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Eden and Neill Lakes Watershed Basin Inventory and Maintenance Assessment

Prepared for:

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Acronyms

AF	Acre-feet
BMP	Best Management Practice
BWSR	Board of Water and Soil Resources
DNR	Department of Natural Resources
EPA	Environmental Protection Agency
GIS	Geographic Information System
HUC	Hydrologic Unit Code: 8-digit HUC fourth-level (cataloguing unit)
MDH	Minnesota Department of Health
MnDOT	Minnesota Department of Transportation
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
NURP	Nationwide Urban Runoff Program
PAHs	Polycyclic Aromatic Hydrocarbons
PCCA	Purgatory Creek Conservation Area
SCS	Soil Conservation Service
SDS	State Disposal System
SWPPP	Stormwater Pollution Prevention Plan
TIN	Triangulated Irregular Networks
TP	Total Phosphorus
TSS	Total Suspended Solids
WCA	Wetland Conservation Act

Executive Summary

The City of Eden Prairie, MN (population 60,797) is a suburb of Minneapolis with an area of approximately 36 square miles. The City's stormwater system consists of approximately 970 water bodies or basins. These include constructed ponds, stormwater wetlands, wetland mitigation areas, lakes, infiltration BMPs, drainage swales or ditches, and creek segments. Following NPDES requirements, the City inspects a minimum of 20% of publically-owned or maintained basins annually. The Minnesota Pollution Control Agency (MPCA), however, has asked the City to take an additional step to evaluate the treatment effectiveness of key water quality treatment basins (constructed ponds, infiltration BMPs and wetlands which receive stormwater). For this analysis, the City included water bodies that are either City-owned, under a drainage easement, receive public drainage or are within City right-of-way.

BASIN INVENTORY & ASSESSMENT

In 2009, the Minnesota Pollution Control Agency (MPCA) asked the City to take an additional step to monitor the 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 Eden and Neill Lake watersheds.

In 2011, the basin inventory completed by the City identified 35 basins within the Eden Lake and Neill Lake project area. The first step in the process was to determine which of the 35 basins were considered "public" by determining which ones are located on City property, within City right-of-way, under a drainage and utility easement, or private but receiving runoff from public right-of-way. In the end, a total of 21 basins were identified as "public" in the project area.

A total of 26 basins, including 6 which were determined to be private, were assessed for functionality and sedimentation. Of the "public" inventoried basins, 4 were designated constructed ponds, 11 were stormwater wetlands, 3 were determined to be swales and not excavated basins, and 2 were identified as lakes. Of the private inventoried basins, 1 was designated a constructed pond and 5 were stormwater wetlands.

SEDIMENTATION SURVEY

The sedimentation survey was conducted using a survey-grade sub-centimeter GPS unit to complete bathymetric surveys of the basins. A "Stormwater System Follow-up Checklist" was developed to document information collected during the field survey. The following information was collected in the field:

- Bottom elevation of each basin
- Estimated accumulated sediment depth

- Approximate percent coverage of the permanent pool surface that appeared to be regularly covered by aquatic vegetation
- Water surface elevation
- Basin outlet/overflow data, including elevations and location
- Basin length and width
- Photographs of key features of the basins

During the field review, Wenck also documented any “plain-sight” maintenance needs on the worksheets. This included items such as erosion, accumulation of debris on trash racks, damaged structures and others.

The City provided storm sewer, grading and as-built plans when available for use during the field evaluation. The plans were taken into the field with the inspector to allow for easy comparison between proposed and constructed facilities.

Bathymetric surveys were conducted using cross-sections surveyed throughout each basin. At each survey point in the cross-section, the basin bottom elevation and the top of accumulated sediment were determined. Sediment depth was determined by advancing a rod into the basin muck until resistance is felt (the original basin bottom).

BASIN ANALYSIS

Data collected from the sedimentation survey was used to determine sedimentation amounts, pollutant removal effectiveness, and sediment removal. The load-based removal efficiency was calculated and compared to Nationwide Urban Runoff Program (NURP) design standards. Maintenance needs were prioritized by degree of sedimentation, proximity to public waters, location within the stormwater treatment system, potential water quality benefits, and budget available.

The project area was broken into several smaller subwatersheds that represent basins in series to better evaluate the critical basins and the overall treatment in that subwatershed prior to discharge to receiving waters. A total of two constructed ponds were identified as critical basins in determining water quality benefits. Six basins were identified for potential expansion or clean-out to improve water quality performance.

WATER QUALITY AND LAKE-RESPONSE MODELS

The tasks and analysis discussed above provide the City with an assessment of individual basin performance throughout much of Eden and Neill Lake watersheds. It does not, however, indicate whether there is an adequate level of pollutant removal for Eden and Neill Lakes and what the overall benefit to the lake would be as a result of key projects. Therefore, a watershed-wide P8 model and a lake-response model were created for Eden Lake and Neill Lake.

RESULTS

The basin inventory and assessment identified 6 basins as high priority basins that should be routinely inspected at a frequency of 5-7 years which is approximately twice the current frequency of 12 years. These basins were identified based on evidence of potential sedimentation and location in the treatment train. One constructed pond and 4 stormwater wetlands were identified as possible projects for cleanout or expansion through as-built comparisons and the sedimentation survey.

The BATHTUB lake response model indicates that in order to meet State standards (60 µg/L for phosphorus), Eden Lake requires 314 lbs/yr of phosphorus reduction (222 lbs/yr reduction from the watersheds and 92 lbs/yr from internal loading). If all the proposed projects are completed in the Eden Lake watershed, 23.8 lbs/yr, or 8% of the total phosphorus reduction required is projected. The estimated cost of the proposed projects is $239,000, equating to $10,042.02 per pound phosphorus removal. To meet the standard, a reduction of 67% from all watersheds is required.

The BATHTUB lake response model indicates that in order to meet State standards (60 µg/L for phosphorus), Neill Lake requires 74 lbs/yr of phosphorus reduction. Of the 74 lbs/yr total phosphorus reduction required, 22 lbs/yr need to come from Neill Lakes direct watershed and 52 lbs/yr total phosphorus need to come from a reduction in the internal load. Currently, no stormwater basins exist in the Neill Lake watershed which indicates that retrofitting the watershed will be necessary to meet the reduction requirements.

1.0 Introduction

1.1 BACKGROUND

The City of Eden Prairie, MN (population 60,797; Figure 1.1) is a suburb of Minneapolis with an area of approximately 36 square miles. The City's stormwater system consists of approximately 970 basins including constructed ponds, stormwater wetlands, natural wetlands, lakes, infiltration BMPs, drainage swales or ditches and creek segments. This system has been designed to be used for flood control and water quality treatment for many years. Some constructed ponds and stormwater wetlands are now greater than 20 years old and may have reached a point where dredging of accumulated sediment may be needed to retain their effectiveness.

The City operates the stormwater management system under the General NPDES Permit for Municipal Separate Storm Sewer Systems (MS4). Following NPDES requirements, the City must manage, operate, and maintain the stormwater management system in a manner to reduce the discharge of pollutants to the maximum extent practicable. To this end, the City inspects a minimum of 20% of their basins annually and recently completed an inventory to identify and help track all of the basins in the City.

In 2009, the Minnesota Pollution Control Agency (MPCA) asked the City to take an additional step to monitor the basins that are either City-owned, under a drainage easement, receive public drainage or are within a City right-of-way. The phase of the project conducted in 2011 covers the Eden and Neill Lake watershed.

1.2 PURPOSE

The purpose of this study was to enhance the understanding of the City's maintenance responsibilities, assist City staff with scheduling and budgeting resources, and maintain compliance with the City's MS4 SWPPP. As described below, this assessment included three main components to achieve these objectives:

- Inventory and Assess Stormwater Systems – identify basins to be maintained by the City; visually inspect City-maintained basins for routine maintenance issues; perform bathymetric survey of City-maintained basins.
- Evaluate Data – evaluate sedimentation levels in City-maintained basins; identify key basins and their water quality effectiveness; evaluate receiving water impacts including Eden and Neill Lake.
- Recommend Improvements – identify improvements/maintenance action items; complete cost estimates for sediment removal; prioritize basin maintenance efforts.

1.3 PROJECT AREA

The project area includes the drainage area north and west of Eden Lake and Neill Lake and also includes the Olympic Hills Golf Course (Figure 1.2). Eden Lake (listed as DNR Unnamed Lake ID 27-1011) and Neill Lake (DNR Lake ID 27-0079) are off-line lakes that drain to Purgatory Creek, which is a tributary to the Minnesota River. Eden Lake is a wetland just south of Eden Prairie Center and has a surface area of 18 acres and a maximum depth of 7 feet; it drains to the wetland located south of Neill Lake. Although Eden Lake is a wetland, it was treated as a lake for this analysis. Neill Lake is located to the southeast of Eden Lake and to the west of the Olympic Hills Golf Course. Neill Lake is a constructed lake and drains to the adjacent wetland to the south through a constructed outlet; the lake is otherwise separated from the wetland by a berm. Prior to 1971 Neill Lake and the adjacent wetland to the south were one large wetland. In 1971, the Preserve Association dredged and diked Neill Lake. The drainage system for Neill Lake was further installed in 1974. Neill Lake has a surface area of 36 acres and a maximum depth of 8 feet.

1.4 PROJECT HISTORY AND PLANS

The inventory and maintenance assessment for the City of Eden Prairie is a project with multiple phases that have and continue to span multiple years. Project information for each phase that has been completed, in progress or planned is included below.

Phase I

The inventory and maintenance assessment started with the Staring Lake watershed. The project extents included the contributing Purgatory Creek watershed between the northern city limit where Purgatory Creek enters Eden Prairie to Staring Lake, and the Staring Lake watershed. The Staring Lake watershed was selected as Phase I to support the efforts of the RPBCWD (Riley Purgatory Bluff Creek Watershed District) with an intensive lake management project for Staring Lake. The field assessment was conducted in 2010.

Phase II

The second phase of the inventory and maintenance assessment was the Eden and Neill Lake watersheds. The project extents included the Eden and Neill Lake watersheds. The Eden and Neill Lake watersheds were selected because the proposed light rail corroder is along the northern extents of the project area. The field assessment was conducted in 2011.

Phase III

The Duck and Red Rock Lake watershed project area is Phase III in the plan to survey and inspect basins throughout Eden Prairie. The project extents include the Duck Lake and Red Rock Lake watersheds, and the upper Purgatory Creek watershed from the western city limit where Purgatory Creek enters Eden Prairie to the northern city limit where Purgatory Creek leaves Eden Prairie. The Phase III project area was selected because the assessment for the

Purgatory Creek direct watershed upstream of Staring Lake would be completed, Duck Lake drains to Purgatory Creek upstream of Staring Lake, and Red Rock Lake is the first lake in a chain of lakes upstream of Staring Lake. The field assessment was conducted in 2012.

Phase IV

The lower Riley Creek watershed is Phase IV of the inventory and maintenance assessment. The project extents include the Riley Creek watershed south of Riley Lake and extend from the western city limit to the western portion of Flying Cloud Airport. The field assessment was conducted in 2013.

Phase V

The Round Lake and Mitchell Lake watersheds are planned for Phase V of the inventory and maintenance assessment. The Round Lake and Mitchell Lake watersheds are upstream of Staring Lake and have not been inventoried and assessed. This phase will complete the Purgatory Creek watershed upstream of Staring Lake. The field assessment is planned for 2014.

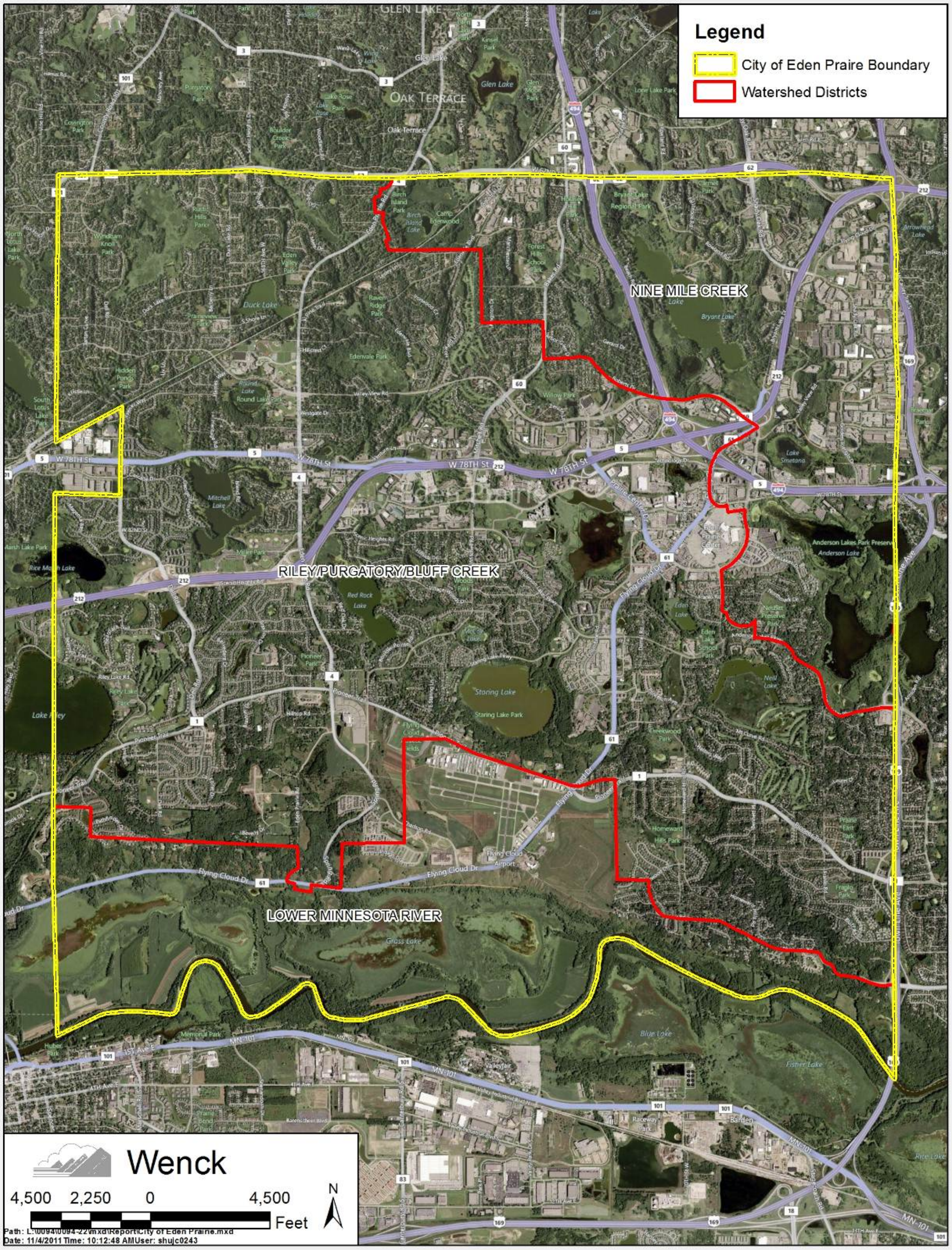


Figure 1.1. City of Eden Prairie.

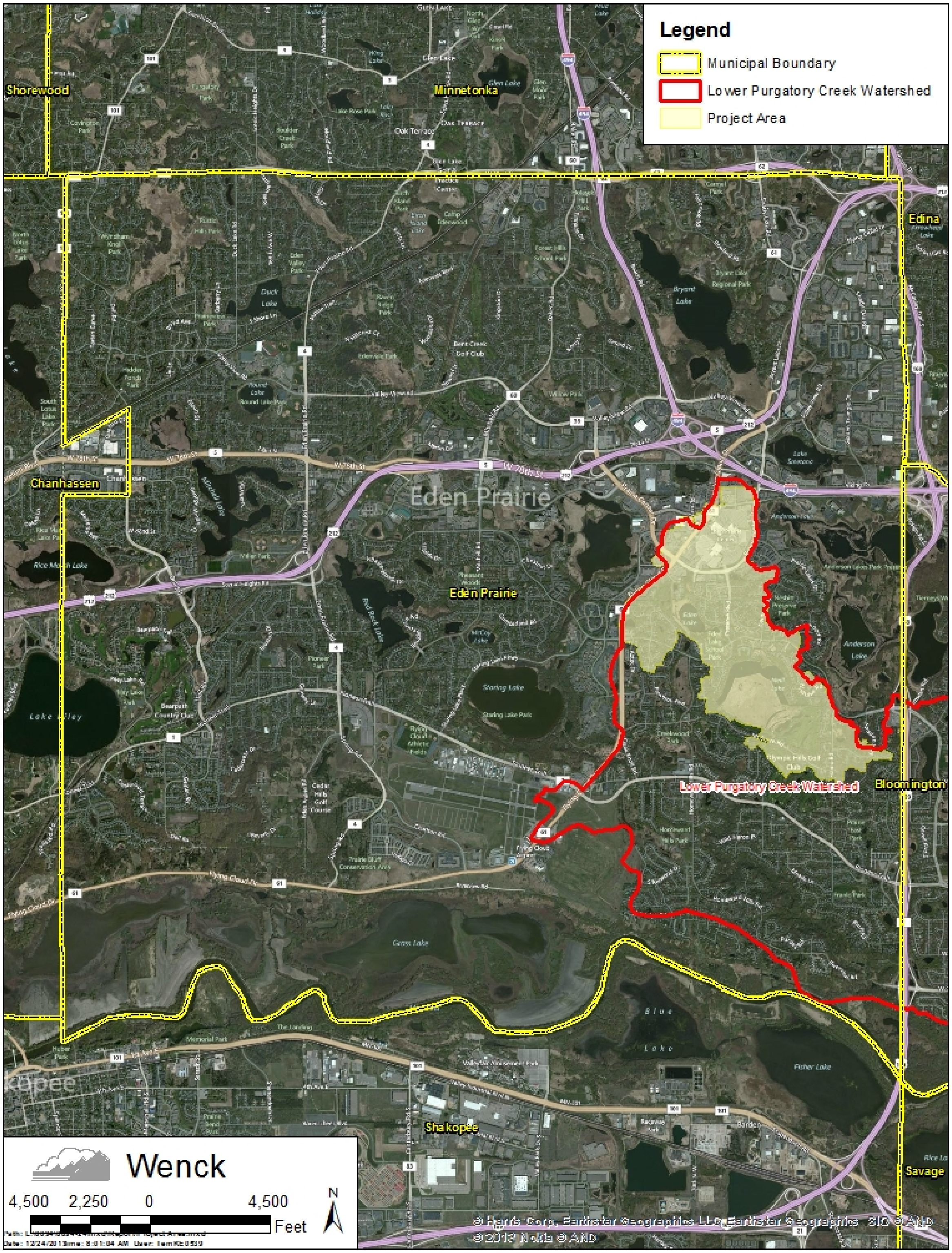


Figure 1.2. Project Area.

2.0 Stormwater System Assessment Methodology

2.1 BASIN INVENTORY AND ASSESSMENT

In 2011, the City completed a basin inventory in the Eden and Neill Lake watersheds and identified 35 basins that were designated for stormwater management (Figure 2.1). The basins were further researched to determine which could be categorized as public. The criteria to be considered a public basin included one or more of the following:

- Located on City property
- Within a public right-of-way
- Under a drainage and/or utility easement
- Private but receiving runoff from a public right-of-way

Research efforts involved reviewing design and record drawings to locate easements, using geographic information system (GIS) based parcel information to determine ownership, and delineating subwatersheds using two foot contours. Ultimately, a total of 21 basins were given a public designation in the project area watershed. However, 1 of the basins was under 0.25 acres so it was not inspected or surveyed.

In the end, 20 public basins, and 6 private basins, were visually inspected along with site surveys to help assess the maintenance needs and existing storage capacities. These data were needed to estimate sediment volumes, complete water quality modeling, provide cost estimates, and prioritize maintenance activities. Five of the 6 private basins are owned by the Olympic Hills Golf Club and the other one basin was not determined to be private until after it was surveyed.

Prior to conducting basin surveys, Wenck and City of Eden Prairie staff reviewed available design and as-built plans of the basins. Information obtained from the design or as-built plans included basin outlet elevations; basin flood or high water level elevations; size, type, and material of outlet structure; and basin length and width. Using a planimeter to obtain distances and areas from the design or as-built plans, the City of Eden Prairie staff also calculated permanent pool and flood pool areas and volumes for each basin.

2.1.1 Visual Inspections

During each basin survey, Wenck conducted a visual inspection based on the City's "Stormwater System Follow-Up Checklist." Wenck completed the checklist by documenting the overall condition of the basin, including the condition of structures, the presence of erosion, maintenance needs, the presence of trash or debris, and aquatic vegetation coverage. Information from the checklist was used in the analysis of each basin and was entered into the City's database.

