTAL =	$	185,185.00

PROBABLE RANGE -50% to +100% ($93,000) to ($370,000)

DOES NOT INCLUDE EASEMENTS OR WETLAND MITIGATION
LINE ITEMS, UNIT COSTS, AND AMOUNTS COME FROM THE CITY OF EDEN PRAIRIE'S LOCAL SURFACE WATER MANAGEMENT PLAN (WENCK ASSOCIATES, 2016).

E.2 Cost estimates for creek restoration and stabilization

The costs in dollars per linear foot for each creek restoration site were previously estimated in the Creek Restoration Action Strategy (Barr Engineering Co. & Riley Purgatory Bluff Creek Watershed District, November 2015). The unit costs are listed below. At the time of the CRAS, the accuracy range of the cost estimate was -50% to +100% which is different than the range of the rest of the BMPs. This wider range of uncertainty was retained for the creek restoration and stabilization BMPs.

Table D.2.1 Table of expected chemical dosing and cost based on 2005 sediment sampling and analysis

BMP	Estimated Unit Cost ($/ft)	Reach Length (feet)	Opinion of Cost	Low Opinion of Cost (-50%)	High Opinion of Cost (+100%)
LL_4	$450	960	$432,000	$216,000	$864,000
StL_1	$350	3,350	$1,173,000	$586,500	$2,346,000
StL_17	$550	1,000	$550,000	$275,000	$1,100,000
StL_21	$450	1,000	$450,000	$225,000	$900,000

E.3 Cost estimates for slope stabilization

Because of the similarity in the nature of the BMP, the cost estimates for the slope stabilization BMPs was estimated as a unit cost per length of slope. A value of $400 per linear foot was used because it was roughly the average of the creek restoration estimates. This estimate applies to BMPs Sil_3 through SiL_6. These estimates are highly uncertain because of the limited field reconnaissance. Therefore an uncertainty range of -50% to +100% was used here instead of the -20% to +40% that was used for other BMPs.

Table D.3.1 Table of expected chemical dosing and cost based on 2005 sediment sampling and analysis

BMP	Estimated Unit Cost ($/ft)	Reach Length (feet)	Opinion of Cost	Low Opinion of Cost (-50%)	High Opinion of Cost (+100%)
SiL_3	$400	215	$86,000	$43,000	$172,000
SiL_4	$400	200	$80,000	$40,000	$160,000
SiL_5	$400	200	$80,000	$40,000	$160,000
SiL_6	$400	130	$52,000	$26,000	$104,000

E.4 Cost estimates for internal load control

Sediment sampling was conducted in the lakes of the Purgatory Creek watershed in 2005. Mobile phosphorus was analyzed for the purpose of determining an appropriate alum dose, necessary for inactivating mobile phosphorus (Barr Engineering Co., 2005). Cost estimates were completed for two of the lakes in that study by estimating the necessary dosing rate in gallons per acre, depending on the mobile P concentration. In Round Lake, where the mobile phosphorus concentration was 0.75 $g/m^2/cm$, the dosing rate was 3826 gallons per acre. In Mitchell Lake, where the mobile phosphorus concentration was 0.24 $g/m^2/cm$, the dosing rate was 1202 gallons per acre. A linear fit between these points suggests that the dosing rate can be roughly estimated with the following equation:

$$D = 5145.1 * P_m - 32.825$$

where D is the dosing rate in gallons per acre, and P_m is the mobile phosphorus concentration in $g/m^2/cm$. The dosing rates of the other lakes were estimated with the above equation.

The cost estimate that was included in the 2005 study noted that the alum cost was $1 per gallon. It was assumed that other chemicals would have similar costs. Using an online US inflation calculator, the present value is estimated to be $1.23 per gallon (Coin News Media Group, LLC, 2016). A higher unit cost was assumed for Silver Lake, assuming an alternative chemical is required (sodium aluminate for example, (Barr Engineering Co., September 2013)). The treatment area was measured in GIS as roughly the surface area of the lake. The table below summarizes the method for estimating the alum treatment cost for each lake.

Additionally, $6,000 was estimated for sediment core analysis and a refined dosing estimate, $10,000 was estimated for site restoration, and 10% was estimated for mobilization and demobilization. Finally, 30% was assumed for monitoring and observation during application.

Table D.4.1 Table of expected chemical dosing and cost based on 2005 sediment sampling and analysis

Lake, BMP	Mobile P (g/m2/cm)	Estimated gallons per acre	Estimated cost per gallon	Approximate Treatment Area, acres	Chemical cost	Probable opinion of cost per treatment
Lotus Lake, LL_6	0.30	1,500	$1.23	230	$424,000	$629,000
Silver Lake, SiL_7	0.12	580	$2.50	69	$100,000	$166,000
Duck Lake, DL_2	0.11	530	$1.23	47	$31,000	$67,000
Round Lake, RL_3	0.75	3,830	$1.23	33	$155,000	$245,000
Mitchell Lake, ML_2	0.24	1,200	$1.23	112	$165,000	$259,000
Staring Lake, StL_18	0.27	1,360	$1.23	160	$268,000	$406,000

E.5 Cost estimates from others

Some of the BMPs described in this report were previously identified by others (Wenck Associates, Inc., December 2014). Those BMPs are LI_1, LI_1a & LI_2b, LI_3, StL_8, StL_9, StL_10, StL_11, StL_12, and StL_13. The construction costs and operation and maintenance costs were estimated in previous recent work and were used in this report rather than determining new cost estimates. For BMP StL_6, the cost was scaled from other tree trench BMPs based on the watershed area that is treated.

The treatment effectiveness and estimates of phosphorus loading reduction however were re-calculated with the P8 model described in this report. Therefore, the unit cost of the BMP in terms of dollars per pound of phosphorus removed have been updated and do not match the previous work done by others.

Two additional BMPs were added to the report after the first draft was published. These were PC_1 and PC_2, which were two groups of stream bank stabilization BMPs in the Lower Valley of Purgatory Creek. These BMPs were described in the city of Eden Prairie's Local Water Management Plan (Wenck Associates, Inc., August 2016). The costs presented in Appendix D of that management plan were used here (see Section E.1), with an additional 30% contingency because they were low in our opinion. Additionally, the estimated reduction in sediment and phosphorus presented in that management plan were also used to calculate the cost per pound of phosphorus and per ton of sediment.

E.6 References

American Society for Testing and Materials. (2006). *ASTM E2516-06 Standard Classification for Cost Estimate Classification System.* West Conshohocken, PA: ASTM International.

Association for the Advancement of Cost Estimating. (2005). *AACE International Recommended Practice NO. 18R-97.*

Barr Engineering Co. & Riley Purgatory Bluff Creek Watershed District. (November 2015). *Creek Restoration Action Strategy, 2015 Report.*

Barr Engineering Co. (2005, November 10). Mobile P-Alum Dosing Study.

Barr Engineering Co. (September 2013). *Lake Lucy and Lake Ann Use Attainability Analysis Update.*

Coin News Media Group, LLC. (2016, 8 30). *US Inflation Calculator*. Retrieved from www.usinflationcalculator.com

MDNR. (2011). *LiDAR Data.* St. Paul, MN: Minnesota Department of Natural Resources.

Wenck Associates, Inc. (August 2016). *Local Water Management Plan.* City of Eden Prairie, MN.

Wenck Associates, Inc. (December 2014). *Eden Prairie Town Center Stormwater Management Guide.*

Appendix F

Potential Stabilization Measures

Stream Stabilization Plan

Healthy, intact woodland and forest communities can prevent or reduce streambank erosion and decrease or delay surface runoff. A healthy intact forest community is composed of a tree canopy with 60% - 100% tree cover, an intermittent mid-height shrub layer, and a groundlayer of grasses, sedges and herbaceous plants. Damaged forest plant communities can be managed and manipulated to restore these ecological and hydrologic functions.

In a healthy forest the vegetative layers intercept rainfall and delay fall of rain to the ground below. This occurs at multiple levels within the forest to reduce overland flows. This interception and evaporation results in little or no overland flow. Most healthy forest communities have a thick layer of duff, composed of leaf litter in various stages of decomposition that further protects the soil from rainfall. This litter layer is responsible for high infiltration rates and thus little surface runoff. Most surface runoff within healthy forest occurs during the snowmelt period, due to spring runoff over frozen soils, and immediately following leaf drop in the fall. Native plant species grow dense root networks that bind bank sediments, increase bank strength due to the reinforcement by roots, and help resist plant removal by flood scour.

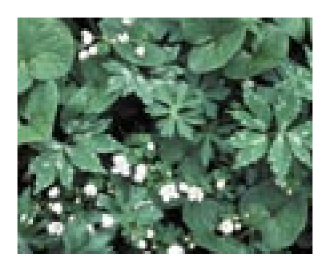
In many cases simply establishing a preservation area may not be enough to allow natural forest regeneration due to the highly altered and damaged condition of the forest. Areas with invasive species or dense turf will require the removal of invasive species or turf to improve plant regeneration potential. In cases where the native plant species have been greatly reduced, replanting or seeding may be needed. Dormant woody stakes and posts can be used to stabilize eroding banks and bare-root trees can be used in the riparian and flood plain areas, as well on the upslope areas. Properly selected and planted vegetation can withstand flooding and high velocity water but woody vegetation may not always solve slope stability problems. The groundlayer and shrub layer also need to re-establish for long term stability. In areas with high numbers of white-tailed deer plant protection measures such as fencing will need to be installed if deer numbers cannot be reduced to levels that will prevent damage.