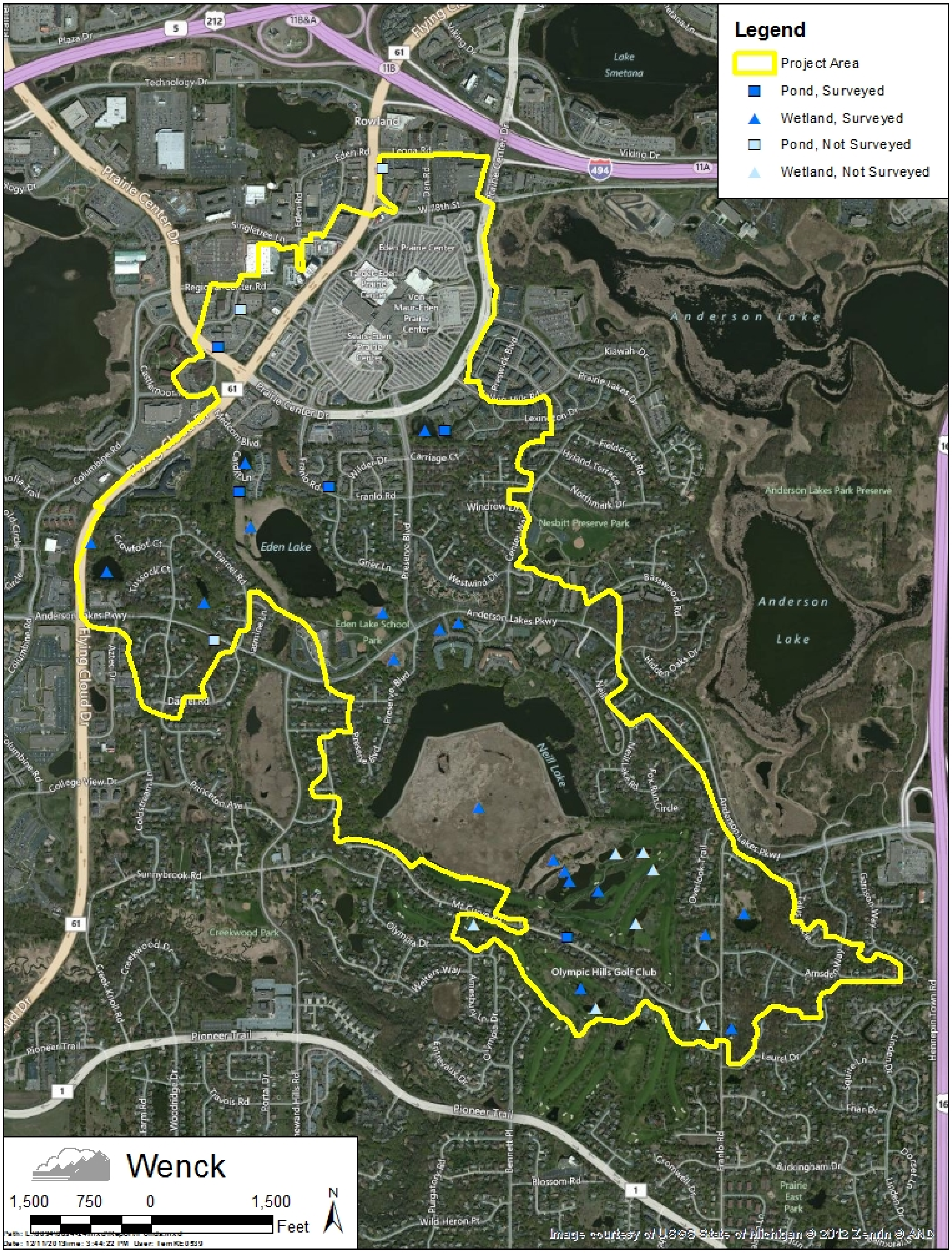


Figure 2.1. Basins in the Survey Area of the City of Eden Prairie Determined to Receive Public Drainage.

2.1.2 Sedimentation Surveys

Sedimentation surveys were conducted at each basin during 2011. Wenck used a Trimble R8 survey-grade GPS unit with sub-centimeter accuracy to collect elevation and location data at each basin. The survey included a bathymetric survey of the basin in which cross-sections were surveyed throughout each basin. Surveyed elevations include the basin bottom, the water surface elevation, and additional ground shots extending beyond the flood elevation.

At each survey point, Wenck collected the basin bottom elevation and the top of the accumulated sediment. Sediment depth was estimated by advancing a rod through the sediment until refusal. The inverts of outlets, inlets, or other structures, and water level elevations were also surveyed. Representative photos of each basin and structures within the basin were also taken.

2.1.2.1 Estimation of Sediment Quantities

Wenck used ArcMap 10 GIS software to process the GPS data collected during the sedimentation survey and estimate sediment deposition in each basin. The GIS software allowed Wenck to calculate the surface area of each basin, as well as the permanent pool and flood volumes. Basin volumes were calculated from elevation contours generated using ArcMap. The volume of sedimentation in each basin was determined by using the sediment depth measured in the field at survey points or by comparing the survey volumes to the as-built or design volumes.

Figure 2.2 shows the plan view of a typical stormwater basin. Each survey point collected was geographically referenced and has a corresponding elevation. Survey points represent water surface elevations, basin bottom transects, and overflow elevations. These data were combined with data from a digital elevation model to create Triangulated Irregular Networks (TINs). The differences between various TINs were used to generate estimates of the basins volumes.

The permanent pool, or dead storage volume, is the volume below the outlet elevation. The flood pool is the volume between the outlet and the overflow point. If no outlet is present, the permanent pool was calculated as the volume below the overflow point.

The extent of sediment deposition in the stormwater basins was estimated by comparing the existing permanent pool volume to the estimated "original" permanent pool volume for each basin. Determining the original permanent pool volume of a basin can be a challenge since accurate data on the "as-built" construction of the basin is not often readily available. In fact, errors in the as-builts often resulted in negative values for changes in permanent pool volume, though some positive values were noted. Since it is unlikely that permanent pool volumes increased, it was determined that these values were likely associated with inaccuracies in the as-built documents.

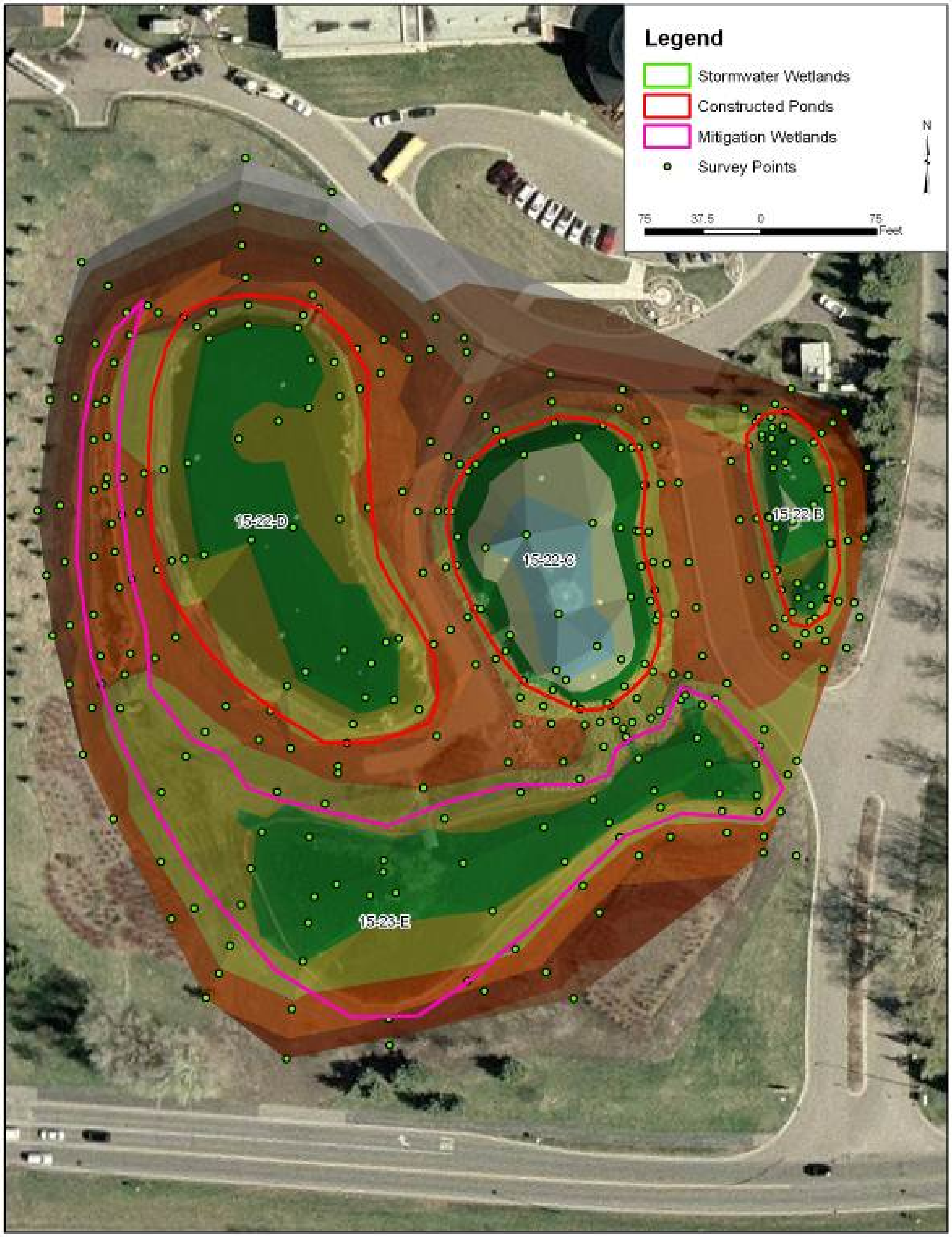


Figure 2.2. Plan View of Typical Stormwater Basins.

2.1.2.2 NURP Evaluation

The Environmental Protection Agency's (EPA) Nationwide Urban Runoff Program (NURP) focuses on detention basin design criteria related to phosphorus removal from urban watersheds. Sources from urban areas such as fertilizers, leaves, grass, bird dropping, pet waste, or erosion around the basins contribute to increased total phosphorus loadings. Because basin depth and permanent storage capacities have been linked to Total Suspended Solids (TSS) and Total Phosphorus (TP) removal efficiencies, NURP standards require stormwater detention basins to have a permanent storage volume equal to or greater than the runoff from a 2.5-inch, 24-hour storm event. The permanent pool storage volume that is needed to meet NURP standards was calculated for each basin using the estimated impervious surface area, pervious surface area based on soil types and vegetative cover, and the subwatershed area tributary to each basin. The purpose of this evaluation was to determine the optimal areas that could be improved to provide additional treatment within the Eden and Neill Lake watersheds.

2.1.3 Planning Level Sediment Removal Cost Estimates

Planning level sediment removal costs were developed for the removal of accumulated sediments or for expansion of basins (Table 2.1). The cost estimates are based on past experience with basin expansions and construction as well as discussions with local contractors. The cost estimates include mobilization, site preparation, sediment excavation and disposal, minor storm sewer or structural work, and erosion control. These costs assume that the sediments are level 2 sediments according to the MPCA guidance. The cost estimates also include an additional 30% for engineering and 30% for contingencies.

These costs do not include laboratory analysis, wetland mitigation, sediment characterization, major structural work or land/easement acquisition. Sediment characterization is discussed in more detail in Section 5.4.2.

Table 2.1. Planning Level Costs for Basin Excavation.

Vasin Excavation Volume (acre-feet)	Approximate Unit Cost ($ per acre-foot)
0 to 0.5	$138,560
0.5 to 1	$107,315
1 to 5	$51,207

2.1.4 Sediment Characterization Costs

Basin sediments need to be characterized to determine disposal options. This analysis includes particle size analysis, laboratory analysis for potential contaminates, and determination of the number of samples to be collected. Excavated material that is mostly sand and/or gravel (>93%) is unlikely to be contaminated and chemical laboratory analysis would typically not be required.

If lab sediment analysis is required, sediment samples must be analyzed for a list of parameters established by the MPCA. Based on recent MPCA guidance, Managing Dredged Materials in the State of Minnesota (June 2009), sediment samples from urban stormwater basins must be analyzed for copper, arsenic, and Polycyclic Aromatic Hydrocarbons (PAHs). The historic land use within the drainage area of a stormwater basin must also be reviewed to help determine the likelihood of other pollutants being present in the sediment.

The recommended number of sediment samples to be collected is dependent upon the estimated volume of material to be excavated. Table 2.2 summarizes the minimum recommended number of samples to be collected for urban stormwater basins, based on the MPCA's most recent guidance (MPCA, 2009).

Table 2.2. MPCA Recommended Number of Samples for Sediment Characterization.

Estimated volume of dredge material (cubic yards)	Minimum recommended number of samples for analysis
0 to 100	0
100 to 500	1
500 to 3,000	2
3,000 to 30,000	3
30,000 to 100,000	5
100,000 to 500,000	6
500,000 to 1,000,000	8
>1,000,000	>8

Costs for sediment analysis including collection and lab processing can range from $2,000 to $4,000. These costs are included in the planning level cost assessment.

2.2 P8 MODEL

2.2.1 Model Construction

The P8 Model (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds, IEP, Inc., 1990) is a computer model used for predicting the generation and transport of stormwater runoff pollutants in urban watersheds. The P8 model was used in this study to simulate the hydrology, total suspended solids, and phosphorus loads introduced from the watershed of each basin and the transport of phosphorus throughout the stormwater system. P8 is a useful diagnostic tool for evaluating and designing watershed improvements and best management practices (BMPs). The model requires user input on watershed characteristics, basin attributes, local precipitation and temperature, and other parameters relating to water quality and basin removal performances.

Examination of the watershed characteristics for each basin being modeled involved assessment of soil type, land use and residential density, and the impervious fraction of the land in the watershed. Arcview GIS software was used extensively in assessing the watershed characteristics.

In P8, pervious and impervious areas are modeled separately. Runoff volumes from pervious areas are computed using the Soil Conservation Service (SCS) Curve Number method. Runoff from impervious area begins once the cumulative storm rainfall exceeds the specified depression storage, with the runoff rate equal to the rainfall intensity.

Because P8 calculates runoff separately from pervious and impervious areas, it was necessary to determine the impervious fraction of each watershed. For the P8 models, the impervious areas were assumed to be directly connected. An impervious area is considered directly connected if runoff flows directly from it into the drainage system via continuous paved areas. The directly-connected impervious fraction was calculated for each watershed based on the land use(s), with each land use having an assumed impervious percent. The assumed impervious percent's are listed in Table 2.3.

Watershed runoff volumes from pervious areas were computed for P8 by using the SCS Curve Number (CN) method. Within each watershed a pervious CN was calculated based on the soil type and land use. The pervious CN was area weighted in each subwatershed using the values in Table 2.3.

Table 2.3. Assumed Impervious Percent and Pervious Curve Numbers for Land Uses in Eden Prairie.

Land Use	**Impervious Fraction percent**	**Pervious Curve Number**			
		A	**B**	**C**	**D**
Agriculture	5	49	69	79	84
Airports	30	68	79	86	89
Commercial	67	49	69	79	84
Eden Prairie Wetlands	0	85	85	85	85
Industrial	50	68	79	86	89
Major Highway	50	49	69	79	84
Multi-Family Residential	60	39	61	74	80
Parks and Recreation Areas	10	39	61	74	80
Public/Semi Public	32	39	61	74	80
Railway	20	68	79	86	89
Single Family Residential	25	39	61	74	80
Vacant	5	39	61	74	80

The P8 model requires an hourly precipitation record (rain and snowfall) and daily temperature record. Precipitation and temperature data were obtained from the Minneapolis-St. Paul International Airport.

The NURP50 file was selected for the P8 models. The component concentrations in the NURP 50 file represent the 50th percentile (median) values compiled in the EPA's Nationwide Urban Runoff Program (NURP).

The treatment devices in P8 provide collection, storage, and/or treatment of watershed discharges. A variety of treatment devices can be modeled in P8, including detention basins (wet or dry), infiltration basins, swales, buffers, aquifers, and pipes. For this study, nearly all constructed ponds and wetlands were modeled as detention basins. The user-defined characteristics of these basins are described in the following sections.

2.3 BATHTUB MODEL

A BATHTUB lake response model was developed for Eden Lake and Neill Lake to assess the impacts of various improvement projects on in-lake water quality. The purposes of the model are to develop a phosphorus budget for each lake, identify the major factors influencing current and future water quality, and provide an understanding of the level and magnitude of project implementation required to meet identified water quality goals.

A publicly available model, BATHTUB was developed by William W. Walker for the U.S. Army Corps of Engineers (Walker 1999). BATHTUB has been used successfully in many lake studies in Minnesota and throughout the United States. It is a steady-state model, annual or seasonal, that predicts a lake's summer (June – September) mean surface water quality. Its annual time-scale is appropriate because watershed phosphorus loads are determined on an annual or seasonal basis, and the summer season is critical for lake use and ecological health.

BATHTUB has built-in statistical calculations that account for data variability and provide a means for estimating confidence in model predictions. It accounts for water and phosphorus inputs from tributaries, watershed runoff, the atmosphere, sources internal to the lake, and (if appropriate) groundwater; and accounts for outputs through the lake outlet, groundwater (if appropriate), water loss via evaporation, and phosphorus sedimentation and retention in the lake sediments.

BATHTUB allows choice among several different mass-balance phosphorus models. For lakes in Minnesota, the option of the Canfield-Bachmann lake formulation (Canfield and Bachmann 1981) has proven to be appropriate in most cases.

In addition to total phosphorus concentration, BATHTUB's in-lake water quality predictions include two additional response variables, chlorophyll-*a* concentration and Secchi depth. A response variable is a measured outcome from changes in nutrient loading. For example, increases in total phosphorus are typically followed by increases in chlorophyll-*a* because phosphorus limits the growth of algae. Increases in algae lead to a decrease in water clarity or Secchi depth which is another response to changes in phosphorus loading. Empirical relationships between in-lake total phosphorus, chlorophyll-*a*, and Secchi depth form the basis for predicting the two response variables.

2.4 SEDIMENT RELEASE RATE ASSESSMENT

Wenck collected four intact sediment cores (undisturbed) from the deepest part of Eden Lake and Neill Lake each. At the same location, data was collected to develop dissolved oxygen, pH and temperature profiles at the time of sampling. The samples were analyzed to estimate the anoxic and oxic release of phosphorus from the sediments.

These results were combined with dissolved oxygen and temperature profiles from Eden Lake and Neill Lake to develop a component of the annualized phosphorus load from the sediments of Eden Lake and Neill Lake (internal load).

3.0 Stormwater System Conditions

3.1 BASIN IDENTIFICATION

The City of Eden Prairie maintains a database of basins within the City. Basins in the database are classified as constructed ponds, wetlands, creek segments, swales, ditches and infiltration BMPs such as rain gardens. This database was used along with a review of aerial photographs to identify potential basins in the project area. Thirty-five basins were identified in the Eden and Neill Lake watersheds that were designated for stormwater management.

Wenck delineated the watersheds of the 35 stormwater basins to determine whether they receive public stormwater drainage from the City or were wholly private. Ultimately, a total of 21 basins (Figure 2.1) were given a public designation in the Eden and Neill Lake watersheds. However, 1 of the basins was under 0.25 acres so it was not inspected or surveyed.

A total of 26 basins, including 6 which were determined to be private, were assessed for functionality and sedimentation. Of the “public” inventoried basins, 4 were designated constructed ponds, 11 were wetlands that receive stormwater (stormwater wetlands), 3 were determined to be swales, and 2 were identified as lakes (Eden and Neill Lakes). Of the private inventoried basins, 1 was designated a constructed pond and 5 were stormwater wetlands.

3.1.1 Constructed Ponds

A total of 6 constructed ponds were identified in the project area, with 3 shown to receive City drainage and have a permanent pool area greater than 0.25 acres. The remaining 3 constructed ponds were designated as private constructed ponds that do not receive City drainage. Constructed ponds are those basins designed and built specifically for the purpose of stormwater control including either flooding or water quality.

3.1.2 Stormwater Wetlands

The project area contained a total of 23 stormwater wetlands, with 12 shown to receive City drainage and 11 designated as private. A stormwater wetland is defined as any natural wetland that receives stormwater from impervious or developed areas. Stormwater inflow may be from an open channel (overland flow) or pipe.

The purpose of the wetland survey was to identify the wetlands used for stormwater management and evaluate their current condition and performance. Because this analysis was focused on sedimentation, only the open water area of the wetlands were surveyed. Additionally, all of the inlets and outlets were inspected for maintenance needs. For wetland areas that did not have significant open water, the perimeter of the wetland was surveyed. Many of these do not have as-builts or grading plans available for comparison.

3.1.3 Swales

Four of the identified basins in the City database were classified as swales. Swales are defined as vegetated depressions used for the conveyance of stormwater. Swales may provide infiltration of vegetative uptake of stormwater so they were included in the analysis.

3.1.4 Lakes

Two of the identified basins in the City database are listed as lakes, specifically Eden and Neill Lake. Eden Lake is a wetland; however, it was treated as a lake in this analysis.