SIMILAR PROJECTS

A project to rejuvenate a 1,500 foot reach of Shingle Creek in the City of Brooklyn Park was undertaken as part of a neighborhood revitalization plan. The project included stream channel improvements (using over 500 tons of native rock), installation of a pedestrian bridge, and vegetation management. The vegetation management included removal of non-native trees and vegetation and planting of native, deep-rooted plants.

EXISTING CONDITIONS

Changes in forest plants can lead to increased surface runoff rates and decreased stream bank stability. Vegetation loss can be brought about by invasive species replacing native species (such as buckthorn or garlic mustard), tree loss from diseases such as oak wilt or Dutch elm disease, or changes in plant community structure due to high numbers of white-tailed deer. High numbers of earthworms can dramatically reduce the duff layer, and lead to a loss of the groundlayer vegetation. These changes in plant community lead to increased surface runoff that can negatively impact the stability of stream banks. The loss of vegetation also decreases bank stability due to reduced root reinforcement of the slopes.



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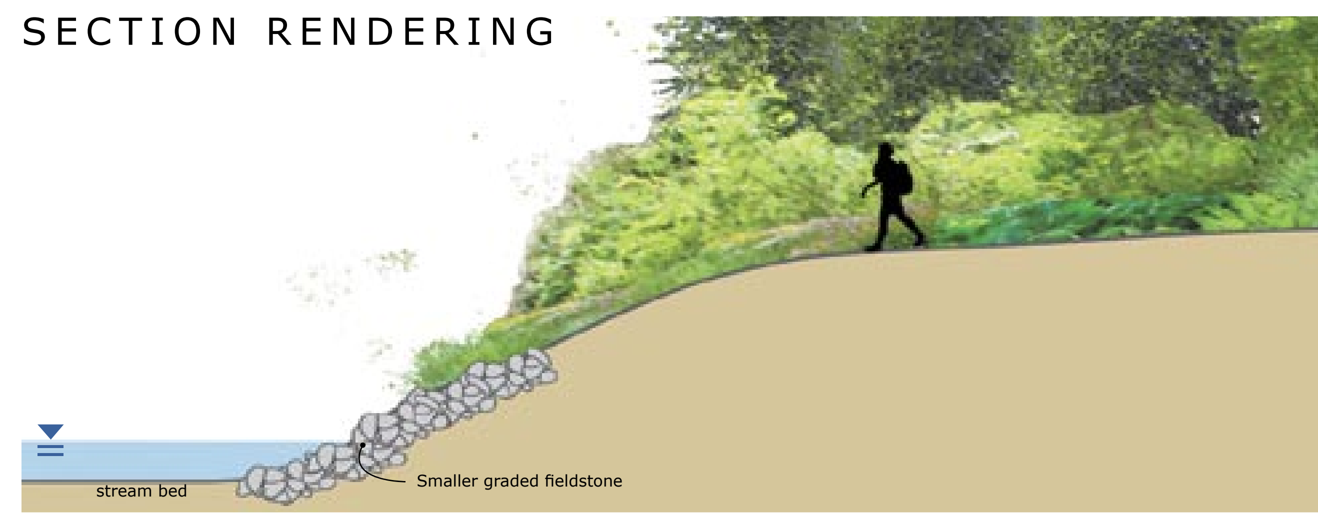