3.2 STORMWATER BASIN VISUAL INSPECTION

Visual inspections were conducted at each of the basins in 2011 to identify any structural maintenance needs at the basin. Visual inspections included any signs of erosion, sedimentation, failing infrastructure or clogged inlets and outlets. Selected results are provided in Table 3.1. All results where some issue was identified are presented in Appendix A. A rating of good meant that the basin inlets and outlets were in operating condition and there was little erosion. A rating of fair indicated that there was some obstruction of inlets and outlets, and/or some bank erosion. A rating of poor meant that the inlets or outlets were clogged or not functioning and/or bank erosion was severe.

Table 3.1. Selected Visual Inspection Results for the Eden and Neill Lake Watersheds Basin Survey.

Basin ID	Priority	Overall Condition	Erosion Concern	Sediment Concern	Sediment Delta	Vegetation Overgrowth	Debris Concerns	Notes/ Other issues
14-43-A	High	Poor	N	Y	Y	Y	Y	6” Sediment with 6” tree growing in it
14-44-A	High	Fair	N	Y	Y	N	Y	Sediment inhibiting outlet flow
23-14-A	High	Poor	Y	N	N	Y	Y	Debris in trashguard
23-14-B	High	Poor	Y	N	N	N	N	Erosion channel present to wetland
23-22-A	High	Fair	Y	Y	Y	N	Y	Sediment delta 4” deep, 30’ across, 20’ to water edge, erosion channel up to 1’ deep
23-22-B	High	Fair	Y	N	Y	N	N	Outlet channel is eroding down the slope

3.3 STORMWATER BASIN SEDIMENTATION

Constructed ponds, and stormwater wetlands, were evaluated for sediment deposition by comparing the existing permanent pool volume to the estimated original permanent pool volume for each constructed pond and stormwater wetland. Estimating the original permanent pool volume was accomplished by reviewing as-builts where available. Basin sedimentation was also evaluated using field collected sediment depth data for all of the constructed ponds and wetlands. To assess sediment depths, a rod was pushed into basin sediments to refusal. Surface contours were then developed for the refusal depths and the sediment surface to determine sediment volumes.

There are a few considerations that must be taken into account when interpreting the results of the survey including:

1. Estimating the original permanent pool volume is difficult and highly dependent on the accuracy of the as-built information or design plans. Furthermore, many of the constructed ponds and wetlands do not have design plans or as-built information available. The absence of accurate design plans or as-built information for estimating the original permanent pool volumes can result in significant error in the sedimentation analysis. Consequently, results should be used cautiously in light of the uncertainty.

2. The depth to refusal may or may not represent sediment that has accumulated in the basin. Some or all of the sediment may be original basin or wetland sediment. However, there is no accurate way to distinguish between the original sediment and accumulated sediment.

3. Construction information is not readily available for all basins, so it is not certain which stormwater wetlands are natural wetlands or constructed ponds.

3.3.1 Constructed Ponds and Stormwater Wetlands with As-Built Information

Of the 6 constructed ponds and 23 stormwater wetlands in the project area, there were 3 constructed ponds and 2 stormwater wetlands with design or as-built information (Table 3.2). As-built information was not available for the 4 swales and 2 lakes. To evaluate the usefulness of comparing as-built dead pool storage to field surveyed dead pool storage, the basin surface areas were first compared.

The difference between the field surveyed dead pool areas and the as-built dead pool areas range from -23 to 2.3%, with a negative value indicating the surveyed dead pool was larger than the as-built dead pool. Data for constructed ponds were more reliable than data for stormwater wetlands likely due to changes in wetland vegetation over time.

Those basins with field surveyed dead pool areas less than the design or as-built dead pool areas may offer an opportunity to increase basin storage and improve water quality treatment.

Table 3.2. Constructed Pond and Wetland Characteristics for Basins with As-Built or Design Information.

Basin ID	As-Built Permanent Pool (acres)	Surveyed Permanent Pool Area (acres)	As-Built Permanent Pool Volume (acre-feet)	Surveyed Permanent Pool Volume (acre-feet)	Permanent Pool Difference[1] (acre-feet)	Accumulated Sediment Volume (acre-feet)	Sediment Percent of Permanent Pool
Constructed Ponds							
14-31-A[1]	0.04	0.00	0.04	0.00	0.04	0.00	0.0
14-43-A	0.23	0.15	0.80	0.38	0.42	0.07	9.0
14-44-B	0.31	0.52	1.25	1.76	-0.54	0.32	17.9
Wetlands							
14-34-A	0.96	1.14	5.40	7.00	-1.60	0.73	10.7
14-44-A	2.19	1.99	6.92	6.76	0.16	0.30	4.4

[1] Bottom elevation equal to outlet elevation, no permanent pool.

Negative values indicate that the surveyed volume was larger than the as-built volume.

3.4 CRITICAL STORMWATER BASINS

Basin performance was evaluated for the basins in series using P8 and by evaluating NURP requirements cumulatively for each basin. Stormwater basin performance was evaluated by comparing surveyed permanent pool volumes to the required permanent storage volume to meet NURP standards. The number is presented as a ratio where values less than one do not meet NURP standards and values greater than one exceed NURP standards. For our purposes, NURP standards are defined as having a permanent pool volume equal to the 2.5 inch, 24 hour storm event runoff volume (Table 3.3).

The term "NURP pond" refers to retention basins (also called "wet ponds") constructed to capture sediment from stormwater runoff as it is detained, and that are designed to perform to the level of the more effective basins observed in the NURP studies. Some practitioners may assume that a "NURP pond" design conforms to some particular standard issued by EPA, but in fact EPA has issued no regulations or other requirements regarding the design of stormwater basins. However, some states and municipalities have issued stormwater design manuals, and these publications may include a reference to a "NURP pond."

Table 3.3. Typical Minnesota Basin Design Standards.

Parameter	Standard Design
Permanent Pool Depth	4 to 10 feet
Permanent Pool Surface Area	Greater of 2% of watershed’s impervious area and 1% of the watershed
Permanent Pool Length to Width Ratio	3:1 or greater with an irregularly shaped shoreline
Side Slopes	10:1 for 10-foot bench centered on the normal water elevation and between 3:1 and 20:1 elsewhere
Side Slope Stabilization	Native seed with MnDOT 310, BWSR W2 or equivalent between NWL and HWL, provide 10’ buffer where possible with MnDOT 330 (short) or MnDOT 340 (tall)
Floatable Removal	Skimming device discharging at no greater than 0.5 fps during the 1-year event or a submerged outlet with a minimum 0.5 feet from the normal water level to the crown of the outlet pipe
Sediment Accumulation Area	Provide maintenance pads to remove sediment deltas at inlets
Permanent Pool Volume	A 4-foot mean depth and equal to 2.5-inch rain over the watershed

Source: Protecting Water Quality in Urban Areas (MPCA 2000)

All of the tables are organized so that the constructed ponds and wetlands move from the top of the watershed to the bottom of the watershed as you move down the table.

3.4.1 Eden Lake Area

The Eden Lake area includes the basins that drain to the Eden Lake wetland (23-21-B) including the stormwater from the Eden Prairie shopping center (Figure 3.1). The area was grouped into three areas based on drainage patterns in the subwatershed. During overflow periods, Eden Lake drains through a deep pipe that goes under Neill Lake and discharges to the wetland south of Neill Lake.

Group 1 basin 14-34-A accepts all the stormwater from the Eden Prairie shopping center. It demonstrates sediment accumulation and does not meet NURP standards.

Group 2 basins, 14-44-B and 14-44-A, both demonstrate sediment accumulation. However, the cumulative NURP ratio is over three times the required permanent pool storage and therefore the area is well protected for water quality and no improvements are recommended for this group.

Basin 14-34-C is designated as a stormwater wetland and discharges to Eden Lake. The basin has a small creek that runs from 14-34-A to Eden Lake and also contains two off-line basins that have permanent pools. Basin 14-34-C accepts a large portion of the stormwater from the north and west of Eden Lake. It does not meet NURP standards and has a large sediment accumulation.

Basin 14-34-A (Pond K) which accepts all the flow from Eden Prairie Center and flows south to 14-34-C, it does not meet NURP standards. However, due to its location, expansion is not a feasible option and sediment accumulation only accounts for ten percent of the volume. Instead, the outflow from 14-34-A could be split between 14-34-B and 14-34-C. Basin 14-34-B has room for expansion and already exceeds NURP standards. 14-34-C accepts most of the stormwater west and north of Eden Lake. The basin is on City owned property and has room for expansion or an addition of a filter bench.

Direct drainage to Eden Lake appears to be undertreated. Installing rain gardens along roads and creating swales along ditches are possible ways of retrofitting the areas that contribute directly to Eden Lake.

Table 3.4. Constructed Pond and Wetland Characteristics for the Eden Lake Subwatershed.

Basin ID	Surveyed Permanent Pool Volume (AF)	NURP ratio[1]	Sediment Volume (AF)	P8 Predicted TSS (mg/L)	P8 TSS removal (%)	P8 Predicted TP (µg/L)	P8 TP removal (%)	Basin Type[2]
Discharges to 14-34-A (Group 1)								
14-31-B	--	--	--	95	0	255	0	PP
14-31-A[3]	0.00	0.00	0.00	63	33	229	8	PP
14-12-A	--	--	--	95	0	253	0	PP
Discharges to 14-34-C (Group 1)								
14-34-A	6.86	0.23	0.73	36	69	198	36	SW
14-34-B	0.73	1.22	0.03	8	91	106	59	CP
Discharges in sequence to 14-34-C (Group 3)								
23-24-B	Swale			37	61	185	25	SE
23-21-A	12.82	4.11	1.29	3	96	90	62	SW
Discharges in sequence to 14-34-C (Group 3)								
23-22-B	Swale			20	81	133	50	SW
23-22-A	0.23	0.20	0.05	4	95	92	61	SW
Discharges in Sequence to Eden Lake (Group 2)								
14-44-B	1.76	0.99	0.32	64	33	242	6	CP
14-44-A	6.76	3.44	0.30	4	94	94	62	SW
Discharges to Eden Lake (Group 2)								
14-43-A	0.38	0.65	0.07	15	84	123	51	CP
14-34-C	7.74	0.70	1.61	25	34	169	12	SW
23-13-B	Swale			37	57	188	22	SW
23-13-A	2.37	3.74	0.00	2	98	83	65	SW
Eden Lake	79.31	8.03	47.42	4	89	102	42	Lake

[1] The NURP ratio is based on the cumulative area and dead storage to account for basins in sequence. Values over 1 exceed NURP standards and values under 1 do not meet NURP standards.

[2] CP= Constructed Pond; SE=Swale; SW = Stormwater Wetland; PP= Private Pond.

[3] Outlet elevation equal to or below bottom elevation.

-- Indicates the basin was not surveyed.

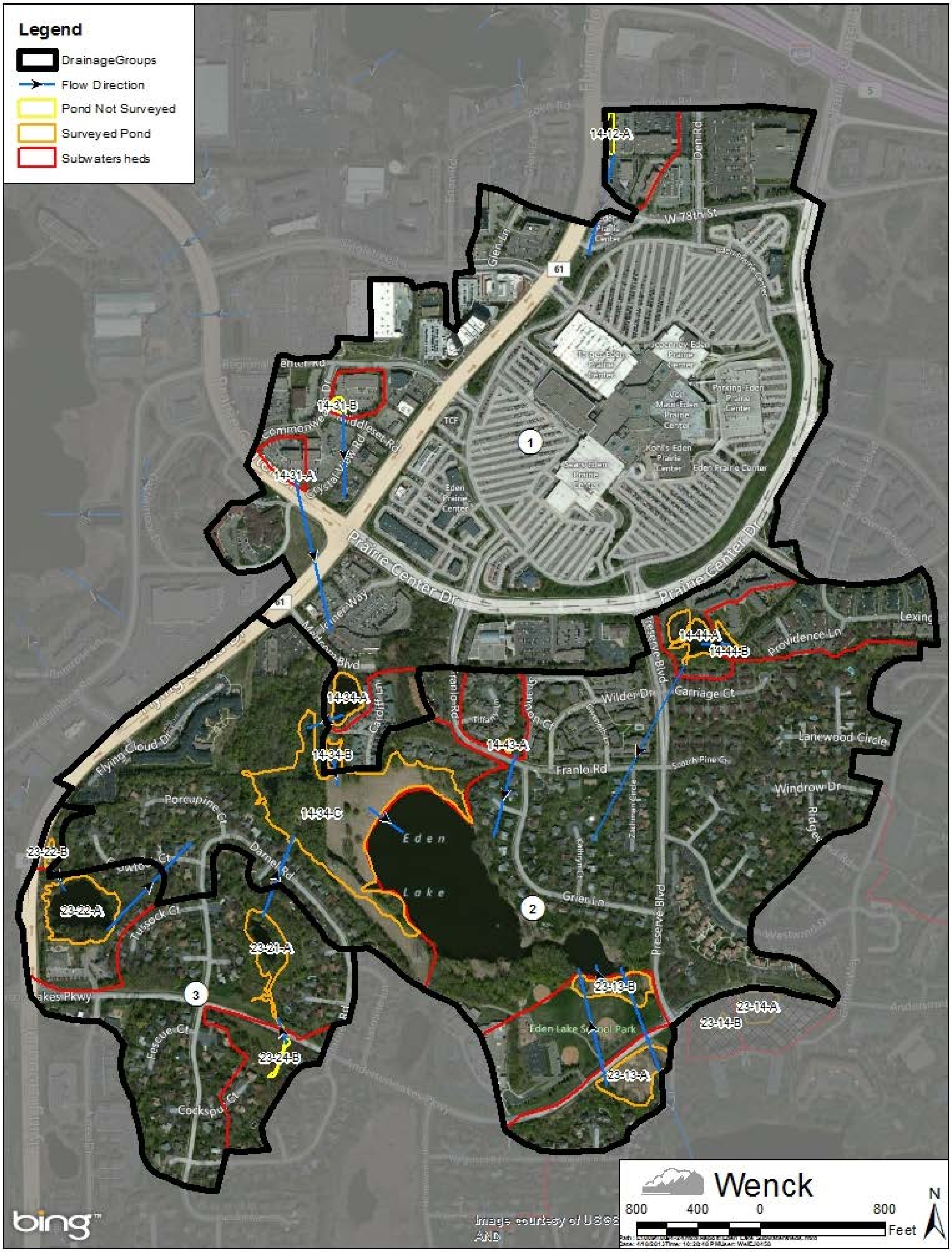


Figure 3.1. Constructed Ponds, Wetlands and Flow Patterns in the Eden Lake Area Subwatershed.

3.4.2 Neill Lake Area

The Neill Lake area includes both the watershed that drains directly to Neill Lake (23-41-A) and the wetland (23-41-B) to the south of the lake. Overflow from Eden Lake discharges to 23-41-B through a storm sewer pipe that is constructed beneath Neill Lake. Neill Lake drains into 23-41-B through an outlet structure near the golf course, which eventually drains to Purgatory Creek. (Figure 3.2).

There are two basins to the north of Neill Lake that are landlocked and therefore were not considered as part of the drainage network.

Since all the stormwater in this area drains directly untreated to Neill Lake or Neill Lake Marsh, there are no basins in this area to be considered for improvements. However, to reduce the stormwater runoff into Neill Lake or Neill Lake Marsh, retrofitting the drainage area could be considered. Improvements made in the drainage area would also have direct improvements on Neill Lake water quality. There is a large field at the end of Flyway Circle that could be considered for a basin addition.

Table 3.5. Constructed Pond and Wetland Characteristics for the Neill Lake Area Subwatershed.

Basin ID	Surveyed Permanent Pool Volume (AF)	NURP ratio[1]	Sediment Volume (AF)	P8 Predicted TSS (mg/L)	P8 TSS removal (%)	P8 Predicted TP (µg/L)	P8 TP removal (%)	Basin Type[2]
23-14-A	0.49	1.09	0.03	Landlocked				SW
23-14-B	0.22	0.75	0.00	Landlocked				SW
Neill Lake	204.53	17.54	12.75	1	99	83	66	Lake
23-41-B	Neill Lake Marsh			6	0	103	0	SW

Note: 23-14-A flows into 23-14-B. Since 23-14-B is landlocked, 23-14-A is also considered landlocked.

[1] The NURP ratio is based on the cumulative area and dead storage to account for basins in sequence. Values over 1 exceed NURP standards and values under 1 do not meet NURP standards.

[2] CP= Constructed Pond; SW = Stormwater Wetland.

Figure 3.2. Constructed Ponds, Wetlands and Flow Patterns in the Neill Lake Area Subwatershed.

3.4.3 Olympic Hills Golf Course Area

The Olympic Hills Golf course area includes basins in the Olympic Hills Golf Course property and basins directly east of the golf course (Figure 3.3). All of the basins eventually drain to Purgatory Creek. Most of the basins in the area are private constructed ponds and wetlands owned by the Olympic Hills Golf Course.

Basins 24-43-A and 24-34-E are both owned by the city and designated stormwater wetlands. No as-built information is available for these basins and neither meets the NURP standard. Sediment accumulation in 24-43-A is over half of the permanent pool volume. However, this is a natural wetland and it is unclear if the sediments are wetland soils or have accumulated from stormwater runoff.

Field surveys indicate that 24-34-E has no permanent pool volume (outlet elevation is equal to the bottom elevation). This basin is surrounded by housing and is designated as a wetland.

Field survey for 24-33-C indicated that the sediment volume is almost equal to the permanent pool volume. This basin is owned by the Olympic Hills Golf Course though accepts city stormwater. The Olympic Hills Golf Course has planned expansion of this basin in 2014.

Field survey for 24-33-A indicated a significant amount of sediment volume has accumulated in this basin. This basin is owned by the Olympic Hills Golf Course though accepts city stormwater. The Olympic Hills Golf Course has planned expansion of this basin in 2014.

The Olympic Hills Golf Course has also planned expansions of basins 24-34-A and 24-34-B in 2014 with widespread improvements to the entire golf course.

As-built information for private wetland 24-33-D, also owned by the golf course, was not available but the field survey showed the outlet elevation is approximately equal to the bottom elevation.

Table 3.6. Constructed Pond and Wetland Characteristics for the Olympic Hills Golf Course Subwatershed.

Basin ID	Surveyed Permanent Pool Volume (AF)	NURP ratio[1]	Sediment Volume (AF)	P8 Predicted TSS (mg/L)	P8 TSS removal (%)	P8 Predicted TP (µg/L)	P8 TP removal (%)	Basin Type[2]
Discharges in sequence 24-33-B (Group 5)								
24-43-A	0.36	0.09	0.23	22	76	146	41	SW
24-34-E[3]	0.00	0.08	0.00	18	50	134	19	SW
24-33-C	3.71	0.74	3.54	6	82	98	37	PW
24-33-A[3]	0.00	0.67	19.21	8	51	104	11	PW
24-33-D[3]	0.00	0.63	8.47	6	40	99	9	PW
24-33-B	1.23	0.72	2.19	3	64	90	14	PW
Discharges in sequence 24-33-C (Group 5)								
24-34-D	--	--	--	81	0	231	0	PW
Discharges in sequence 24-33-A (Group 5)								
24-34-C	--	--	--	79	0	228	0	PW
24-34-B	--	--	--	81	0	233	0	PW
24-34-A	--	--	--	81	0	232	0	PW
Landlocked (Group 5)								
25-21-B	--	--	--	Landlocked				PW
25-12-A	0.31	0.42	0.08	Landlocked				SW
Discharges OFF (Group 6)								
25-22-A	--	--	--	71	0	215	0	PW
25-22-B	0.03	0.11	0.00	18	77	138	40	PW
25-22-C	Swale			60	0	198	0	SE
23-44-A	--	--	--	84	0	236	0	PW

Note: Basin 25-12-A outlet is a pump. Since the basin is drawn down by the pump infrequently, it is considered landlocked. Since 25-12-A is landlocked, 25-21-B is also considered landlocked.

[1] The NURP ratio is based on the cumulative area and dead storage to account for basins in sequence. Values over 1 meet NURP standards and values under 1 do not meet NURP standards.

[2] CP=Constructed Pond; SE=Swale; SW=Stormwater Wetland; PW=Private Wetlands.

[3] Outlet elevation equal to or below bottom elevation. Sediment volume estimation is based on flood pool.

-- Indicates the basin was not surveyed.

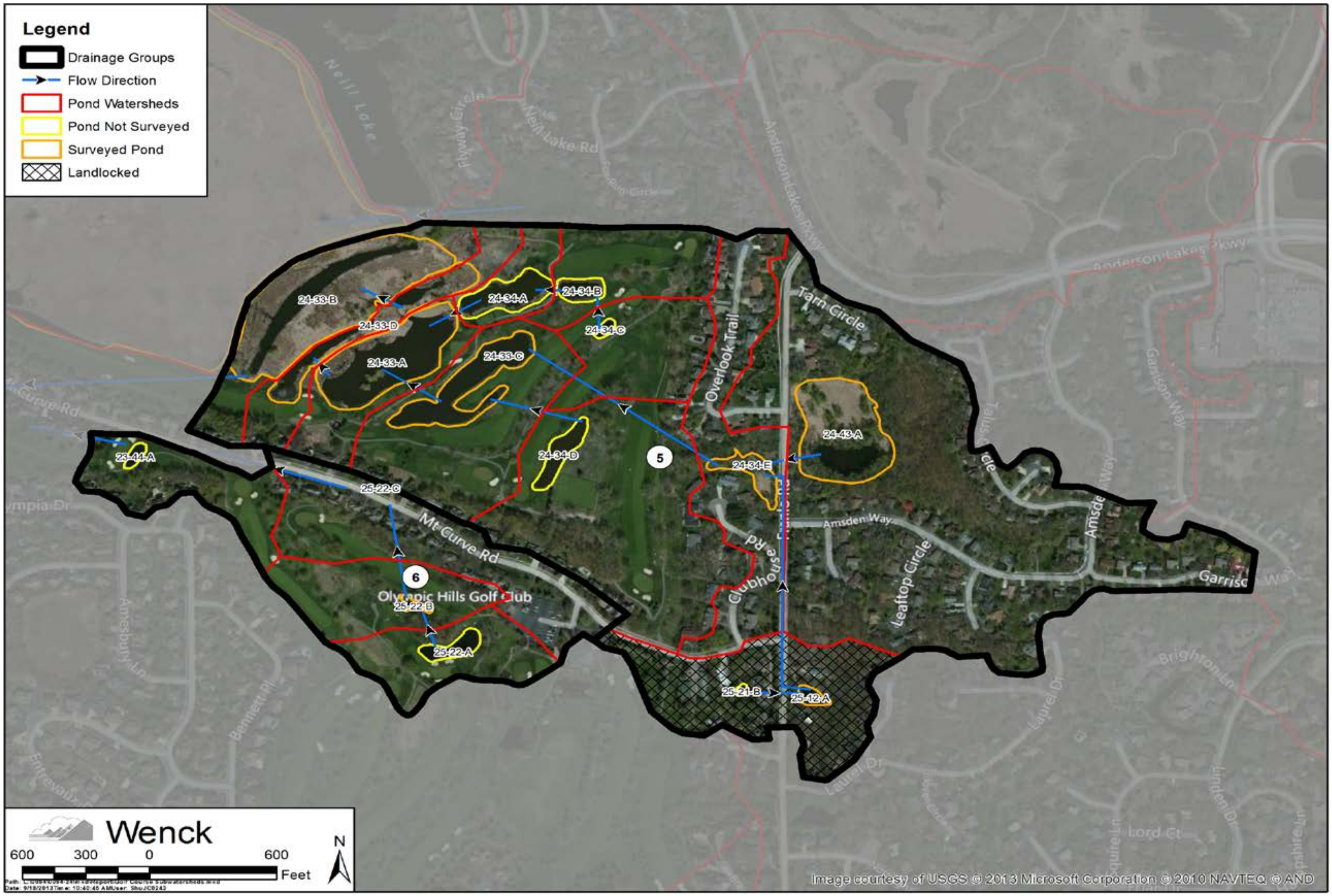


Figure 3.3. Constructed Ponds, Wetlands and Flow Patterns in the Olympic Hills Golf Course Area Subwatershed.

4.0 Lake Nutrient Budget

4.1 INTRODUCTION

A nutrient budget is critical in understanding the potential impacts of stormwater on the receiving waters. To that end, a nutrient budget and lake response model were developed for Eden Lake and Neill Lake to better understand the role of stormwater on the quality of the lakes.

The drainage areas for Eden Lake and Neill Lake are completely within the City of Eden Prairie and include the Eden Prairie shopping center.

4.2 EDEN LAKE AND WATERSHED CHARACTERIZATION

Eden Lake is an off-line lake to Purgatory Creek, a tributary of the Minnesota River. Located in Hennepin County, Eden Lake is just south of the Eden Prairie Center and north of Eden Lake School Park and Neill Lake. Eden Lake does not have public access.

4.2.1 Watershed Land Use and Hydrology

Eden Lake watershed is located to the west of Staring Lake watershed and drains approximately 540 acres.

Land use in the Eden Lake watershed is predominantly retail and other commercial (35%), residential (33%) and open space (21%), including parks, wetlands and open water (Table 4.1; Figure 4.1). The remaining 11% is a mix of institutional, office and mixed use properties. The watershed contains one major highway, Highway 61 (Flying Cloud Drive) in the western-most part of the watershed.

Table 4.1. Land Use Within the Eden Lake Watershed.

Land use	Acres	%
Retail and Other Commercial	189.5	35.1
Single Family Detached	124.2	23.0
Park, Recreational, or Preserve	45.6	8.4
Institutional	43.0	8.0
Undeveloped	42.4	7.9
Multifamily	35.2	6.5
Open Water	26.3	4.9
Single Family Attached	17.5	3.2
Office	10.2	1.9
Mixed Use Commercial	6.3	1.2
Major Highway	0.2	<0.1
Golf Course	0.0	<0.1
Airport	0.0	<0.1
Agricultural	0.0	<0.1
Industrial and Utility	0.0	<0.1

4.2.2 Lake Morphometry

Eden Lake is classified as a wetland and has a surface area of 20 acres with a maximum depth of 7 feet (Table 4.2). Although Eden Lake is a wetland, it was treated as a lake for this analysis. The Eden Lake wetland has characteristics similar to a shallow lake. The Minnesota Pollution Control Agency defines a shallow lake as any lake less than 15 feet in depth or with more than 80% capable of supporting submerged aquatic vegetation. The shallow nature of Eden Lake suggests that the lake should support submerged aquatic vegetation through most if not all of the lake. The area expected to support plant growth (less than 15 feet) is also defined as the littoral zone, the area where light penetration is deep enough to support submerged vegetation. Eden Lake has a short residence time with lake water being replaced by runoff approximately every 40 days. This suggests that the lake will be quite sensitive to stormwater quality.

Table 4.2. Eden Lake Characteristics.

Parameter	Eden Lake
Surface Area (acres)	20
Average Depth (feet)	3.5
Maximum Depth (feet)	7
Volume (acre-feet)	79
Residence Time (years)	0.11
Littoral Area (acres)	20
Littoral Area (%)	100
Watershed (acres)	540

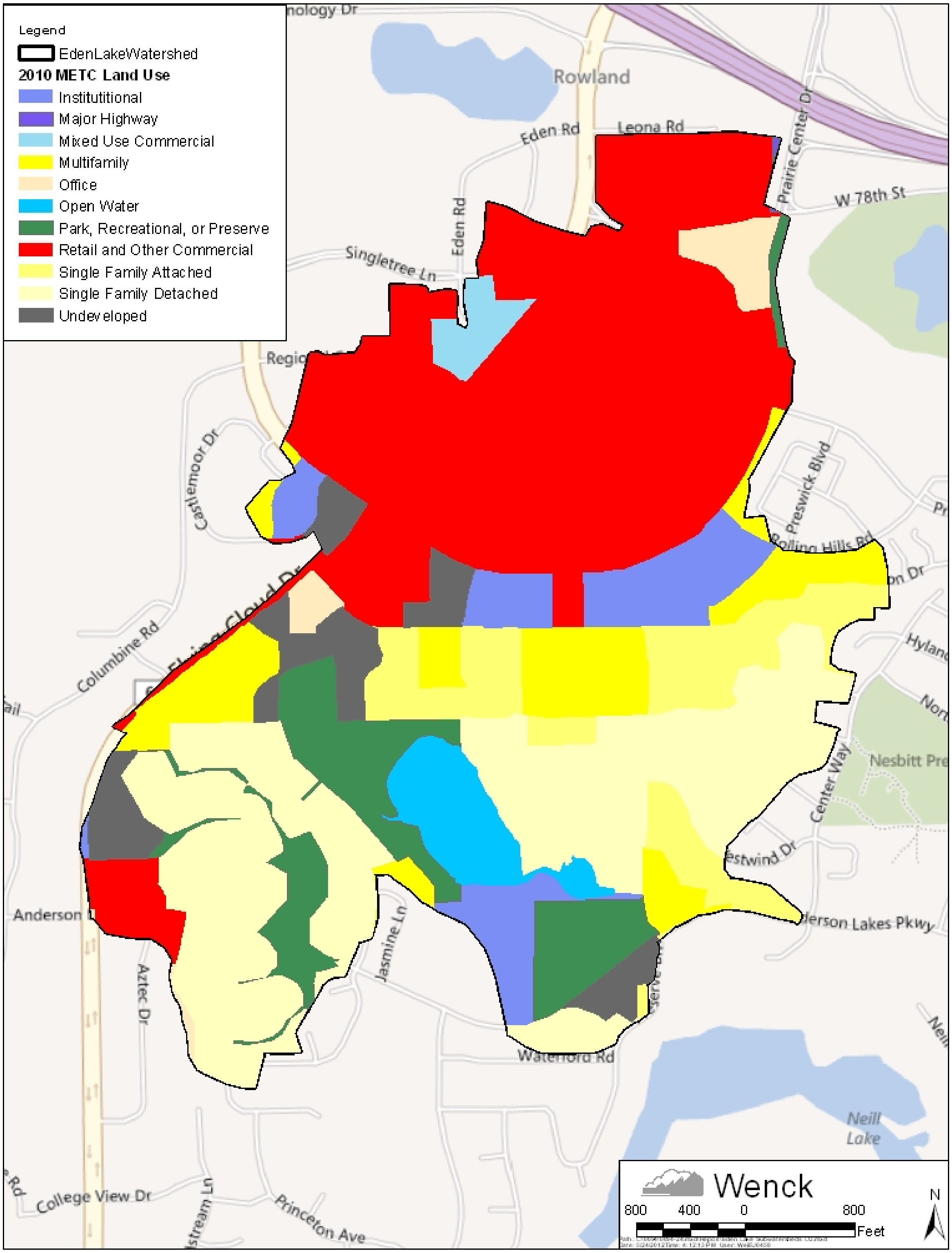


Figure 4.1. Land Use Within the Eden Lake Watershed.

Shallow lakes are ecologically different from deep lakes. In shallow lakes, there is a greater area of sediment-water interface, which can potentially allow larger sediment contributions to nutrient loads and potentially more sediment re-suspension resulting in decreased water clarity. Biological organisms also play a greater role in maintaining water quality in shallow lakes. Submerged aquatic vegetation also provides refugia (places to avoid predation) for zooplankton, a group of small crustaceans that consumes algae.

All of these interactions reflect a lake existing in two alternative stable states: a clear water state and a turbid water state. The clear water state is characterized by a robust and diverse submerged aquatic vegetation community, balanced fish community and large daphnia (zooplankton that are very effective at consuming algae). Alternatively, the turbid water state typically lacks submerged aquatic vegetation, is dominated by rough fish, and is characterized by both sediment resuspension and algal productivity.

The state in which the lake persists depends on the biological community as well as the nutrient conditions in the lake. Therefore, lake management must focus on the biological community as well as the water quality of the lake.

4.2.3 Groundwater

Groundwater was not explicitly incorporated into the water budget of Eden Lake. Based on desktop review of available hydrogeological information, Eden Lake is at an average elevation of approximately 810 feet Above Mean Sea Level (AMSL), roughly 120 feet above the lakes within the adjacent Minnesota River valley. Its morphology suggests a kettle lake in the sandy outwash in the area. According to the Hennepin County Geologic Atlas, it is at the approximate level of the perched aquifer in the area. Lakes and wetlands immediately north are at higher elevations. Based on its proximity to the Minnesota River valley bluffs, and higher water levels to the north, it appears to be a flow-through lake where shallow groundwater enters along the northern perimeter and discharges from the southern perimeter. There are no perched aquifer wells in the vicinity, based on the Minnesota Department of Health (MDH) well database, so further refinement of the lake’s relationship to the local water table isn’t possible at this time.

4.2.4 Water Quality

Lake water quality is typically measured by assessing the amount of algal growth and water clarity during the summer growing season. When excessive algae grow in a lake, water clarity is reduced and noxious smells can emit. These are symptoms of lake eutrophication. When lakes become hypereutrophic (excess nutrients leading to heavy algae growth), the entire food web is affected. Changes are found in the algal community and water quality, including depletion of dissolved oxygen and decreased water clarity. A healthy lake has a balanced growth of algae supporting the base of the food chain without degrading water quality or harming biological organisms.

Phosphorus

Algal growth (measured as total chlorophyll-*a*) is typically limited by the amount of phosphorus in the water column. Therefore, total phosphorus is considered the causative factor for algal growth. Water clarity is affected by the amount of algae as well as suspended and dissolved particles in the water column.

Water quality data was collected twelve times in 2012 from Eden Lake by Blue Water Science and had an average value of 185.1 µg/L. Water quality data had not been collected before 2012 for Eden Lake. The state shallow lake standards for the North Central Hardwood Forest Ecoregion is <60 µg/L.

Chlorophyll-a

Chlorophyll-*a* is a measure of the amount of algal biomass in a basin at any given time. The greater the algal biomass and corresponding chlorophyll-*a* values, the more green and productive a lake appears with worst case scenarios including algal scum and foul odors. These conditions are considered nuisance algal blooms, and are both aesthetically unpleasing and potentially bad for fish and other biological organisms. Nuisance algal blooms cause poor smells and aesthetics, and can lead to more severe problems such as summer fish kills. Ultimately, a shallow lake should have a modest amount of algal productivity with light penetrating approximately 15 feet into the water column.

Water Quality Data was collected twelve times in 2012 from Eden Lake by Blue Water Science and had an average summer value of 73.7 µg/L. Water quality data for Eden Lake had not been collected prior to 2012. The North Central Hardwood Forest Ecoregion standard is <20 µg/L during the summer months (April – September).

Water Clarity

Water clarity in lakes is typically measured using a Secchi disk. A Secchi disk is a black and white disk that is lowered into the water column until it can no longer be seen. The depth at which the disk disappears is known as the Secchi depth and is considered the depth where 90% of the light is extinguished.

Water clarity in shallow lakes is controlled by several factors including the amount of algae in the water column as well as other suspended particles such as suspended sediment as a result of wind resuspension and bioturbation (such as carp). Since Eden Lake is a shallow lake, wind mixing can reach the sediments and stir up particles into the water column.

Visual inspection and Secchi depths from 2012 (average of 1.96 ft) indicate that water clarity is generally poor in Eden Lake. Algal biomass may be contributing to the poor clarity, although resuspension of sediments due to lack of submerged aquatic vegetation also plays a role. However, no submerged aquatic vegetation surveys have been performed on Eden Lake to validate this statement.

4.2.5 Fisheries

No fish surveys have been conducted on Eden Lake at the time of this report.

4.2.6 Aquatic Vegetation

No submerged aquatic vegetation data were available at the time of this report. Submerged aquatic vegetation are critical in shallow lakes because they stabilize lake sediments preventing wind resuspension of sediments. Submerged aquatic vegetation also provides refugia for cladocerans to avoid fish predation.

4.3 PHOSPHORUS SOURCES

One of the primary drivers for lake productivity or algal growth is phosphorus. So, to better understand what is driving water quality in Eden Lake, a detailed phosphorus budget needs to be developed to identify both the sources and magnitude of the phosphorus sources. Phosphorus sources to lakes include stormwater runoff, internal sediment release of phosphorus, and direct atmospheric deposition of phosphorus to the lakes surface. In this section, a brief description of the potential source of phosphorus to Eden Lake is provided.

4.3.1 Atmospheric Deposition

Precipitation picks up dust particles that contain phosphorus that can ultimately end up in Eden Lake as a result of direct input on the basin surface or as a part of stormwater runoff from impervious surfaces in the watershed. Although they must be accounted for in development of a nutrient budget, atmospheric inputs are difficult if not impossible to control and are usually small compared to other sources (internal and external).

Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report “Detailed Assessment of Phosphorus Sources to Minnesota Watersheds” (Barr Engineering, 2004), and are based on annual precipitation. The values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km^2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre-year for dry, average, and wet years in English units, respectively.

4.3.2 Stormwater

Phosphorus transported by stormwater represents one of the largest external contributors of phosphorus to surface waters in Minnesota. Impervious surfaces and storm sewer systems in the watershed improve the efficiency of runoff moving to streams, wetlands and lakes, resulting in increased transport of phosphorus into local basins. Phosphorus in stormwater is a result of leaves and grass clippings, fertilizers, sediments, pet waste, excessive lawn watering, automobiles and illicit sanitary sewer connections. Managing stormwater is a high-priority concern in urban watersheds.

Excess fertilizer applied to lawns is readily transported to local streams, wetlands and lakes during runoff events and is immediately available for algal growth. However, State law prohibits the use of lawn fertilizer containing phosphorus except when new lawns are being established by seeding or laying sod or when soil testing shows a need for additional phosphorus.

The majority of stormwater enters Eden Lake through a constructed pond that drains the Eden Prairie Center, representing 56% of the stormwater volume and 60% of the total phosphorus budget (Figure 4.2). Direct stormwater discharges into the lake either without stormwater treatment (21%) or with treatment (19%). These areas collectively represent about 76% of the phosphorus load in Eden Lake, the rest of the load is attributed to atmospheric and internal loads.

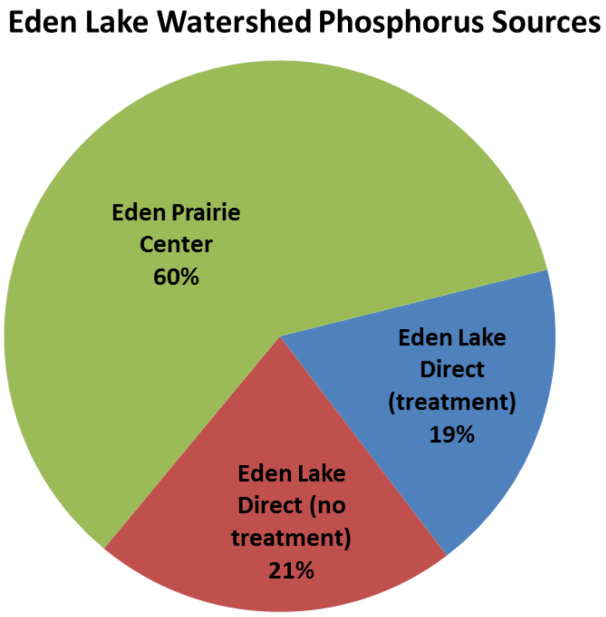


Figure 4.2. Watershed Phosphorus Sources for Eden Lake.

4.3.3 Internal Loading

Over time, basins tend to accumulate phosphorus in their bottom sediments. One of the primary bonds for phosphorus is with iron. When oxygen is depleted near the sediment surface (water concentration less than 2.0 mg/L), phosphorus-iron ($FePO_4$) bonds and other chemical bonds are broken, releasing dissolved phosphorus for transport into the water column. This phosphorus is in a dissolved form that is readily available to algae and plants.

Internal phosphorus loading from sources already in basins has been demonstrated to be an important aspect of the phosphorus budgets of basins. However, measuring or estimating internal loads can be difficult, especially in shallow lakes that may mix many times throughout the year. To estimate internal loading, an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, is estimated from the dissolved oxygen profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor is then used along with a sediment release rate to estimate the total phosphorus load from the sediments.

Because shallow lakes mix often, and dissolved oxygen data is typically collected every other week or monthly, a shallow lake equation that uses morphometry and lake water quality was applied to estimate internal load. Water quality data was collected from Eden Lake in 2012.

Phosphorus release rates were estimated by collecting cores from Eden Lake and incubating them in the lab under anoxic conditions (ACOE-ERD 2010; Appendix B). Table 4.3 summarizes the internal loading for Eden Lake.

Table 4.3. Internal Phosphorus Load Summary for Eden Lake.

Year	Release Rate (mg/m^2/day)	AF	Gross Load (mg/m^2/summer)	Kilograms	Pounds
Average	8.2	67.3	552	44	98

4.4 SOURCE SUMMARY AND CURRENT PHOSPHORUS BUDGET

Following is a description of the primary sources of phosphorus to Eden Lake based on the phosphorus source inputs and lake response (BATHTUB) modeling. Lake response modeling was conducted for 12 years (2001 through 2012) and compared to data collected from Eden Lake in 2012.

4.4.1 Lake Phosphorus Budget

Water quality was collected in 2012 at Eden Lake and therefore the only year used to develop a total phosphorus budget for Eden Lake (Figure 4.3). Additional data will need to be collected to calibrate the model to any further extent. Internal loading represents 23% of the total phosphorus inputs to Eden Lake with stormwater comprising over 76% of the total phosphorus load. Stormwater is the dominant source of phosphorus to Eden Lake due to the watershed being dominated by commercial land use.