Vegetation Management

Bank Protection

BARR

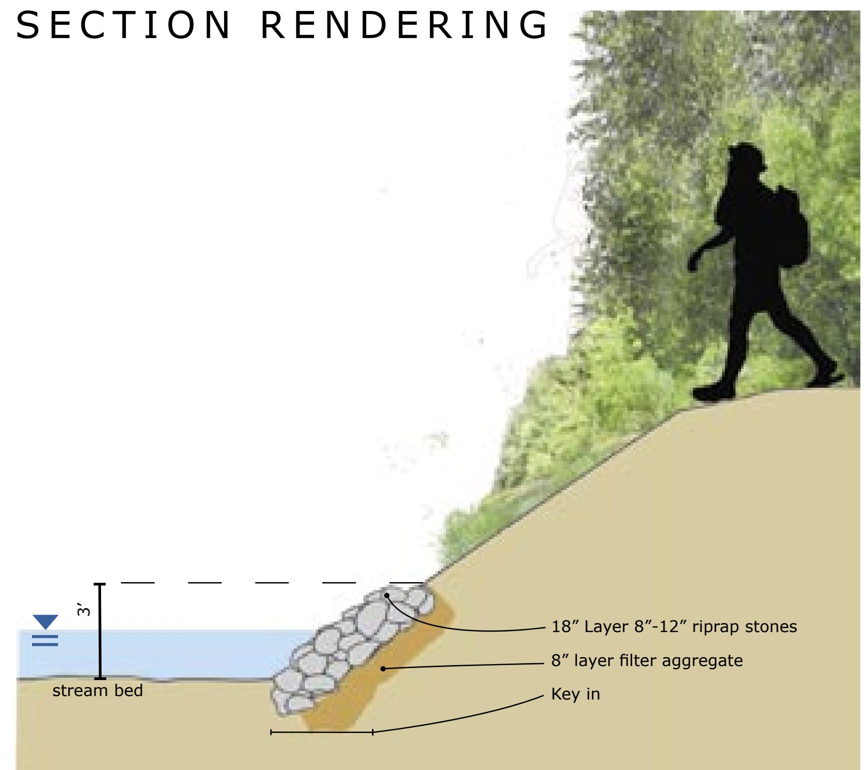
Stream Stabilization Plan

Stone Toe Protection is constructed from cobble-sized rock on the creek edges. It extends to approximately the bankfull level, which will protect the channel banks for flow events that occur every 1 to 2 years or less. The material will extend into the ground to resist scour. Coarse gravel is used to separate the larger rock material from underlying soil. Stone toe protection is typically used in conjunction with revegetation of the upper banks.

SIMILAR PROJECTS

Stone toe protection has been used extensively in Nine Mile Creek's Lower Valley, in conjunction with deflector dikes, grade control measures and stabilization of large bank failures. Following the 1987 "super storm," the proposed design allowed the stream to continue its course while taking measures to protect areas where water flow was eroding valley walls. The resulting measures have stabilized the stream channel and valley walls while blending seamlessly with the natural environment.

SECTION RENDERING

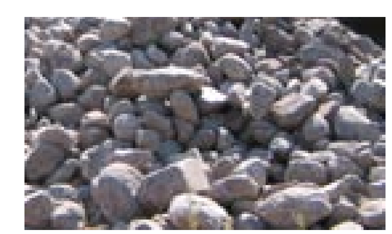


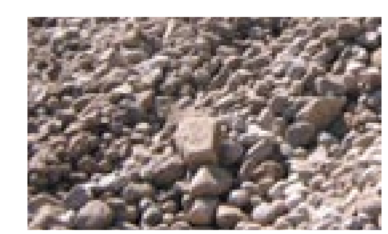
EXISTING CONDITIONS

Fluvial bank erosion is caused by water in the stream moving past the streambanks. The shear stress caused by the flow entrains soil particles into the flow, causing the stream bank to erode away. This is the most common type of erosion that occurs in streams. Virtually all streams experience this type of erosion as their flow path evolves over time. However, the rate of fluvial bank erosion can increase when the stream is out of equilibrium with its watershed. Increased flow from a watershed will increase the rate of fluvial bank erosion. In many cases, it appears to be a part of the natural process of stream evolution. In places where the channel is confined by the valley walls, however, fluvial bank erosion can lead to failure of the high banks. It can also undermine storm sewer inlets.

MATERIALS

Materials will consist of cobble-sized material with coarse gravel filter layer to provide separation from the underlying soil. Natural fieldstone material will be used.