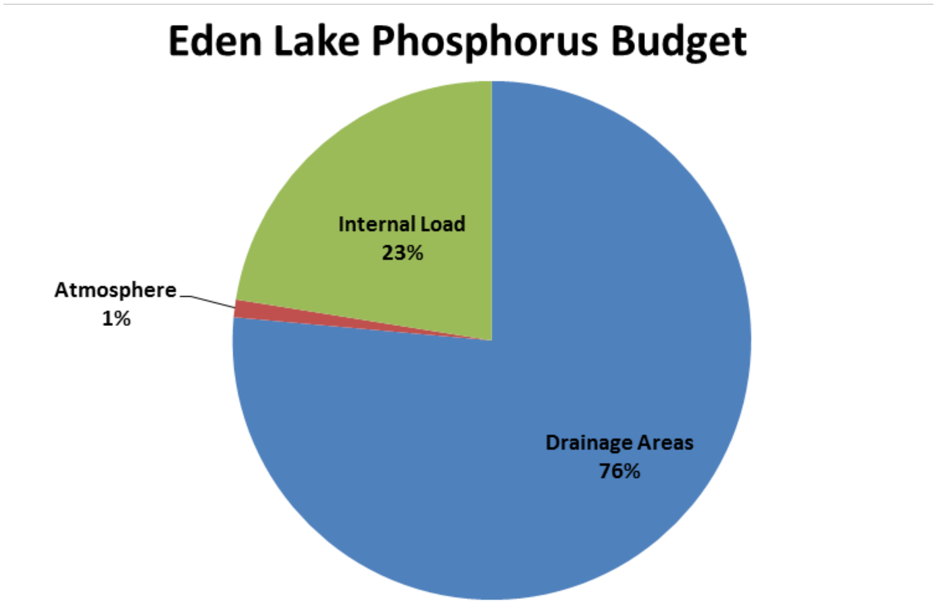


Figure 4.3. Phosphorus Sources for Eden Lake.

4.4.2 Phosphorus Load Reductions

To determine the required phosphorus loads to meet State water quality standards for shallow lakes in the North Central Hardwood Forest Ecoregion (NCHF; Table 4.4), the baseline phosphorus budget was used to determine the response of Eden Lake to total phosphorus reductions.

Table 4.4. Numeric Water Quality Goals for Eden Lake.

	Average June-September Values		
Intended Use	**Total Phosphorus (µg/L)**	**Chlorophyll-*a* (µg/L)**	**Secchi Depth (m)**
Indirect Contact Recreation	≤60	≤20	≥1

First, internal phosphorus loading was reduced to a rate of 0.5 $mg/m^2/day$ based on other reference shallow lakes. Then the watershed loads were reduced until the baseline lake response model predicted a summer average of 60 µg/L total phosphorus.

To meet this quality goal, modeling suggests a total reduction of 314 pounds of phosphorus loading to Eden Lake would need to occur with 134 pounds coming from the Eden Prairie Center, 89 pounds from the rest of the Eden Lake drainage area and 92 pounds coming from the internal load (Table 4.5).

Table 4.5. Current Phosphorus Loading and Predicted Phosphorus to Meet the State Water Quality Standards in Eden Lake.

	Current TP Load (pounds)	TP Load at the Standard (pounds)	Required Reduction (pounds)	Percent Reduction
Eden Prairie Center	199	66	134	67%
Eden Lake Direct	132	44	89	67%
Atmospheric	5	5	0	0%
Internal	98	6	92	94%
TOTAL	434	120	314	72%

4.5 NEILL LAKE AND WATERSHED CHARACTERIZATION

Neill Lake (DNR Lake ID 27-0078) is an off-line lake to Purgatory Creek, a tributary of the Minnesota River. Located in Hennepin County, Neill Lake is just south of Eden Lake and Anderson Lakes Parkway and east of Homeward Hills Road. Neill Lake does not have public access and is surrounded by a large wetland complex on the south side that is separated by a berm. Prior to 1971 Neill Lake and the adjacent wetland to the south were one large wetland. In 1971, the Preserve Association dredged and diked Neill Lake. The drainage system for Neill Lake was further installed in 1974.

4.5.1 Watershed Land Use and Hydrology

Neill Lake has a watershed that drains approximately 156 acres. Land use in the Neill Lake watershed is predominantly residential (66%) and open space (34%) if wetlands and open water are included (Table 4.6; Figure 4.4). The watershed does not contain any major highways.

Table 4.6. Land Use Within the Neill Lake Watershed.

Land use	Acres	%
Multifamily	39.5	25
Single Family Detached	37.8	24
Open Water	35.3	22
Single Family Attached	26.1	17
Park, Recreational, or Preserve	16.9	11
Undeveloped	0.14	<1
Golf Course	0.1	<1

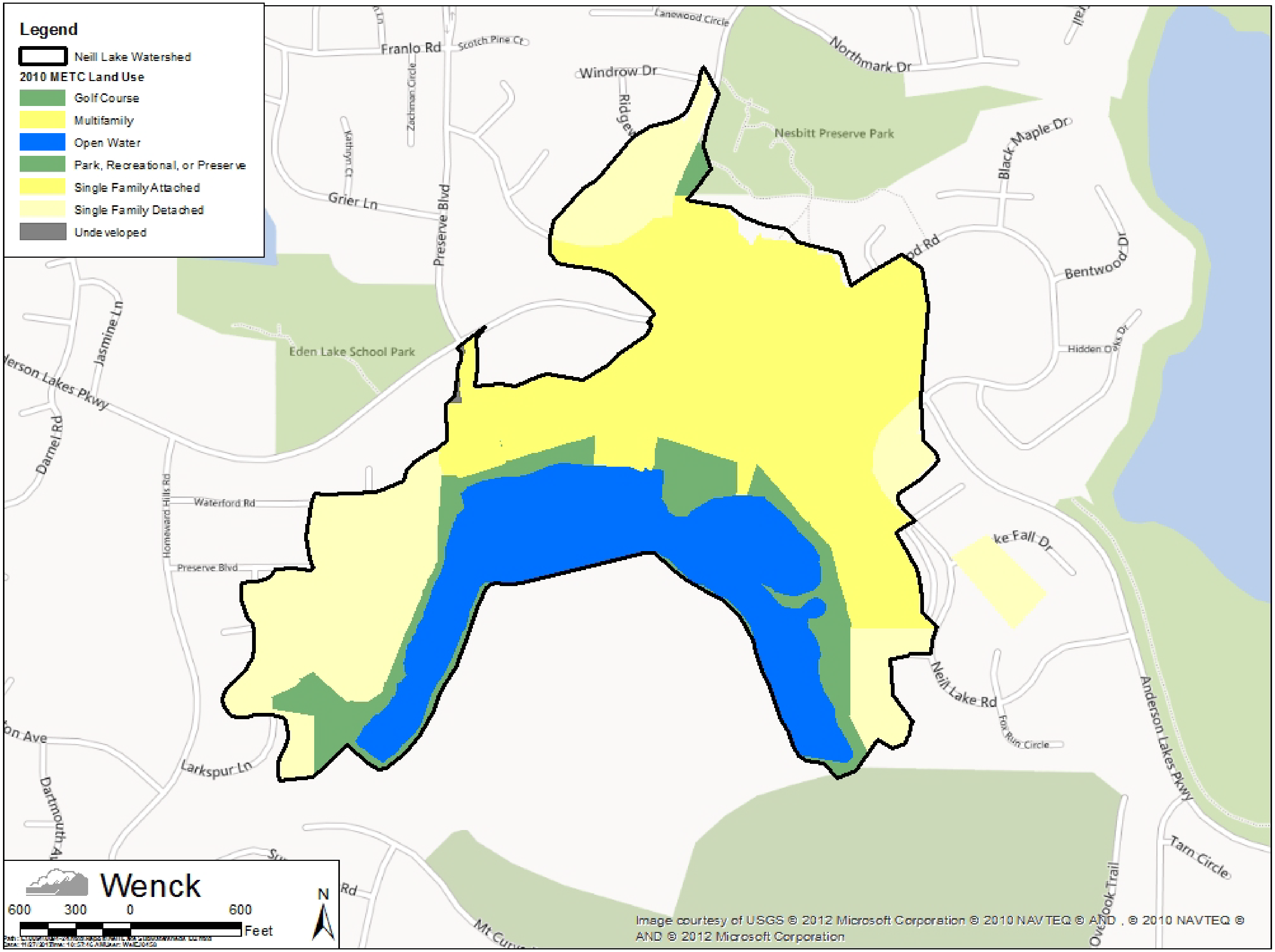


Figure 4.4. Land Use Within the Neill Lake Watershed.

4.5.2 Lake Morphometry

Neill Lake is a small, urban shallow lake with a surface area of 36 acres and a maximum depth of 8 feet (Table 4.7). The Minnesota Pollution Control Agency defines a shallow lake as any lake less than 15 feet in depth or with more than 80% capable of supporting submerged aquatic vegetation. The shallow nature of Neill Lake suggests that the lake should support submerged aquatic vegetation through most if not all of the lake. The area expected to support plant growth (less than 15 feet) is also defined as the littoral zone, the area where light penetration is deep enough to support submerged vegetation. Neill Lake has a short residence time with lake water being replaced by runoff approximately every 131 days. This suggests that the lake will not be as sensitive to stormwater runoff as the neighboring Eden Lake, which has a residence time of 40 days.

Table 4.7. Neill Lake Characteristics.

Parameter	Neill Lake
Surface Area (acres)	36
Average Depth (feet)	2.8
Maximum Depth (feet)	8
Volume (acre-feet)	204.5
Residence Time (years)	0.36
Littoral Area (acres)	42
Littoral Area (%)	100
Watershed (acres)	156

4.5.3 Groundwater

Groundwater was not explicitly incorporated into the water budget of Neill Lake. Based on desktop review of available hydrogeological information, Neill Lake is at an average elevation of approximately 812 feet AMSL, roughly 120 feet above the lakes within the adjacent Minnesota River valley. According to the Hennepin County Geologic Atlas, it is at the approximate level of the perched aquifer in the area. Lakes and wetlands immediately north are at higher elevations though the wetland to the south is lower in elevation. Based on its proximity to the Minnesota River valley bluffs, and the surrounding water levels, it appears to be a flow-through lake where shallow groundwater enters along the northern perimeter and discharges from the southern perimeter. There are no perched aquifer wells in the vicinity, based on the Minnesota Department of Health (MDH) well database, so further refinement of the lake's relationship to the local water table is not possible at this time.

4.5.4 Water Quality

Lake water quality is typically measured by assessing the amount of algal growth and water clarity during the summer growing season. When excessive algae grow in a lake, water clarity is reduced and noxious smells can emit. These are symptoms of lake eutrophication. When lakes become hypereutrophic (excess nutrients leading to heavy algae growth), the entire food web is affected. Changes are found in the algal community and water quality, including depletion of dissolved oxygen and decreased water clarity. A healthy lake has a balanced growth of algae supporting the base of the food chain without degrading water quality or harming biological organisms.

Phosphorus

Algal growth (measured as total chlorophyll-*a*) is typically limited by the amount of phosphorus in the water column. Therefore, total phosphorus is considered the causative factor for algal growth. Water clarity is affected by the amount of algae and suspended and dissolved particles in the water column.

Blue Water Science collected water quality data from Neill Lake in 2011; though not in 2012. Average total phosphorus concentrations was 96.8 µg/L, exceeding the state shallow lake standards for the North Central Hardwood Forest Ecoregion (<60 µg/L) in 2011.

Chlorophyll-a

Chlorophyll-*a* is a measure of the amount of algal biomass in a basin at any given time. The greater the algal biomass and corresponding chlorophyll-*a* values, the more green and productive a lake appears with worst case scenarios including algal scum and foul odors. These conditions are considered nuisance algal blooms, and are both aesthetically unpleasing and potentially bad for fish and other biological organisms. Nuisance algal blooms cause poor smells and aesthetics, and can lead to more severe problems such as summer fish kills. Ultimately, a shallow lake should have a modest amount of algal productivity with light penetrating approximately 15 feet into the water column.

The 2011 summer average chlorophyll-*a* concentration in Neill Lake was 21 µg/L, which slightly exceeds the state water quality standard for shallow lakes in the North Central Hardwood Forest Ecoregion (<20 µg/L as a summer average). Additional data should be collected to determine long-term averages in Neill Lake.

Water Clarity

Water clarity in lakes is typically measured using a Secchi disk. A Secchi disk is a black and white disk that is lowered into the water column until it can no longer be seen. The depth at which the disk disappears is known as the Secchi depth and is considered the depth where 90% of the light is extinguished.

Water clarity in shallow lakes is controlled by several factors including the amount of algae in the water column as well as other suspended particles such as suspended sediment as a result of wind resuspension and bioturbation (such as carp). Since Neill Lake is a shallow lake, wind mixing can reach the sediments and stir up particles into the water column.

Water clarity is fair in Neill Lake with the 2011 average Secchi of 1.16 m. Algal biomass (see chlorophyll-*a* data) may be a main contributing factor to water clarity as submerged vegetation is present and prevents resuspension of sediment in Neill Lake.

4.5.5 Fisheries

No fish surveys have been conducted on Neill Lake as of the date of this report.

4.5.6 Aquatic Vegetation

A submerged aquatic vegetation survey was completed on Neill Lake in June and August of 2011 by Blue Water Science. During both visits, submerged aquatic vegetation had a modest plant diversity that covered 95% of the lake area and had five species present. The June survey was dominated by stringy pondweed and the August survey was dominated by coontail. This is a typical plant diversity condition for a shallow urban lake (Blue Water Science, 2011).

Submerged aquatic vegetation is critical in shallow lakes because they stabilize lake sediments preventing wind resuspension of sediments. Submerged aquatic vegetation also provides refugia for cladocerans to avoid fish predation.

4.6 PHOSPHORUS SOURCES

4.6.1 Atmospheric Deposition

See section 4.3.1 for information on atmospheric inputs of phosphorus.

4.6.2 Stormwater

All of the stormwater enters Neill Lake as direct runoff from it’s watershed, representing 100% of the total phosphorus source budget. There are no treatment basins located in the watershed drainage area and the drainage from Eden Lake is discharged to Neill Lake Marsh, not Neill Lake.

See section 4.3.2 for additional information on stormwater phosphorus sources.

4.6.3 Internal Loading

Phosphorus release rates were estimated by collecting cores from Neill Lake and incubating them in the lab under anoxic conditions (ACOE-ERD 2010; Appendix B). Table 4.8 summarizes the internal loading for Neill Lake.

Table 4.8. Internal Phosphorus Load Summary for Neill Lake.

Year	Release Rate (mg/m^2/day)	AF	Gross Load (mg/m^2/summer)	Kilograms	Pounds
Average	3.5	57.24	200	29	64

4.7 SOURCE SUMMARY AND CURRENT PHOSPHORUS BUDGET

Following is a description of the primary sources of phosphorus to Neill Lake based on the phosphorus source inputs and lake response (BATHTUB) modeling. Water quality data was only collected at Neill Lake in 2011, which was the only year modeled. Additional data should be collected to calibrate the model to any great extent.

4.7.1 Lake Phosphorus Budget

An average of the 11 modeled years was used to develop an average total phosphorus budget for Neill Lake (Figure 4.6). Internal loading represents 44% of the total phosphorus inputs to Neill Lake with stormwater comprising 50% of the total phosphorus load. Stormwater is the majority source of phosphorus to Neill Lake; however, internal load plays a significant role in the phosphorus budget.

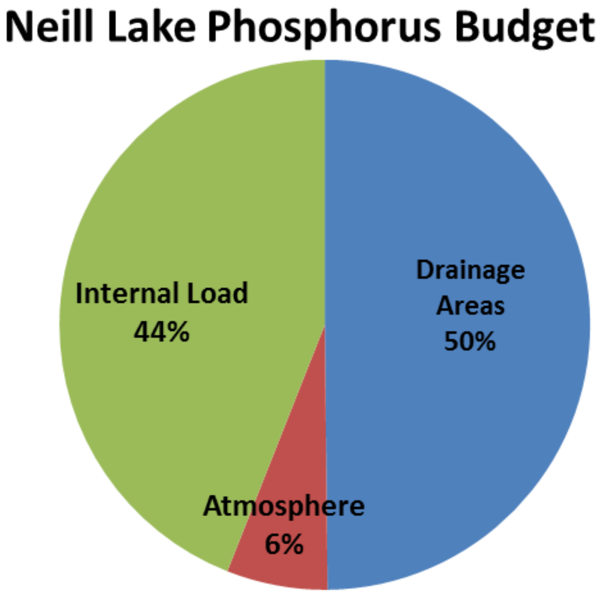


Figure 4.5. Phosphorus Sources for Neill Lake.

4.7.2 Phosphorus Load Reductions

To determine the required phosphorus loads to meet State water quality standards for shallow lakes in the North Central Hardwood Forest Ecoregion (NCHF; Table 4.9), the baseline phosphorus budget was used to determine the response of Neill Lake to total phosphorus reductions.

Table 4.9. Numeric Water Quality Goals for Neill Lake.

Intended Use	Average June-September Values		
	Total Phosphorus (µg/L)	Chorophyll-*a* (µg/L)	Secchi Depth (m)
Indirect Contact Recreation	≤60	≤20	≥1

First, internal phosphorus loading was reduced to a rate of 0.5 mg/m^2/day based on other reference shallow lakes. Then the watershed loads were reduced until the baseline lake response model predicted a summer average of 60 µg/L total phosphorus.

To meet this quality goal, modeling suggests a total reduction of 74 pounds of phosphorus loading to Neill Lake would need to occur with 22 pounds coming from the Neill Lake Direct drainage area and 52 pounds coming from the internal load.

Table 4.10. Current and Predicted Phosphorus Loading to Meet the State Water Quality Standards in Neill Lake.

	Current TP Load (pounds)	TP Load at the Standard (pounds)	Required Reduction (pounds)	Percent Reduction
Neill Lake Direct	69	47	22	32%
Internal Load	61	9	52	86%
Atmospheric	9	9	0	0%
TOTAL	139	65	74	54%

5.0 Conclusions and Recommendations

5.1 INTRODUCTION

As part of their MS4 requirements, the City must inspect all outfalls, constructed ponds and stormwater wetlands each permit cycle. The City's current stormwater inventory includes more than 970 constructed ponds, wetlands, mitigation wetlands, infiltration BMPs, ditches, swales and creek segments that receive or route stormwater. For the purposes of this initial evaluation the City was divided up into a number of subwatersheds centering on lakes or creeks. Stormwater basins (constructed ponds, infiltration BMPs and stormwater wetlands) that are either within a drainage easement, on public land or receive public drainage were evaluated.

The purpose of this study was to enhance the understanding of the City's maintenance responsibilities, assist City staff with scheduling and budgeting resources, and maintain compliance with the City's MS4 SWPPP. To that end, the City will use this information to guide annual implementation and maintenance activities.

The results of the survey were used to identify needed maintenance issues, key basins in treatment trains, and basins that either need excavation due to sediment deposition or that can be expanded to improve the efficiency of the system.

5.2 INVENTORY CONTINUATION AND SCHEDULE

The intent of the survey was to identify key constructed ponds or stormwater wetlands that need maintenance or could be expanded; however the survey can also be used to identify key basins in a treatment train, basins that are experiencing sedimentation, and basins that are oversized or non-critical in protecting receiving water quality. Following are the goals of this assessment:

- Prioritize and schedule basins for future inspections and schedules.

- Routinely inspect all basins as required in the City's MS4 Permit for any visual signs of maintenance needs using the City's visual inspection protocol (City of Eden Prairie Stormwater Inventory, Maintenance, and Inspection Plan dated 3/18/11). These basins were identified based on evidence of potential sedimentation and location in the treatment train.

- Evaluate high-priority basins every inventory cycle for sediment accumulation estimates.

- Determine if the cycle could be adjusted based on the results.

- Other basins should be evaluated a minimum of once during every other inventory cycle, which is estimated as 12 years per cycle.

Table 5.1 identifies the basins that demonstrate enough sediment accumulation to warrant a more frequent schedule based on the age of the basins versus the amount of sediment accumulated.

Table 5.1. Basins in Each Subwatershed Identified for Routine Sediment Deposition Monitoring.

Drainage Group	Basin ID	Estimated Sediment (AF)	Basin Type
Eden Lake Area	14-34-A	0.75	Constructed Pond
Eden Lake Area	23-21-A	1.29	Constructed Pond

5.3 SEDIMENT REMOVAL MAINTENANCE

Basins were identified for maintenance based on their position in the watershed and treatment train, their permanent pool volume as compared to NURP requirements, and signs of sedimentation. Basins with as-built information were also considered for expansion when the as-built permanent pool was larger than the surveyed permanent pool.

Planning level cost estimates were developed for each potential project. The cost estimates include sediment characterization, mobilization, site preparation, dredging, sediment disposal, minor storm sewer work, site restoration, erosion control, permitting, and maintenance. Costs exclude wetland restoration/mitigation (about $10/square foot), major storm sewer work, and land/easement acquisition. Additional problems that might occur during projects that would add to the cost are dewatering and access issues such as steep banks and tree removal.

It is important to note that costs can vary greatly if sediments are determined to be contaminated under MPCA guidelines. The estimated excavation cost in Table 5.2 assumes moderate (Level 2) levels of contamination. Sediment characterization is discussed in more detail in Section 5.4.2.

Projects were prioritized based on their position in the watershed and the treatment train in that watershed, the overall effectiveness of the clean-out or expansion, the type of basin and potential impact to the lake. Typically, stormwater wetlands were considered as low priority if no as-built information was available since it is difficult to differentiate between sediments that already existed in the wetland versus new sediment from stormwater. However, a few wetlands were in critical locations and considered medium or high priority even though the costs would likely be higher than the costs presented in this report due to potential requirements for wetland mitigation.