Stone Toe Protection

Bank Protection

BARR

Stream Stabilization Plan

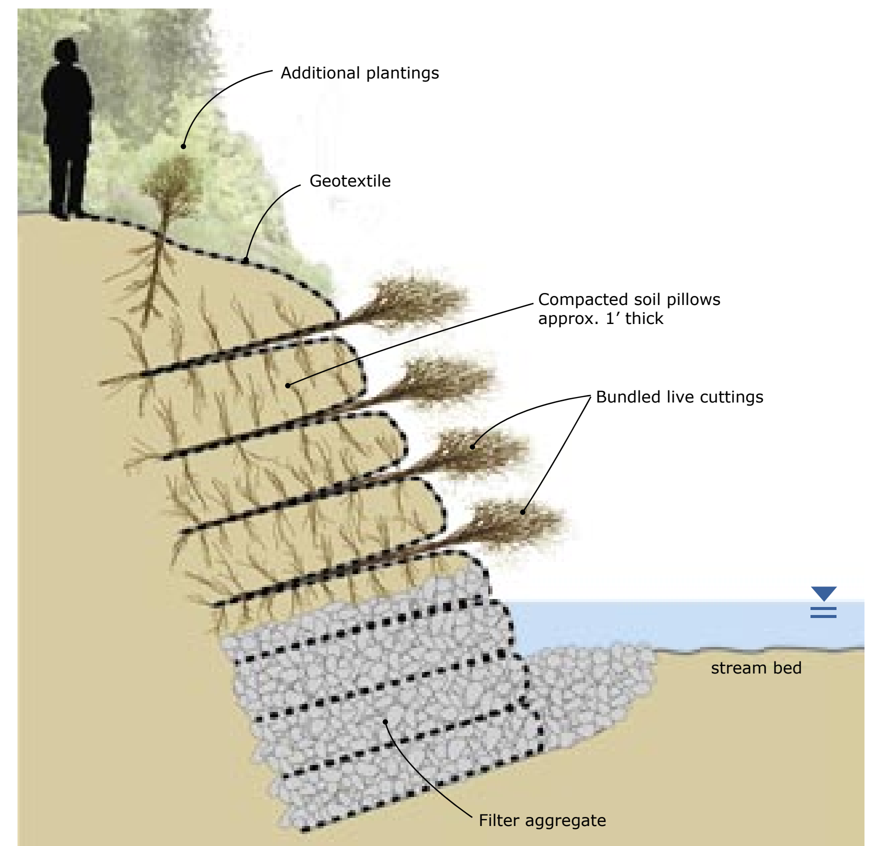
EXISTING CONDITIONS

Fluvial bank erosion is caused by water in the stream moving past the streambanks. The shear stress caused by the flow entrains soil particles into the flow, causing the stream bank to erode away. This is the most common type of erosion that occurs in streams.

Virtually all streams experience this type of erosion as their flow path evolves over time. However, the rate of fluvial bank erosion can increase when the stream is out of equilibrium with its watershed. Increased flow from a watershed will increase the rate of fluvial bank erosion.

Soil Pillows are utilized in a bioengineering method known as Vegetated Reinforced Slope Stabilization (VRSS). The method combines rock, geosynthetics, soil and plants to stabilize steep, eroding slopes in a structurally sound manner. VRSS typically involves protecting layers of soils with a blanket or geotextile material (e.g. erosion control blanket) and vegetating the slope by either planting selected species (often willow or dogwood species) between the soil layers or by seeding the soil with desired species before it is covered by the protective material. In either case, with adequate light and moisture, the vegetation grows quickly and provides significant root structure to strengthen the bank. This method tends to be labor intensive and, therefore, relatively expensive.

SECTION RENDERING



In places where the channel is confined by the steep valley walls, however, fluvial bank erosion can lead to failure of the high banks. It can also undermine storm sewer inlets.

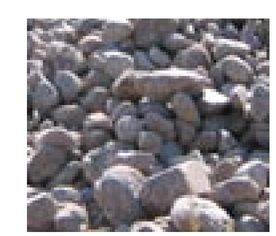
For sites where groundwater seepage is a problem and where it is desirable to maintain steep banks, soil pillows are a feasible solution.

SIMILAR PROJECTS

The Mill Creek Restoration Project utilized soil bioengineering design to stabilize 175 linear feet of severely eroding streambanks within the Caldwell Recreation Park in southeastern Ohio. The work included two 25-foot vegetated reinforced soil slope (VRSS) sections, two 50-foot fill bank sections protected with woven coir and direct woody plantings, and a 12.5-foot tie-in on the upstream and downstream end of streambank work area.

MATERIALS

Materials consist of graded rock for the lower layers of the structure and for internal drainage, if necessary. Geotextile fabric is used to wrap the soil. Plants, such as willow or dogwood, or seed mixture is used for planting in and between the soil pillows.



Soil Pillows

Bank Protection

BARR

Stream Stabilization Plan

Rock vanes are constructed from boulders on the creek bottom. They function by diverting channel flow toward the center and away from the bank. They are typically oriented in the upstream direction and occupy no more than one third of the channel width. Vanes are largely submerged and inconspicuous. The rocks are chosen such that they will be large enough to resist movement during flood flows or by vandalism, with additional smaller rock material to add stability. Rock vanes function in much the same way as root wads in that they push the stream thalweg (zone of highest velocity) away from the outside bend. They also promote sedimentation behind the vane, which adds to the toe protection.

MATERIALS

Materials will consist of various gradations of rock, ranging from large, 3-foot boulders to coarse gravel.

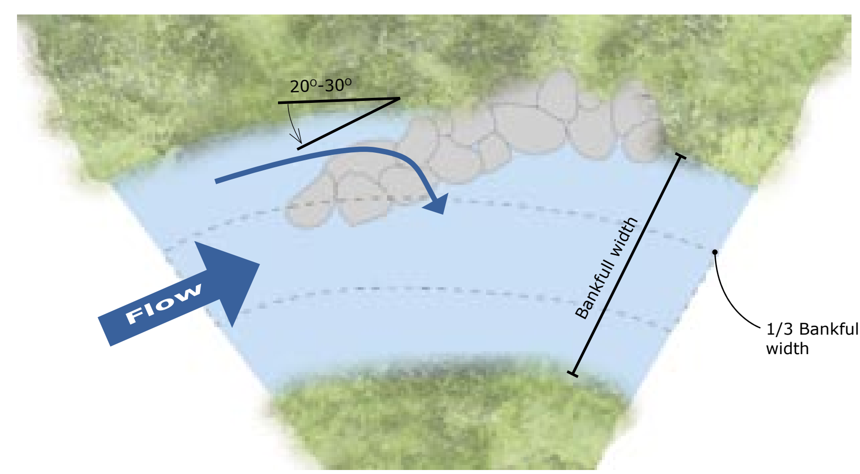
SIMILAR PROJECTS

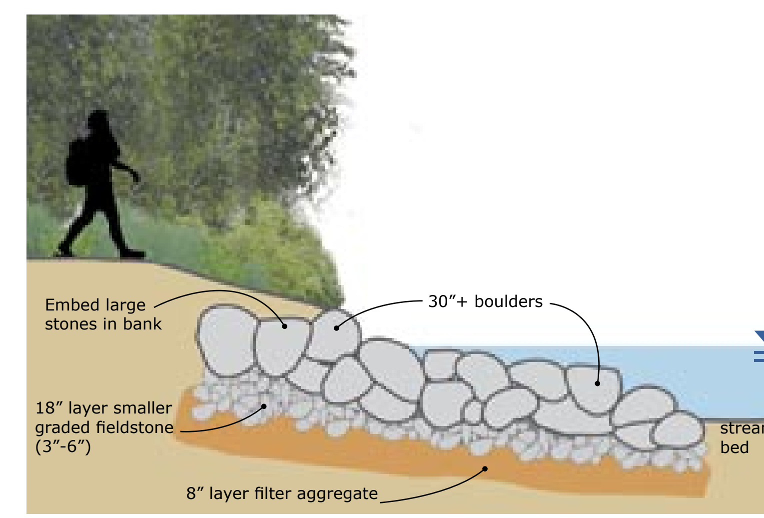
Here is an example of a stabilization project designed for a 1,000-foot long, 20-foot high streambank that was severely eroded. The channel was directed away from the bank toe by installing six rock vanes. The bank was planted with native vegetation and protected with erosion control blanket, while the terrace above the bank was graded to redirect surface runoff to a less vulnerable area. The restored streambank withstood significant flooding during 2001, and has become nicely vegetated (see picture above).

EXISTING CONDITIONS

Fluvial bank erosion is caused by water in the stream moving past the streambanks. The shear stress caused by the flow entrains soil particles into the flow, causing the stream bank to erode away. This is the most common type of erosion that occurs in streams. Virtually all streams experience this type of erosion as their flow path evolves over time. However, the rate of fluvial bank erosion can increase when the stream is out of equilibrium with its watershed. Increased flow from a watershed will increase the rate of fluvial bank erosion. In most cases, it appears to be a part of the natural many of stream evolution. In places where the channel is confined by the valley walls, however, fluvial bank erosion can lead to failure of the high banks. It can also undermine storm sewer inlets.