Table 5.2 presents identified projects for constructed ponds and stormwater wetlands. If historic conditions can be established, excavation of storm sediment is exempted from requiring additional permits. One project (14-34-C) demonstrates a project removal of 22.1 total pounds of phosphorus annually. Basin 14-34-C receives a large amount of stormwater from Eden Prairie Center before discharging to Eden Lake.

Figures 5.1 and 5.2 show the locations of the projects identified in Table 5.2. Cleanout volumes are associated with projects that were identified as having accumulated sediment, and expansion volumes are associated with basins that have as-built information available.

The total cost to complete all of these projects is approximately $544,000 with a total phosphorus reduction of 26 lbs/yr ($21,333/lb).

Identifying projects for key basins in the watershed instead of focusing on small improvements to basins identified in Table 5.2 could provide a larger reduction in watershed loading at a smaller cost. These projects could include:

- Splitting flow from 14-34-A and directing some to 14-34-B, which exceeds NURP standards
- Expansion of 14-34-C and adding an iron enhanced filter bench to treat runoff from Eden Prairie Center
- Adding infiltration BMPs such as rain gardens and swales to the watershed that drains directly to Eden Lake
- Adding infiltration BMPs such as rain gardens and swales to the watershed that drains directly to Neill Lake

Table 5.2. Identified Wetland and Constructed Pond Project Information Including Planning Level Costs.

Drainage Group	Basin ID	Surface Area of As-Built Permanent Pool (acres)	Surface Area of Surveyed Permanent Pool (acres)	Permanent Pool Volume Difference[2] (AF)	Estimated Sediment Volume (AF)	Estimated Excavation Costs[3]	Priority	TSS Reduction (lb/yr)	TP Reduction (lb/yr)
Constructed Ponds									
Eden Lake	14-43-A	0.232	0.15	-0.42	0.07	$69,000	Medium	108	0.3
Wetlands									
Eden Lake	14-34-A	0.956	1.14	1.46	0.73	$81,000	High	428.9	1.4
	14-34-C	--	--	--	1.61	$89,000	High	7842.8	22.1
Olympic Hills Golf Course	24-33-A[1,4]	--	--	--	2.00	$110,000	High	297.8	0.9
	24-33-C[1]	--	3.71	--	3.54	$195,000	Medium	240.5	0.8

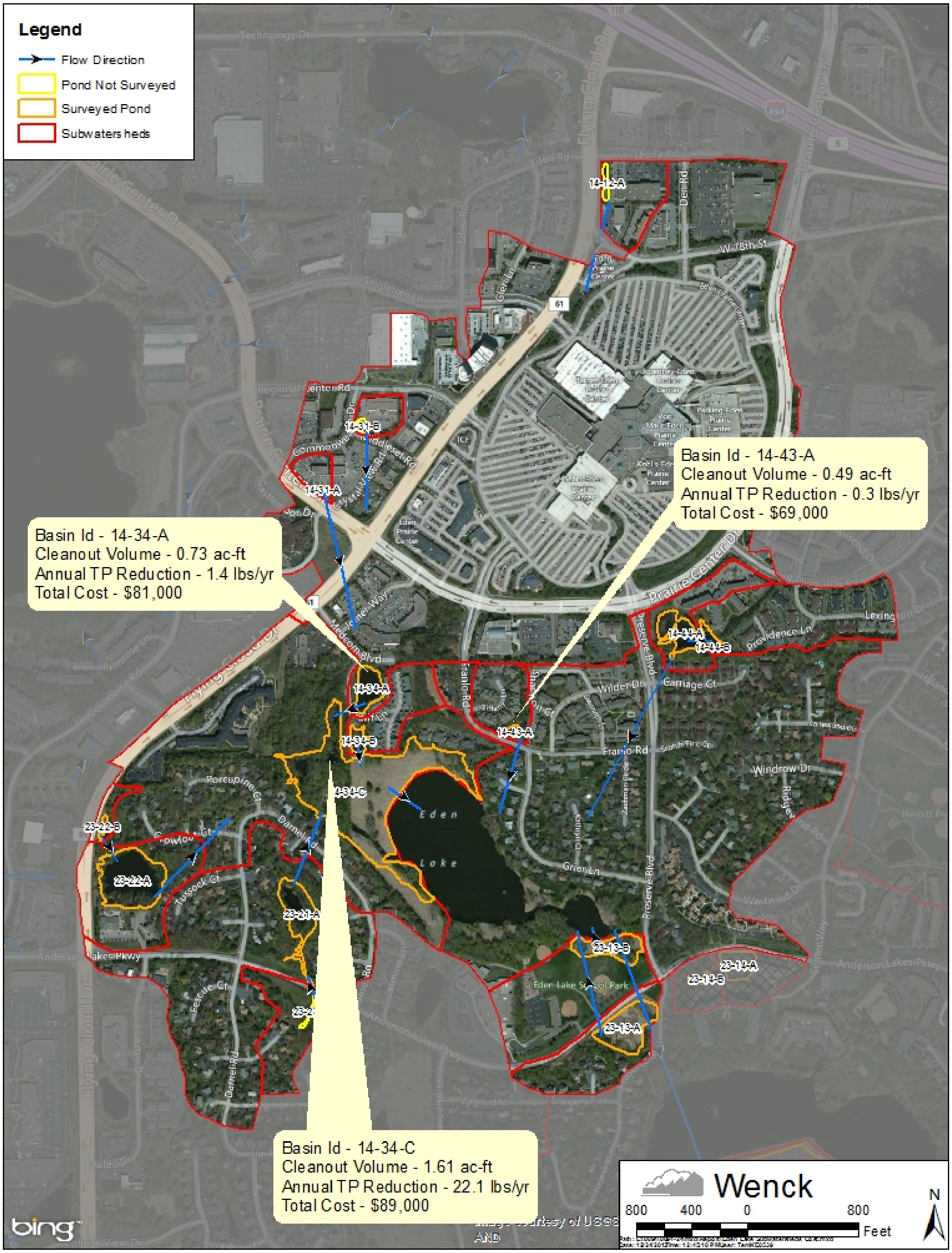
[1] Basins are privately owned; need to work with golf course to proceed with proposed projects.

[2] (Surveyed permanent pool volume) - (As-Built permanent pool volume)

[3] Includes excavating the estimated sediment volume, and the permanent pool volume difference if the As-Built Permanent pool volume is greater than the surveyed permanent pool volume.

[4] Estimated sediment volume to meet NURP standards.

-- Information not available



Basin Id - 14-43-A
Cleanout Volume - 0.49 ac-ft
Annual TP Reduction - 0.3 lbs/yr
Total Cost - $69,000

Basin Id - 14-34-A
Cleanout Volume - 0.73 ac-ft
Annual TP Reduction - 1.4 lbs/yr
Total Cost - $81,000

Basin Id - 14-34-C
Cleanout Volume - 1.61 ac-ft
Annual TP Reduction - 22.1 lbs/yr
Total Cost - $89,000

Figure 5.1. Project Locations Identified in Eden Lake Watershed Area.

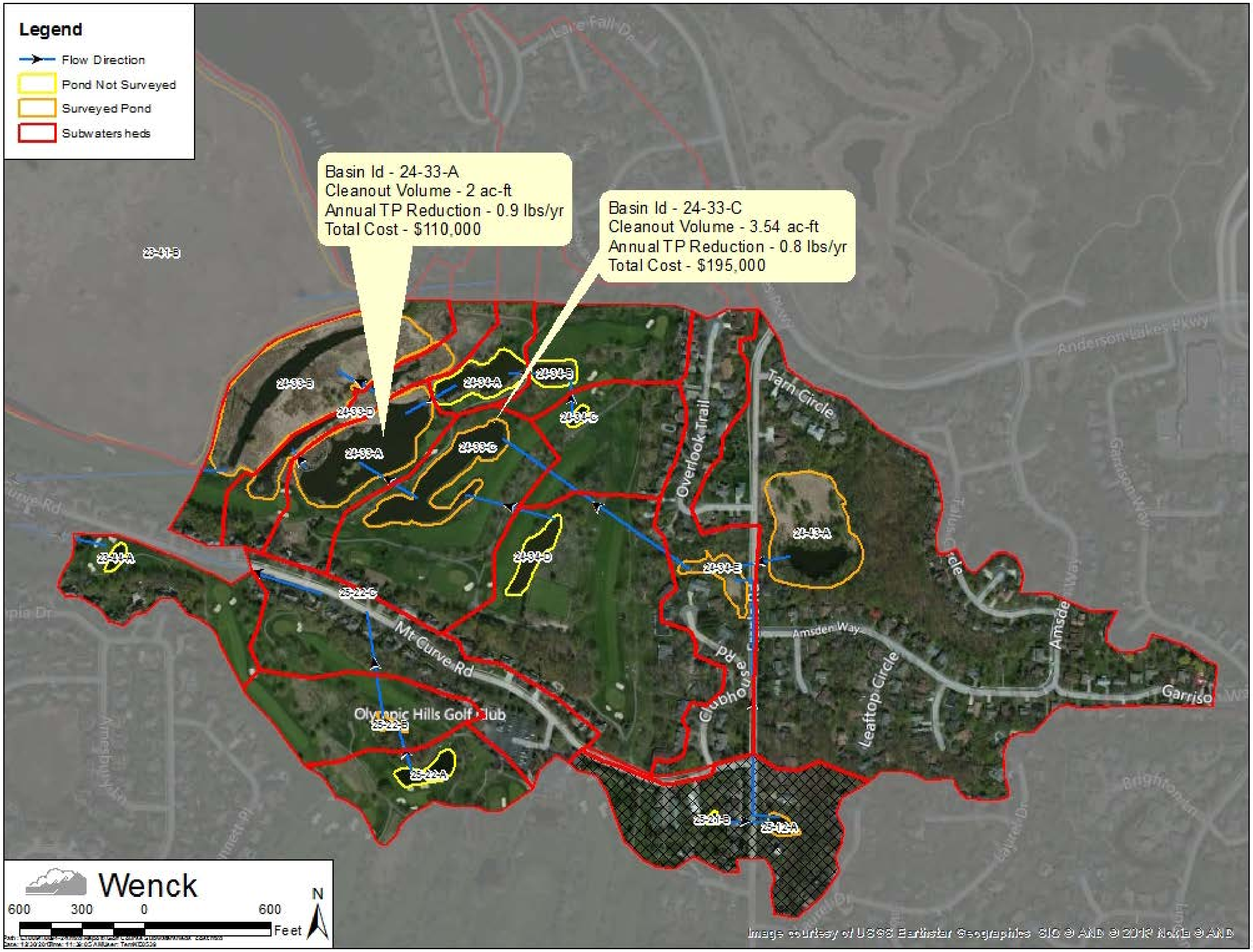


Figure 5.2. Project Locations Identified in Olympic Hills Golf Course Watershed Area.

5.4 PERMITTING REQUIREMENTS

Several permitting requirements should be considered prior to initiating any constructed pond and wetland excavation.

5.4.1 Wetlands

The Minnesota Wetland Conservation Act (WCA) requires replacement for excavation in Type 3, 4, or 5 wetlands, but provides an exemption for maintenance of wetland stormwater treatment basins if it is demonstrated that the wetlands/ponds were established prior to 1991. There is also a “No-Loss” exemption for excavation of deposited sediment for wetlands utilized for stormwater management (8420.0415 Item E). Required information includes engineering plans for the basin, materials that demonstrate the basin was designed and constructed as a stormwater treatment basin, outlet information, permits obtained for pond construction, or sediment measurements. Under the exemptions, the wetland stormwater treatment basin can be excavated to regain their original design or to remove deposited sediment. However, excavation which increases the basin's surface area or depth requires wetland replacement. Wetland replacement may also be required if the excavation will significantly disturb the wetland system, however it is the City’s policy to avoid disturbing natural wetlands if at all possible.

5.4.2 MPCA Dredged Materials Management

The MPCA issues permits for the management of dredged materials under the National Discharge Elimination System (NPDES) and/or the State Disposal System (SDS). In June 2009, the MPCA released *Managing Dredged Materials in the State of Minnesota*, where specific guidance was provided for projects involving sediment removal from municipal or urban stormwater systems.

The MPCA does not require a permit, or reporting of results for small maintenance projects where project maintenance activity is less than 3,000 cubic yards and chemical sample data indicate that the dredge material meets management level 1. Dredged material is divided into 3 management levels based on the amount of contamination and therefore has different restrictions on disposal of the material. Level 1 dredged material, which has the lowest levels of contamination, is suitable for use or reuse on properties with a residential or recreational use category. Materials categorized as Level 2 are suitable for use or reuse on properties with an industrial use category. Level 3 dredged material is considered to be significantly contaminated and must be managed specifically for the contaminants present (MPCA, December 2011).

A sediment characterization needs to be completed to evaluate the dredged materials level risk and to determine disposal options for the dredged sediment. The removal of individual sediment deltas by basin inlets or outfalls does not require the evaluation of the dredged materials level risk. Sampling is recommended by the MPCA if maintenance is performed at multiple inlet locations and if the material consolidated at one location is greater than 500 cubic yards. Sediment from maintenance of individual stormwater inlets and outfalls may be combined for composite sampling as one project.

5.5 EDEN LAKE RESTORATION

5.5.1 Watershed Load Targets

Based on the lake response modeling, required watershed load reductions to meet state water standards in Eden Lake were developed for the modeled years average (Table 5.4). A 67% reduction in the phosphorus loading to Eden Lake or a total phosphorus load reduction of 314 pounds is required.

Table 5.3. Watershed Loading and Estimated Reduction Requirements for the 10-year Average.

Main Watershed	Flow	Total Suspended Solids		Total Phosphorus		TP Reduction	
	Acre-feet	mg/L	lbs /yr	µg/L	lbs /yr	lbs /yr	%
Eden Prairie Center	354	33	38,613	244	199	134	67%
Eden Direct	254	27	24,383	199	132	89	67%
Eden Lake	608	38	62,996	201	332	314	67%

In general, most of the proposed projects have only small benefits in total phosphorus loading to surface waters. If all of the projects were completed, the system would remove an additional 23.8 pounds of phosphorus and 8,380 pounds of total suspended solids. Considering Eden Prairie's stormwater phosphorus contribution to Eden Lake requires a 314 pound reduction, these small upgrades to the ponds are a relatively minor step to meeting this goal (8%). The total cost to complete these projects is approximately $239,000 equating to a cost of $10,042.02 per pound of phosphorus removal.

5.5.2 Internal Load Targets

In addition to the watershed reductions, a total internal load reduction of 92 pounds is required for Eden Lake to meet State water quality standards for shallow lakes in the North Central Hardwood Forest Ecoregion. Internal load reductions can be accomplished through a number of techniques including artificial circulation, aeration, or alum addition.

5.5.3 Ecological Restoration

Shallow lakes are ecologically different from deep lakes. In shallow lakes, there is a greater area of sediment-water interface, allowing potentially larger sediment contributions to nutrient loads and higher potential sediment resuspension that can decrease water clarity. Biological organisms also play a greater role in maintaining water quality. Rough fish, especially carp, can uproot submerged aquatic vegetation and stir up sediment. Submerged aquatic vegetation stabilizes the sediment, reducing the amount that can be resuspended and cloud water clarity. Submerged aquatic vegetation also provides refugia for zooplankton, a group of small crustaceans that consumes algae.

All of these interactions reflect a lake being in two alternative stable states: a clear water state and a turbid water state. The clear water state is characterized by a robust and diverse submerged aquatic vegetation community, balanced fish community and large daphnia (zooplankton that are very effective at consuming algae). Alternatively, the turbid water state typically lacks submerged aquatic vegetation, is dominated by rough fish, and is characterized by both sediment resuspension and algal productivity. The state in which the lake persists depends on the biological community as well as the nutrient conditions in the lake. Therefore, lake management must focus on the biological community as well as the water quality of the lake.

The following five-step process for restoring shallow lakes that was developed in Europe is also applicable here in the United States:

- Forward “switch” detection and removal
- External and internal nutrient control
- Biomanipulation (reverse “switch”)
- Plant re-establishment
- Stabilizing and managing the restored system

The first step refers to identifying and eliminating those factors, also known as “switches,” that are driving the lake into a turbid water state. These can include high nutrient loads, invasive species such as carp and curly-leaf pondweed, altered hydrology, and direct physical impacts such as plant removal.

Once the switches have been eliminated, an acceptable nutrient load must be established.

After the first two steps, the lake is likely to remain in the turbid water state even though conditions have improved, and it must be forced back into the clear lake state by manipulating its biology (also known as biomanipulation). Biomanipulation typically includes whole lake drawdown and fish removal. Once the submerged aquatic vegetation has been established, management will focus on stabilizing the lake in the clear lake state (steps 4 and 5). For Eden Lake, a whole lake drawdown is not feasible due to its large watershed. Rather, plants will need to be reestablished through other lake restoration techniques such as alum treatment.

5.6 NEILL LAKE RESTORATION

5.6.1 Watershed Load Targets

Based on the lake response modeling, required watershed load reductions to meet state water standards in Neill Lake were developed for the modeled years average (Table 5.5). A 36% reduction in the phosphorus loading to Neill Lake or a total phosphorus load reduction of 39 pounds is required.

Table 5.4. Watershed Loading and Estimated Reduction Requirements for the 10-year Average.

Main Watershed	Flow	Total Suspended Solids		Total Phosphorus		TP Reduction	
	Acre-feet	mg/L	lbs /yr	µg/L	lbs /yr	lbs /yr	%
Neill Direct	101	87	2,238	254	69	39	32%

No projects were identified in the Neill Lake direct watershed since there are currently no stormwater basins. The reduction needed to meet Neill Lake standards will need to come from retrofitting subwatersheds leading to the lake.

5.6.2 Internal Load Targets

In addition to the watershed load reductions, a total internal load reduction of 52 pounds is required for Neill Lake to meet State water quality standards for shallow lakes in the North Central Hardwood Forest Ecoregion. Internal load reductions can be accomplished through a number of techniques including artificial circulation, aeration or alum addition.

5.6.3 Ecological Restoration

Neill Lake is also a shallow lake where ecological restoration needs to be considered. However, Neill Lake is currently in the clear water state, so the goal is in protecting the submerged aquatic vegetation community. Restoration and protection of Neill Lake should focus on protecting the lake from invasive species such as carp and curly-leaf pondweed as well as nutrient reductions in the watershed.

6.0 References

Minnesota Pollution Control Agency. 2009. Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List.

Minnesota Pollution Control Agency. 2011. Managing Dredge Materials In the State of Minnesota (December 2011).

IEP Inc. 1990 P8 Urban Catchment Model - User's Manual, DOS Version 1.1, prepared for Narragansett Bay

Canfield, D.E Jr., and R.W. Bachmann. 1981. Prediction of Total Phosphorus Concentrations, Chlorophyll-*a*, and Secchi Depths in Natural and Artificial Lakes. Can. J. Fish Aquat. Sci. 38:414-423.

Barr Engineering. 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Prepared for the Minnesota Pollution Control Agency, St. Paul, MN.

Blue Water Science. 2012. Water Quality and Aquatic Plant Surveys for Neill Lake, Eden Prairie, Minnesota, 2011.

Appendix A

Complete Visual Inspection Results for the Eden and Neill Lake Watersheds Basin Survey

Table A.1. Inlets Visual Inspection Results for the Eden and Neill Lake Watersheds Basin Survey

Basin ID	Inlet ID	Date Evaluated	Condition	Erosion?	Sediment?	Sediment Delta?	Size of Sediment Delta	Veg Overgrowth?	Flared End?	Comments	Misc Comments	Invert Elevation	Flowing?	Depth of Water (in)
14-12-A	1:00	8/16/2010	Good	Yes		No		No	Yes				Partial	
14-12-A	4:00	8/16/2010	Good	No		No		No	No	Overland flow with rip-rap to pond from parking lot.			No	
14-12-A	3:00	8/16/2010	Good	Yes	Yes	Yes		Some	Yes				No	
14-31-A	9:00	8/16/2010	Fair	No	Yes	No		No	Yes			839.8		
14-31-B	11:00	8/16/2010	Fair	Yes	Yes	No		No	Yes			846	No	5
14-31-B	4:00	8/16/2010	Fair	Yes	Yes	Partial		No	Yes			846	No	5
14-34-A	1:00	4/12/2009	Good	No	No	No			No	Large Surge basin			No	
14-34-A	11:00	4/12/2009	Good	No	No	Yes	2.5' x 15' x 2'	No	No	Delta is a sand bar several feet in front of pipe.			No	
14-34-B	3:00	7/22/2011	Good	Yes	No	No		Slight	Yes	Some trash and a sign near inlet.			No	
14-34-B	12:00	7/22/2011	Good	Yes	No	No		Slight	Yes	Inlet from pond 14-34-A			No	
14-34-C	10:00	4/16/2009	Fair	Yes	No				Yes	rip-rapped but erosion is still present (2 x 8 x 5), TG needs to be cleaned out - 2009			No	
14-34-C	2:00	10/21/2011	Good	No	No				Yes				No	
14-34-C	11:20													
14-34-C	11:15													
14-34-C	1:00	10/21/2011	Good	No	Yes	No			Yes	sedimentation in pipe			No	
14-34-C	11:30	10/21/2011	Good	No	No	No		No	No	Three large round CMP pipes next to one another.			Yes	
14-34-C	12:00	10/21/2011	Good	No	No	No		No	N/A	berm			No	
14-34-C	9:00	10/21/2011	Fair	Yes	No	No		No	Yes	pipe haning in air about 4 ft, erosion: 4 x 25 x 8		817	No	
14-34-C	7:00	10/21/2011	Fair	No	No	Yes	2' x 80 ' x 2'	No	No	rusted & dented			No	
14-43-A	10:00	8/2/2011	Poor	No	Yes	Slight		Yes	Yes	6" sediment, 6" tree growing in sediment.			No	
14-44-A	3:00	10/26/2009	Good	No	No	No			Yes				Yes	
14-44-B	3:00	8/19/2011	Good	No	Slight	No		No	Yes				No	
14-44-B	4:00	8/19/2011	Good	No	No	No			Yes				Yes	
23-13-A	7:00	6/10/2008	Fair	Yes	No	No		Yes	Yes	Covered by brush Could not find 2011		818	No	
23-13-B	8:00	10/21/2011	Good	Slight	No	No		No	Yes				No	
23-14-A	3:00	8/2/2011	Poor	Yes		No		Yes	Yes	Vegetation overgrowth, tree growing in trashguard.- 2008 8/2/2011- garbage in trashgaurd				
23-14-A	10:00	2/22/2012	Fair	some	No	Slight	24"	No	Yes	FES off center of pipe appx 2"			No	

Basin ID	Inlet ID	Date Evaluated	Condition	Erosion?	Sediment?	Sediment Delta?	Size of Sediment Delta	Veg Overgrowth?	Flared End?	Comments	Misc Comments	Invert Elevation	Flowing?	Depth of Water (in)
23-14-A	9:30	2/22/2012	Good	Some	No	Slight		No	N/A				No	
23-14-B	2:05	8/2/2011	Poor		No					Rocks and branches in pipe			No	
23-14-B	1:00		Good	Yes		No		No	No	Erosion channel draining parking lot to wetland.				
23-14-B	2:00	8/31/2006	Good	Yes		No		No	No	Erosion channel draining parking lot to wetland.				
23-21-A	2:00	6/13/2008	Unknown							INV = 824.01 Unable to locate in field				
23-21-A	11:30	6/13/2008	Unknown							Unable to locate in field.				
23-21-A	5:00	6/13/2008	Good	No		No		Yes	Yes	INV = 823.98				
23-21-A	5:50	6/13/2008	Good	No		No		No	No					
23-21-A	6:40	6/13/2008	Good	No		No		No	Yes					
23-21-A	7:00	6/13/2008	Good	Yes	Yes	Yes		No	Yes					
23-22-A	7:35	11/17/2011	Fair	No	Unknown	No		No	Yes	Trashgard is rusted, pipe primarily submerged, pipe under berm within wetland			Yes	11
23-22-A	7:30	11/17/2011	Fair	Some	Some	No		Slight	Yes	flow inhibited - leaves			No	
23-22-A	1:00	11/17/2011	Fair	No	Some	No		No	Yes	Trash guard rusted, half full of leaves- inhibited.			No	
23-22-A	7:00	11/17/2011	Fair	Slight	Some	Slight	1"	No	Yes	Flow inhibited - leaves			No	
23-22-A	10:00	5/13/2009	Good	Some	No	Slight	3"	No	Yes	open flow	erosion channel 10' from flared end		No	
23-22-A	11:00	11/17/2011	Fair	Yes	Yes	Yes	appx 4" deep up to 30' across, 20' to wtr edge		No	Inlet is overland flow from 23-22-B that includes an erosion channel up to 1' deep and sediment spreading through forested area to water's edge.			No, open	
23-22-B	12:00	11/17/2011	Good	No	No	No		No	Yes	size of inlet is an estimate- did not measure at time			No	
23-24-B	6:30	4/8/2009	Good	No	No	No			Yes				No	
25-22-A	12:00	12/14/2011	Fair	No	Yes	Yes	5"x6'x6'	No	No	3" sediment in pipe - pipe is perforated and slightly dented near edge by sod			No	
25-22-B	4:00	8/18/2011	Good	No	No	Yes	4"	No	No	End is submerged.			No	

Table A.2. Outlets Visual Inspection Results for the Eden and Neill Lake Watersheds Basin Survey

Basin ID	Outlet ID	Date Evaluated	Condition	Erosion?	Sediment?	Sediment Delta?	Veg Overgrowth?	Debris?	Trash guard?	Flared End Section?	Outlet Comment
14-12-A	9:00	8/16/2010	Good	No	No	No		No	No	No	Large round structure with manhole on top
14-31-A	4:00	8/2/2011	Fair	No	Some	Yes	6"	Yes	No	Yes	Cattails in FES
14-31-B	9:00	8/16/2010	Good	Yes	Yes	No			No	Yes	4-6" sediment in pipe
14-34-A	6:00		Fair	No						Yes	Outlet is assumed to inlet to 14-34-B. Not located in 2006 or 2009 or 2011
14-34-A	7:00	7/22/2011	Good	Unknown	Unknown	No		No	Unknown	No	Looks like a concrete box where outfall is submerged. Pictures taken and filed away.
14-34-B	6:00	7/22/2011	Good	No	No	No		No	No	No	overland flow to 14-34-C - over berm
14-43-A	6:00	8/2/2011	Good	No	No	No		No	No	No	Large circular overflow structure. Manhole cover on top of structure. - in pond below structure
14-44-A	6:00	10/26/2009	Good	No	No	No		No	No	No	large metal pipe sticking vertically out of pond. Overflow basin?
14-44-A	12:00	8/3/2011	Fair	No	Yes	Yes		No	Yes	Yes	some sediment inhibiting outlet 8/3/2011
14-44-B	9:00	8/19/2011	Good	No	No	No		No	No	Yes	overflow basin
23-13-A		10/1/2011	Good	No	No	No		Yes	No	Yes	
23-13-A	5:00										Could not find 2011
23-14-A	9:00		Fair	Yes					No	Yes	Sediment buildup.
23-14-B	9:00		Good	No							In Water
23-21-A	6:30		Fair	Yes	No	No		No	Yes	No	Branches in pipe
23-21-A	12:00		Good	No					No	No	Outlet submerged at time of visit.
23-22-A	4:00	5/13/2009	Fair								CMP is rusting out, work order not needed yet
23-22-A	7:25	11/17/2011	submerged	No	Unknown	No		No	Unknown	Yes	Pipe under berm within wetland
23-22-B	6:00	11/17/2011	Fair	Yes	No	Yes		No	No	N/A	The outlet is a channel that is eroding down the slope.
23-24-A	6:00	10/13/2010	Good	No	No	No		No	No	Yes	

Basin ID	Outlet ID	Date Evaluated	Condition	Erosion?	Sediment?	Sediment Delta?	Veg Overgrowth?	Debris?	Trash guard?	Flared End Section?	Outlet Comment
23-41-B	8:00	5/20/2009	Good								
23-44-A	12:30	5/20/2009	Fair								
24-33-A	7:00	1/18/2002	Good	No						No	Submerged in 2006
24-33-B	7:00	10/24/2011	Unknown	No	No				No	No	11/18/2006 - condition good 10/24/2011 - could not find
24-33-C	9:00	11/18/2002	Good	No					No	No	appears to flow to 24-33-A - size of pipe is a guess
24-33-D	8:00		Good								
24-33-D	11:00	10/24/2011	Good	No	Unknown	Unknown		Unknown		No	water was low, could not reach by boat or on foot
24-34-B	10:00	12/14/2011	Good	No	Yes			No	Some	No	Perforated vertical tube that appears to flow to 24-34-A - there is debris in the pipe, may be slightly inhibiting flow.
24-34-C	10:00	10/27/2010	Fair	No	No	No		No	No	No	
24-34-D	11:00	12/14/2011	Good	No	No	No		No	No	No	Pipe is perforated and has a ~3" pvc pipe underneath it. Perhaps just for support?
24-34-E	9:00	10/21/2011	Fair	Yes	No	No		Slight	No	Yes	Drop Structure - hole next to drop structure
24-43-A	8:00		Good	No					No	No	Partially Submerged
25-22-A	8:00	12/14/2011	Good	No	No	No		No	No	No	
25-22-B	10:00	8/18/2011	Good	No	No	No		No	No	No	dented end
25-22-C	1:00	1/15/2010	Good	No	No	No		No	Some	Yes	some organic debris in pipe but not inhibiting flow

Appendix B

Eden Lake and Neill Lake
Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Eden Lake, Minnesota

01 February, 2012

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OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled anoxic (i.e., anaerobic) conditions and to quantify biologically-labile (i.e., subject to recycling) and refractory (i.e., biologically inert and subject to burial) P fractions for sediments collected in Eden Lake, Minnesota.

APPROACH

Laboratory-derived rates of P release from sediment under anoxic conditions: Replicate sediment cores were collected by Wenck Associates from stations located in the central basin of Eden Lake in October, 2011, for determination of rates of P release from sediment under anoxic conditions. All cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from the lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 to 25 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling nitrogen (anoxic) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment. Anoxic conditions were verified using a dissolved oxygen electrode.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment (mg m^{-2} d^{-1}) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: The upper 10 cm of an additional core collected from the lake was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P, total nitrogen (N), total iron (Fe), total manganese (Mn), and total calcium (Ca; all expressed at mg/g). A known volume of sediment was dried at 105 ^oC for determination of moisture content and sediment density and burned at 500 ^oC for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total N, P, Fe, Mn and Ca using standard methods (Plumb 1980; APHA 2005).

Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that result in desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the loosely-bound and iron-bound P fractions are referred to as redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988; Gächter and Meyer 1993; Hupfer et al. 1995). The sum of redox-sensitive P and labile organic P are collectively referred to a biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound, calcium-bound, and refractory organic P fractions are more chemically inert and subject to burial rather than recycling.

RESULTS AND INTERPRETATION

Phosphorus mass and concentration increased linearly and rapidly in the overlying water column of sediment systems maintained under anoxic conditions (Figure 1). Maximum concentrations of soluble reactive P approached 1.5 $mg \cdot L^{-1}$ near the end of the study. The mean anoxic P release rate was relatively high at 8.2 (± 0.3 S.E.; n = 3) $mg \cdot m^{-2} \cdot d^{-1}$ and fell within the upper quartile compared to the median anoxic P release rate measured in other eutrophic systems in the Minneapolis-St. Paul regional area (Figure 2). Overall, high rates of anoxic P release coupled with seasonal hypolimnetic anoxia during the summer could play an important role in the P budget of the lake.

Profundal sediment in Eden Lake exhibited a high moisture content and low sediment density, indicating fine-grained, flocculent sediment (Table 1). Loss-on-ignition organic matter content was moderate at ~20%. The total P concentration of the sediment was moderate at 0.88 $mg \cdot g^{-1}$ (Table 2) and fell below the lower quartile when compared to other eutrophic lakes in the region (Figure 3).

The biologically-labile (i.e., subject to recycling back to the overlying water column; loosely-bound P, iron-bound P, and labile organic P) P concentration accounted for ~

39% of the total sediment P (Figure 4; Table 2). Redox-sensitive P (i.e., active in anoxic P release from the sediment; loosely-bound and iron-bound P) represented ~61% of the biologically-labile P and ~26% of the total P (Table 2). Iron-bound P dominated the biologically-labile P fraction at ~61%, and the concentration fell near the median concentration compared to other lakes in the region (Figure 3). The concentration normalized with respect to fresh sediment mass (i.e., wet sediment mass that includes interstitial water) also fell within ranges reported for other eutrophic systems in North America (Figure 5; Nürnberg 1988). In contrast, loosely-bound P and labile organic P represented ~5 and 33% of the biologically-labile P, respectively.

Biologically-refractory P (i.e., more inert to recycling and subject to burial; aluminum-bound P, calcium-bound P, and refractory organic P) represented ~61% of the total sediment P (Figure 4; Table 2). Refractory organic P accounted for ~ 52% of the biologically-refractory P. Aluminum-bound P and calcium-bound P each accounted for ~21 and 27%, respectively, of the biologically-refractory P.

Eden Lake sediment exhibited a relatively high total Fe concentration (Table 2) which fell within the upper quartile compared to other lake sediments in the region (Figure 6). Concentrations of sediment total Ca were moderate at 47.78 $mg \cdot g^{-1}$ (Table 2), relative to other lakes in the region (Figure 6). The sediment total Fe:P ratio was high at 24 (Table 2). Ratios > 10 have been associated with regulation of P release from sediments under oxic conditions (Jensen et al. 1992).

REFERENCES

APHA (American Public Health Association). 2005. Standard Methods for the Examination of Water and Wastewater. 21th ed. American Public Health Association, American Water Works Association, Water Environment Federation.

Barko, J.W., and Smart, R.M. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. Ecology 67: 1328-1340.

Boström, B. 1984. Potential mobility of phosphorus in different types of lake sediments. Int. Revue. Ges. Hydrobiol. 69:457-474.

Gächter, R., Meyer, J.S., and Mares, A. 1988. Contribution of bacteria to release and fixation of phosphorus in lake sediments. Limnol. Oceanogr. 33:1542-1558.

Gächter, R., Meyer, J.S. 1993. The role of microorganisms in mobilization and fixation of phosphorus in sediments. Hydrobiologia 253:103-121.

Håkanson, L., and Jansson, M. 2002. Principles of lake sedimentology. The Blackburn Press, Caldwell, NJ USA.

Hjieltjes, A.H., and Lijklema, L. 1980. Fractionation of inorganic phosphorus in calcareous sediments. J. Environ. Qual. 8: 130-132.

Hupfer, M., Gächter, R., Giovanoli, R. 1995. Transformation of phosphorus species in settling seston and during early sediment diagenesis. Aquat. Sci. 57:305-324.

Jensen, H.S., Andersen, F.Ø. 1992. Importance of temperature, nitrate, and pH for phosphate release from aerobic sediment of four shallow, eutrophic lakes. Limnol. Oceanogr. 37:577-589.

Jensen, H.S., Kristensen, P., Jeppesen, E., and Skytthe, A. 1992. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiol. 235/236:731-743.

Mortimer, C.H. 1971. Chemical exchanges between sediments and water in the Great Lakes – Speculations on probable regulatory mechanisms. Limnol. Oceanogr. 16:387-404.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45:453-462.

Plumb, R.H. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical Report EPA/CE-81-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Psenner, R., and Puckso, R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Biel. Erg. Limnol. 30:43-59.

Table 1. Textural characteristics for sediments collected in Eden Lake.				
Station	Moisture Content (%)	Bulk Density (g/cm^3)	Sediment Density (g/cm^3)	Loss-on-ignition (%)
Central	81.1	1.103	0.216	19.7

Table 2. Mean (1 standard error in parentheses; n=3) rates of phosphorus (P) release, concentrations of biologically labile and refractory P, and metals concentrations for sediments collected in Eden Lake. DW = dry mass, FW = fresh mass, N = nitrogen, Fe = iron, Mn = manganese, Ca = calcium.

Station	Diffusive P flux	Redox-sensitive and biologically labile P				Refractory P		
	Anoxic ($mg\ m^{-2}\ d^{-1}$)	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (mg/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
Central	8.2 (0.3)	0.016	0.209	39	0.120	0.114	0.145	0.276

Station	Total P	Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Central	0.880	0.225	25.6%	0.345	39.2%	0.535	60.8%

Station	Total N	Total Fe	Total Mn	Total Ca	Fe:P
	(mg/g DW)	(mg/g DW)	(mg/g DW)	(mg/g DW)	
Central	5.700	21.28	0.37	47.78	24.2

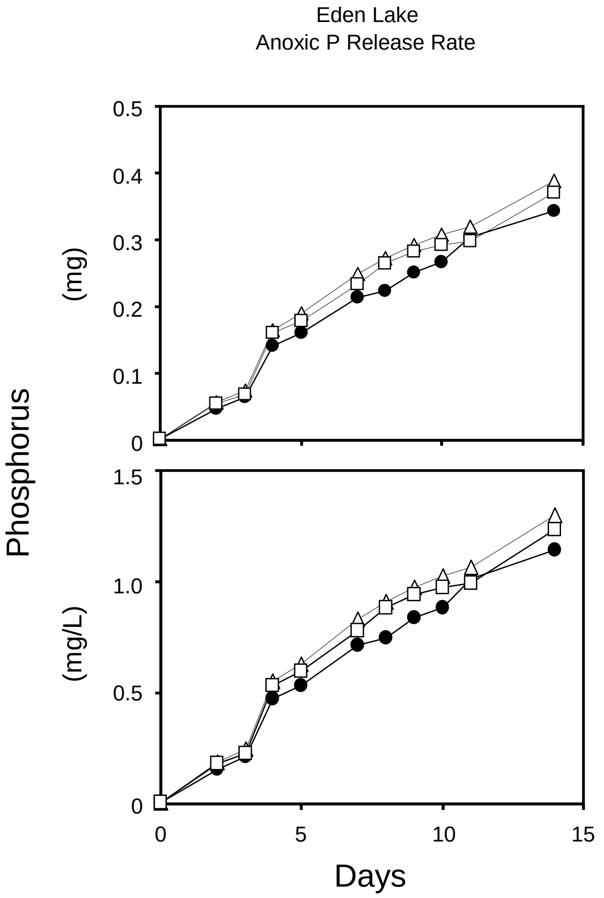

Figure 1. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under anoxic conditions versus time for sediment cores collected in Eden Lake.

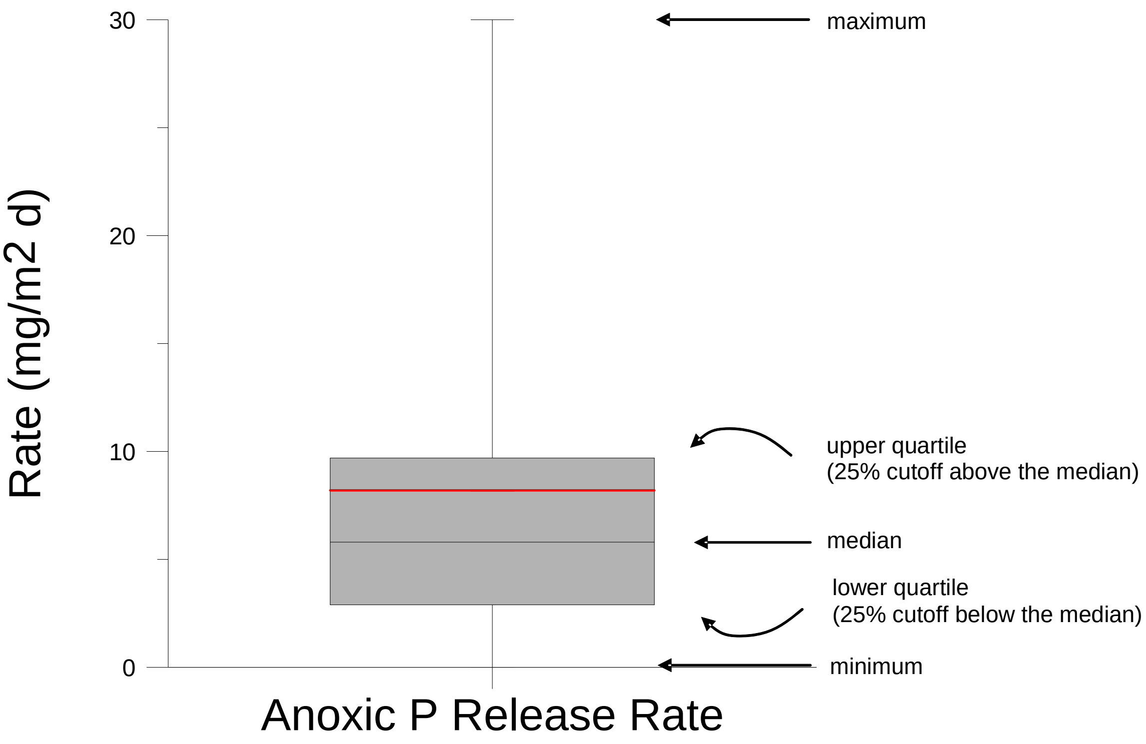

Figure 2. Box and whisker plot comparing the anoxic phosphorus (P) release rate measured for Eden Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area.