PLAN/SECTION RENDERING





Rock Vanes

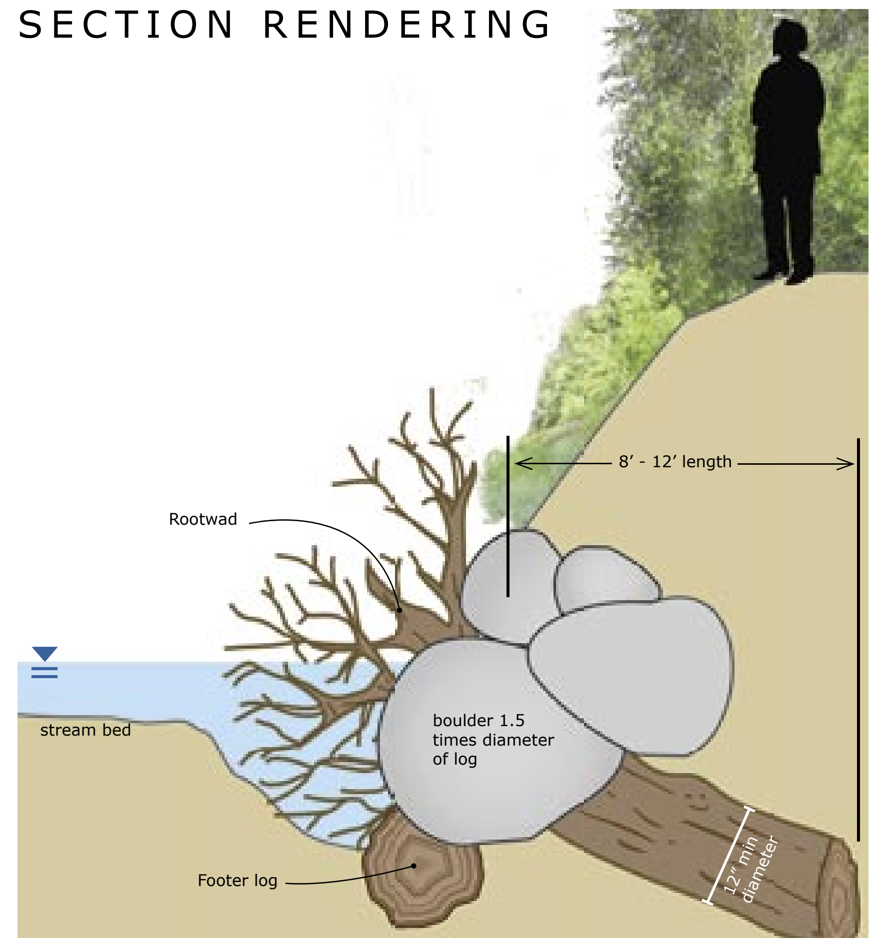
Bank Protection

BARR

Stream Stabilization Plan

Root wads are constructed using sections of tree trunks with their root balls attached. The trunks extend into the stream bank leaving only the roots exposed, partially submerged. The root wads are spaced to protect a given length of bank. Footer logs and boulders are often used to help stabilize the root wads. Root wads work well where the water is deep, such as on the outside of bends, and where there is adequate sunlight to allow vegetation to grow around the exposed root wads.

SECTION RENDERING



EXISTING CONDITIONS

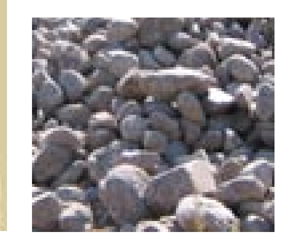
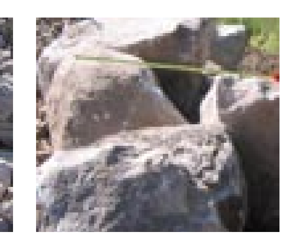
Fluvial bank erosion is caused by water in the stream moving past the streambanks. The shear stress caused by the flow entrains soil particles into the flow, causing the stream bank to erode away. This is the most common type of erosion that occurs in streams. Virtually all streams experience this type of erosion as their flow path evolves over time. However, the rate of fluvial bank erosion can increase when the stream is out of equilibrium with its watershed. Increased flow from a watershed will increase the rate of fluvial bank erosion. In many cases, it appears to be a part of the natural process of stream evolution. In places where the channel is confined by the valley walls, however, fluvial bank erosion can lead to failure of the high banks. It can also undermine storm sewer inlets.

SIMILAR PROJECTS

Root wads were used to stabilize two sites on the Rum River in Anoka, Minnesota, where severe bank erosion threatened to destroy adjacent trails. Approximately six root wads were placed at each site under difficult, high-water conditions. The banks were then graded, topsoil was added, and native vegetation was planted. Despite the difficult placement, the root wads have protected the lower bank, allowing the vegetation to become well established.

MATERIALS

Materials will consist of 12 to 16 foot long tree trunks, minimum 12-inch diameter, with the root ball attached. Materials should be harvested on-site as much as possible. Smaller logs and boulders are also helpful to stabilize and support the root wads.

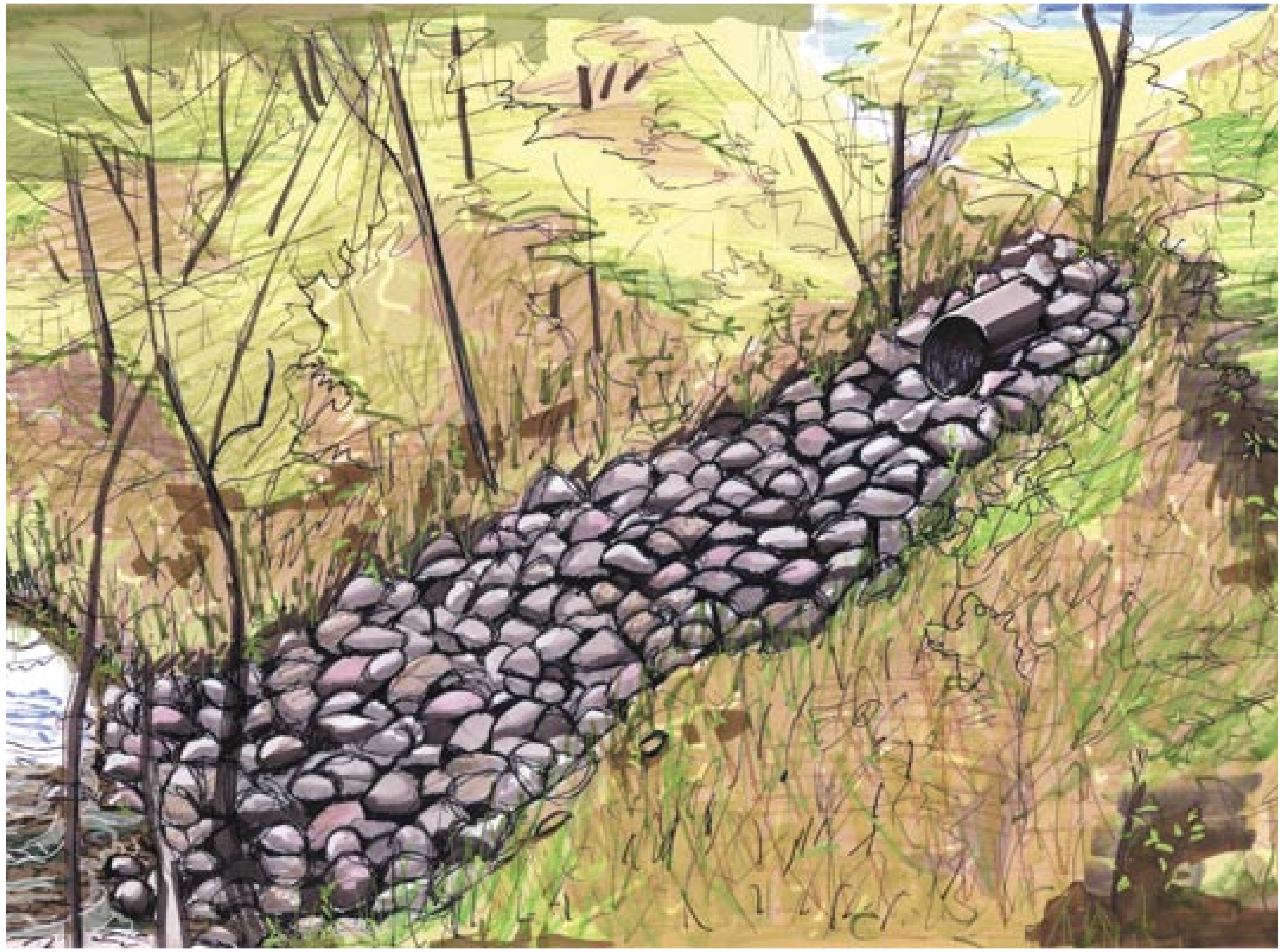




Root Wads

Bank Protection

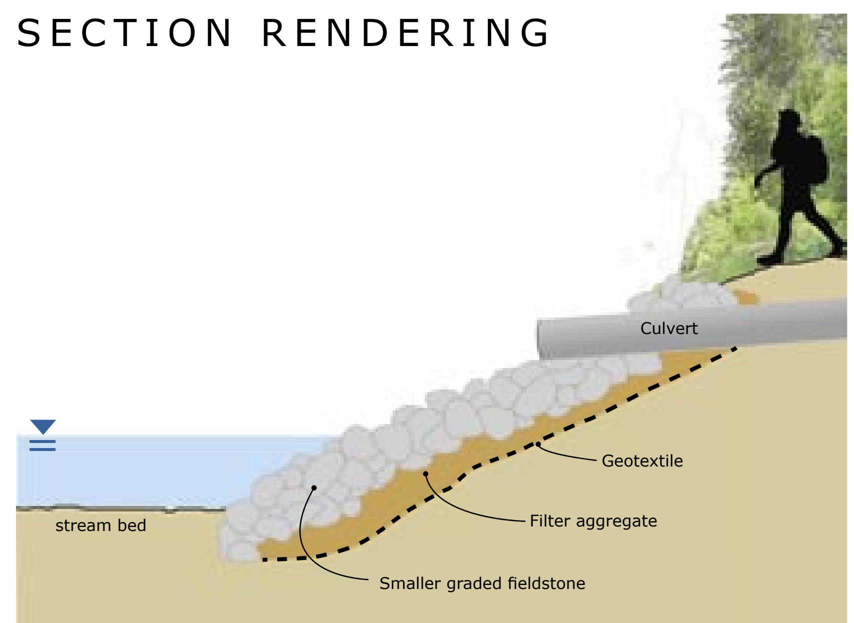
BARR

Stream Stabilization Plan



Culvert Stabilization is somewhat unique to each situation, depending on the site circumstances. Most sites require additional rock placement with a granular filter layer (rather than filter fabric). Some cases may require re-alignment and/or lowering of the outlet to better align with the stream channel. Typically, the outlets are aligned in the downstream channel direction.

SECTION RENDERING



EXISTING CONDITIONS

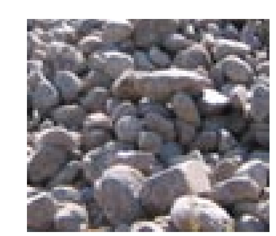
Erosion is frequently observed at culvert outlets for a variety of reasons, including insufficient erosion protection at the culvert outlet, streambank erosion, and channel downcutting, which leaves the culvert perched above the channel. Filter fabric is often used at culvert outlets to separate riprap protection from underlying soils, however the fabric provides a slippery surface for the riprap, which commonly slides into the channel.

SIMILAR PROJECTS

There are many culvert stabilization designs used on various streams and rivers. Because they are often small projects, the work is often performed by local municipalities or completed as part of a larger project.

MATERIALS

Materials will consist rock materials ranging from graded riprap (either fieldstone, or, for steep slopes, angular) and granular filter material (typically coarse gravel). If necessary, additional pipe, manholes and end sections may be necessary.



Culvert Stabilization

Bank Protection

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