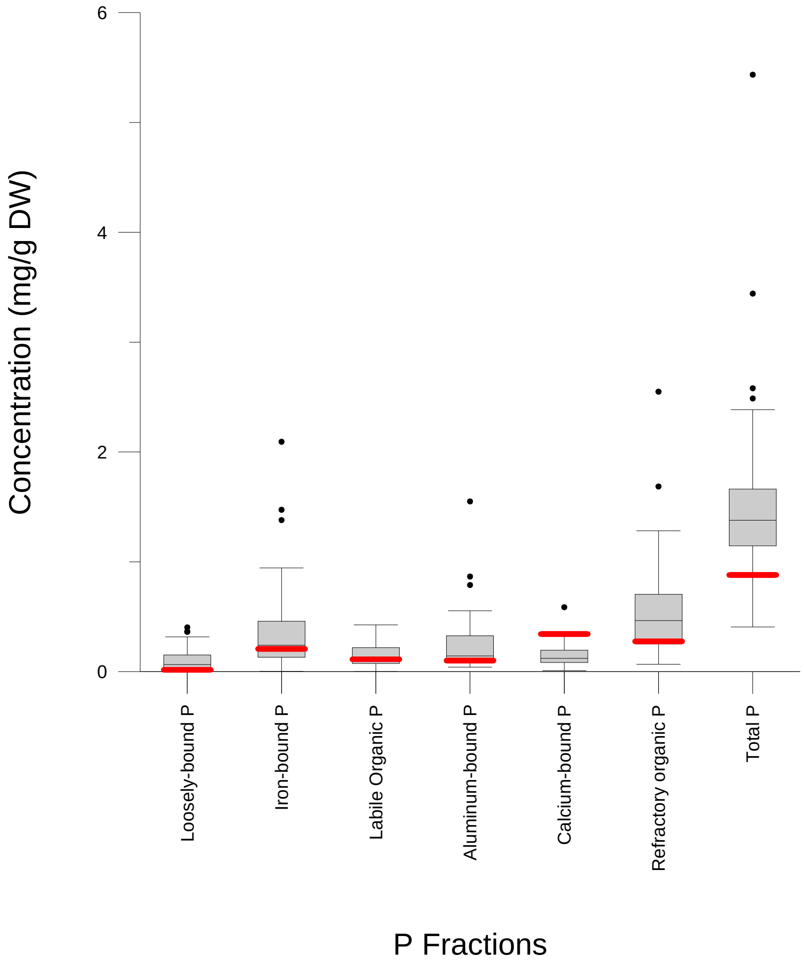

Figure 3. Box and whisker plots comparing various sediment phosphorus (P) fractions measured for Eden Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area. Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling) and aluminum-bound, calcium-bound, and refractory organic P are more are more inert to transformation (i.e., subject to burial). See Figure 2 for legend.

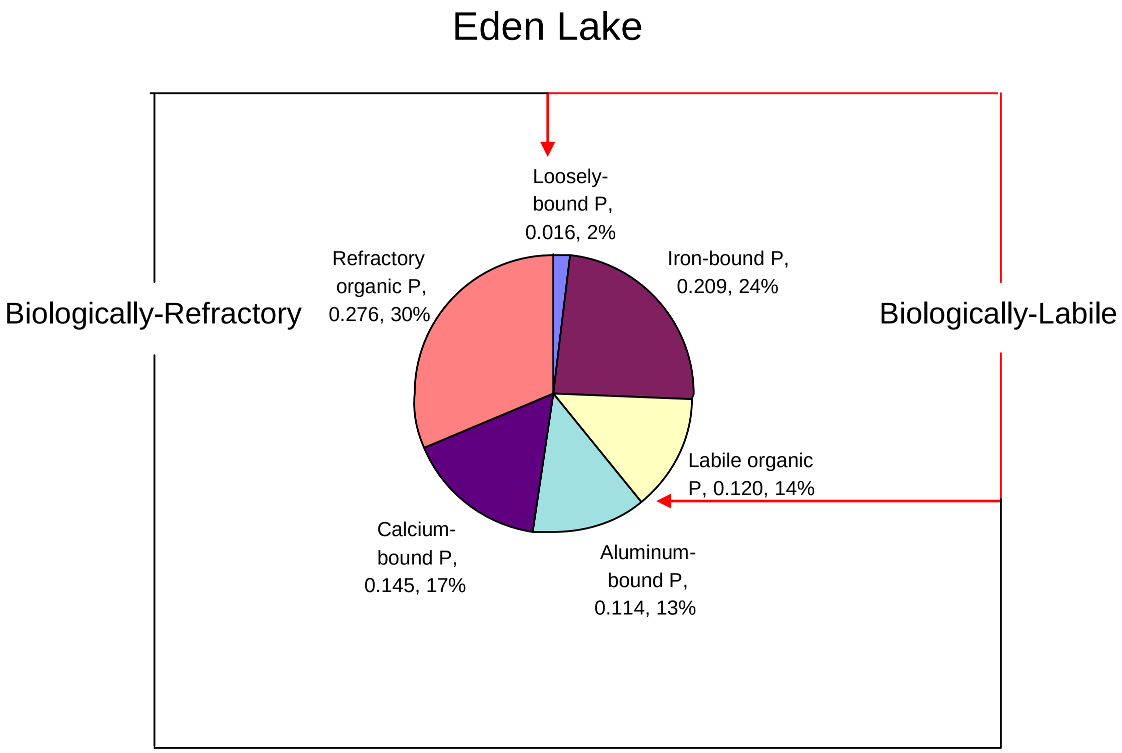

Figure 4. Total phosphorus (P) composition for sediment collected in Eden Lake. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration ($mg \cdot g^{-1}$) and percent total P, respectively.

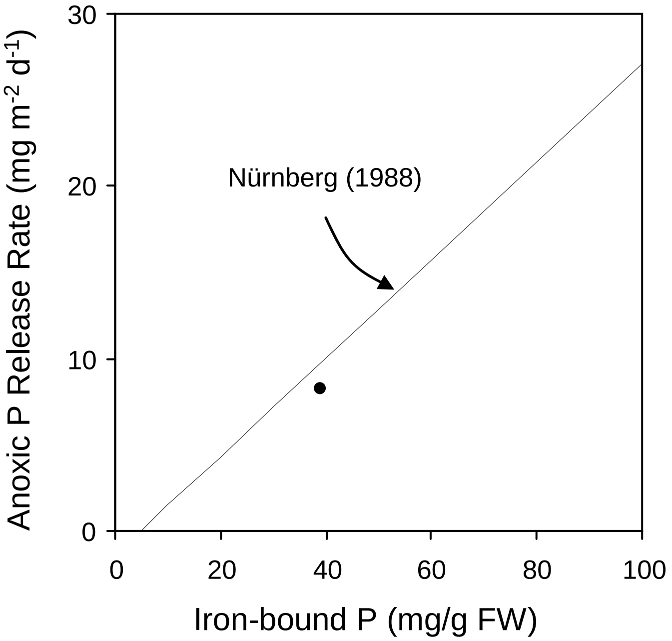

Figure 5. Regression relationships between iron-bound phosphorus (P; mg g^{-1} fresh sediment mass) and rates of P release from sediments under anoxic conditions developed by Nürnberg (1988). The black dot denotes Eden Lake sediment.

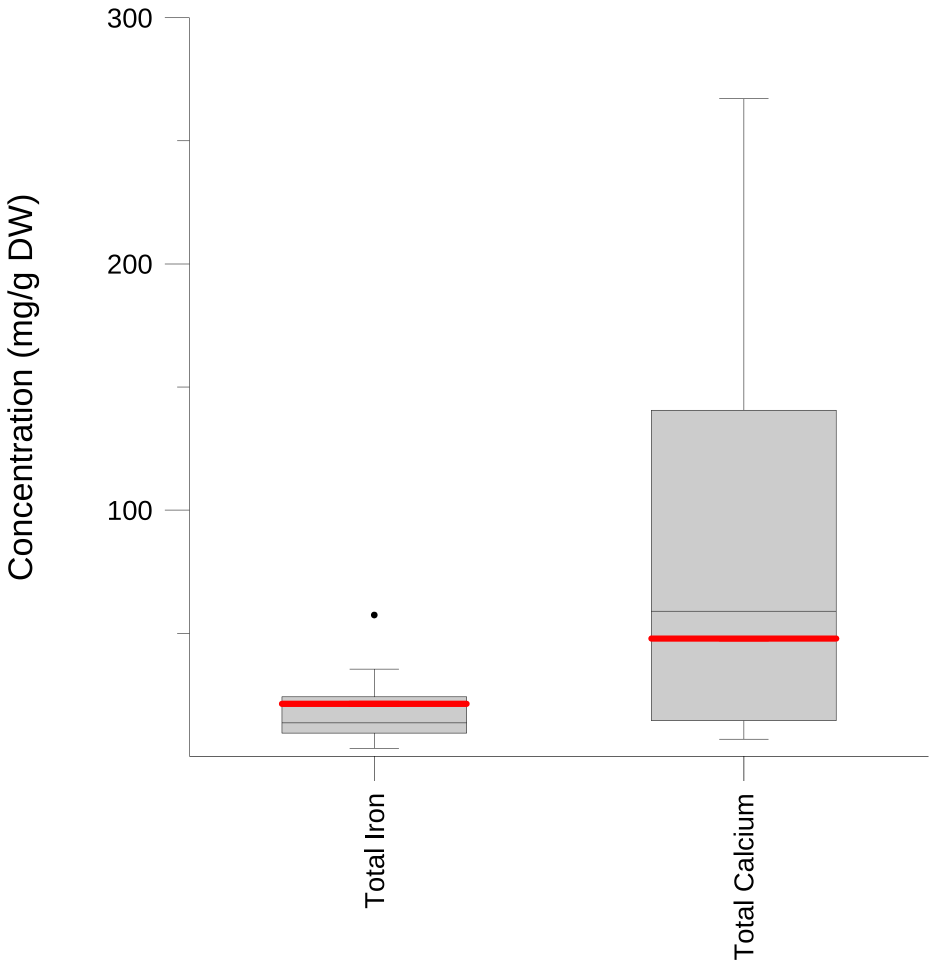

Figure 6. Box and whisker plots comparing sediment total iron and calcium concentrations measured for Eden Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area. See Figure 2 for legend.

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Neill Lake, Minnesota

01 February, 2012

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OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled anoxic (i.e., anaerobic) conditions and to quantify biologically-labile (i.e., subject to recycling) and refractory (i.e., biologically inert and subject to burial) P fractions for sediments collected in Neill Lake, Minnesota.

APPROACH

Laboratory-derived rates of P release from sediment under anoxic conditions: Replicate sediment cores were collected by Wenck Associates from stations located in the central basin of Neill Lake in October, 2011, for determination of rates of P release from sediment under anoxic conditions. All cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from the lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 to 25 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling nitrogen (anoxic) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment. Anoxic conditions were verified using a dissolved oxygen electrode.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment (mg m^{-2} d^{-1}) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: The upper 10 cm of an additional core collected from the lake was sectioned for analysis of moisture content (%), sediment density (g/mL), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P, total nitrogen (N), total iron (Fe), total manganese (Mn), and total calcium (Ca; all expressed at mg/g). A known volume of sediment was dried at 105 ^{o}C for determination of moisture content and sediment density and burned at 500 ^{o}C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total N, P, Fe, Mn and Ca using standard methods (Plumb 1980; APHA 2005).

Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that result in desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the loosely-bound and iron-bound P fractions are referred to as redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988; Gächter and Meyer 1993; Hupfer et al. 1995). The sum of redox-sensitive P and labile organic P are collectively referred to a biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound, calcium-bound, and refractory organic P fractions are more chemically inert and subject to burial rather than recycling.

RESULTS AND INTERPRETATION

Phosphorus mass and concentration increased linearly in the overlying water column of sediment systems maintained under anoxic conditions after ~ day 3 of incubation (Figure 1). Maximum concentrations of soluble reactive P approached or exceeded 0.5 $mg·L^{-1}$ near the end of the study. The mean anoxic P release rate was moderate at 3.5 (± 0.4 S.E.; n = 3) $mg·m^{-2}·d^{-1}$ and fell within the lower quartile compared to the median anoxic P release rate measured in other eutrophic systems in the Minneapolis-St. Paul regional area (Figure 2).

Profundal sediment in Neill Lake exhibited a high moisture content and low sediment density, indicating fine-grained, flocculent sediment (Table 1). Loss-on-ignition organic matter content was moderately high at ~32%. The total P concentration of the sediment was moderate at 1.07 $mg·g^{-1}$ (Table 2) and fell below the lower quartile when compared to other eutrophic lakes in the region (Figure 3).

The biologically-labile (i.e., subject to recycling back to the overlying water column; loosely-bound P, iron-bound P, and labile organic P) P concentration accounted for ~ 21% of the total sediment P (Figure 4; Table 2). Redox-sensitive P (i.e., active in anoxic

P release from the sediment; loosely-bound and iron-bound P) represented ~72% of the biologically-labile P and ~15% of the total P (Table 2). Iron-bound P dominated the biologically-labile P fraction at ~59%, but the concentration (0.132 mg g^{-1}) was relatively low compared to other lakes in the region (Figure 3). The concentration normalized with respect to fresh sediment mass (i.e., wet sediment mass that includes interstitial water) also fell within ranges reported for other eutrophic systems in North America (Figure 5; Nürnberg 1988). In contrast, loosely-bound P and labile organic P represented ~13 and 28% of the biologically-labile P, respectively.

Biologically-refractory P (i.e., more inert to recycling and subject to burial; aluminum-bound P, calcium-bound P, and refractory organic P) represented ~74% of the total sediment P (Figure 4; Table 2). Refractory organic P accounted for ~ 52% of the biologically-refractory P. Aluminum-bound P and calcium-bound P each accounted for ~16 and 32%, respectively, of the biologically-refractory P.

Neill Lake sediment exhibited a moderate total Fe concentration (Table 2) that was close to the median concentration for a variety of lake sediments in the region (Figure 6). Concentrations of sediment total Ca were moderate at 58.93 mg·g^{-1} (Table 2), relative to other lakes in the region (Figure 6). The sediment total Fe:P ratio was high at ~13 (Table 2). Ratios > 10 have been associated with regulation of P release from sediments under oxic conditions (Jensen et al. 1992).

REFERENCES

APHA (American Public Health Association). 2005. Standard Methods for the Examination of Water and Wastewater. 21th ed. American Public Health Association, American Water Works Association, Water Environment Federation.

Barko, J.W., and Smart, R.M. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. Ecology 67: 1328-1340.

Boström, B. 1984. Potential mobility of phosphorus in different types of lake sediments. Int. Revue. Ges. Hydrobiol. 69:457-474.

Gächter, R., Meyer, J.S., and Mares, A. 1988. Contribution of bacteria to release and fixation of phosphorus in lake sediments. Limnol. Oceanogr. 33:1542-1558.

Gächter, R., Meyer, J.S. 1993. The role of microorganisms in mobilization and fixation of phosphorus in sediments. Hydrobiologia 253:103-121.

Håkanson, L., and Jansson, M. 2002. Principles of lake sedimentology. The Blackburn Press, Caldwell, NJ USA.

Hjieltjes, A.H., and Lijklema, L. 1980. Fractionation of inorganic phosphorus in calcareous sediments. J. Environ. Qual. 8: 130-132.

Hupfer, M., Gächter, R., Giovanoli, R. 1995. Transformation of phosphorus species in settling seston and during early sediment diagenesis. Aquat. Sci. 57:305-324.

Jensen, H.S., Andersen, F.Ø. 1992. Importance of temperature, nitrate, and pH for phosphate release from aerobic sediment of four shallow, eutrophic lakes. Limnol. Oceanogr. 37:577-589.

Jensen, H.S., Kristensen, P., Jeppesen, E., and Skytthe, A. 1992. Iron:phosphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. Hydrobiol. 235/236:731-743.

Mortimer, C.H. 1971. Chemical exchanges between sediments and water in the Great Lakes – Speculations on probable regulatory mechanisms. Limnol. Oceanogr. 16:387-404.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant-soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45:453-462.

Plumb, R.H. 1981. Procedures for handling and chemical analysis of sediment and water samples. Technical Report EPA/CE-81-1. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Psenner, R., and Puckso, R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Biel. Erg. Limnol. 30:43-59.

Table 1. Textural characteristics for sediments collected in Neill Lake.

Station	Moisture Content (%)	Bulk Density (g/cm^3)	Sediment Density (g/cm^3)	Loss-on-ignition (%)
Central	80.7	1.087	0.217	32.2

Table 2. Mean (1 standard error in parentheses; n=3) rates of phosphorus (P) release, concentrations of biologically labile and refractory P, and metals concentrations for sediments collected in Neill Lake. DW = dry mass, FW = fresh mass, N = nitrogen, Fe = iron, Mn = manganese, Ca = calcium.

Station	Diffusive P flux	Redox-sensitive and biologically labile P				Refractory P		
	Anoxic ($mg\ m^{-2}\ d^{-1}$)	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (mg/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
Central	3.5 (0.4)	0.030	0.132	25	0.062	0.127	0.253	0.406

Station	Total P	Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Central	1.070	0.162	15.1%	0.224	20.9%	0.786	73.5%

Station	Total N	Total Fe	Total Mn	Total Ca	Fe:P
	(mg/g DW)	(mg/g DW)	(mg/g DW)	(mg/g DW)	
Central	14.600	13.53	0.57	58.93	12.6

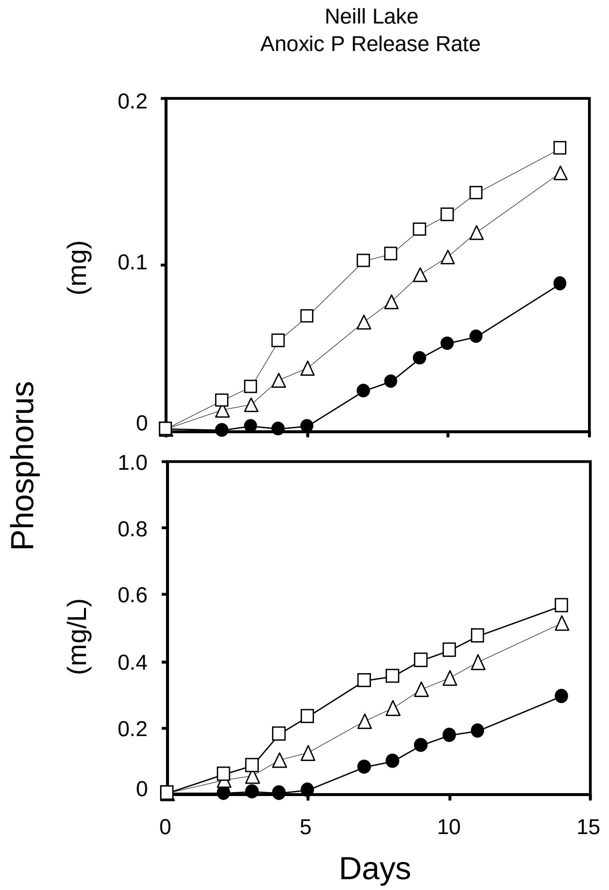

Figure 1. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panel) in the overlying water column under anoxic conditions versus time for sediment cores collected in Neill Lake.

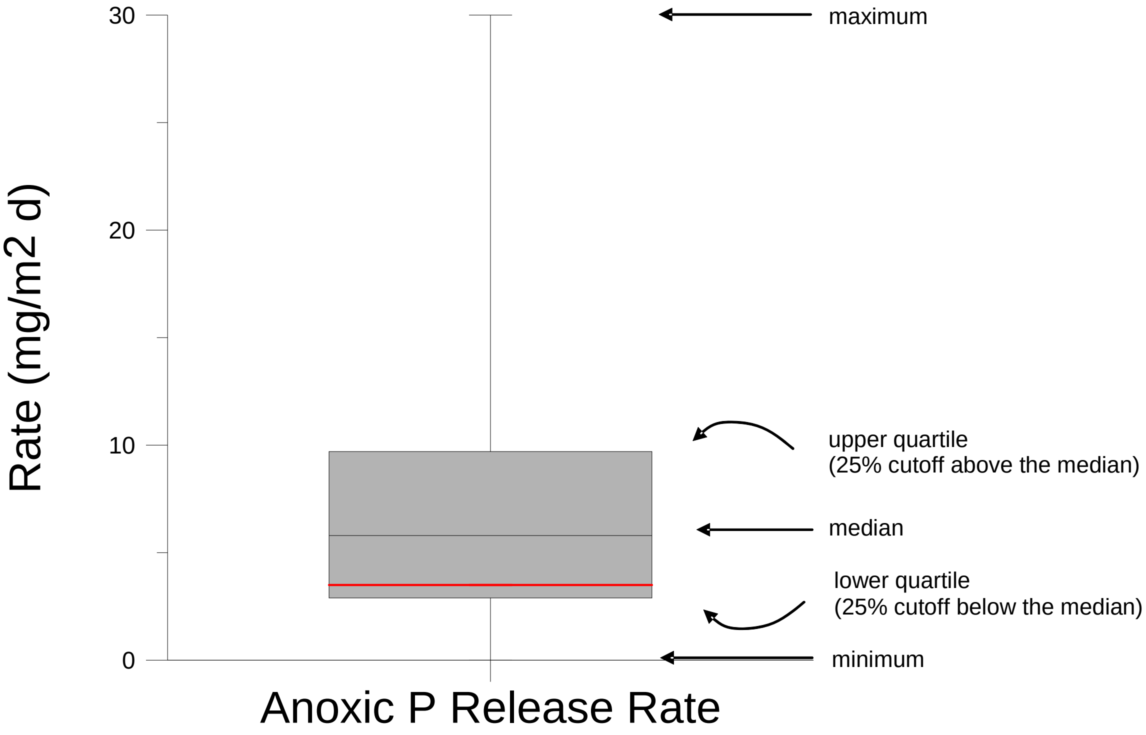

Figure 2. Box and whisker plot comparing the anoxic phosphorus (P) release rate measured for Neill Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area.

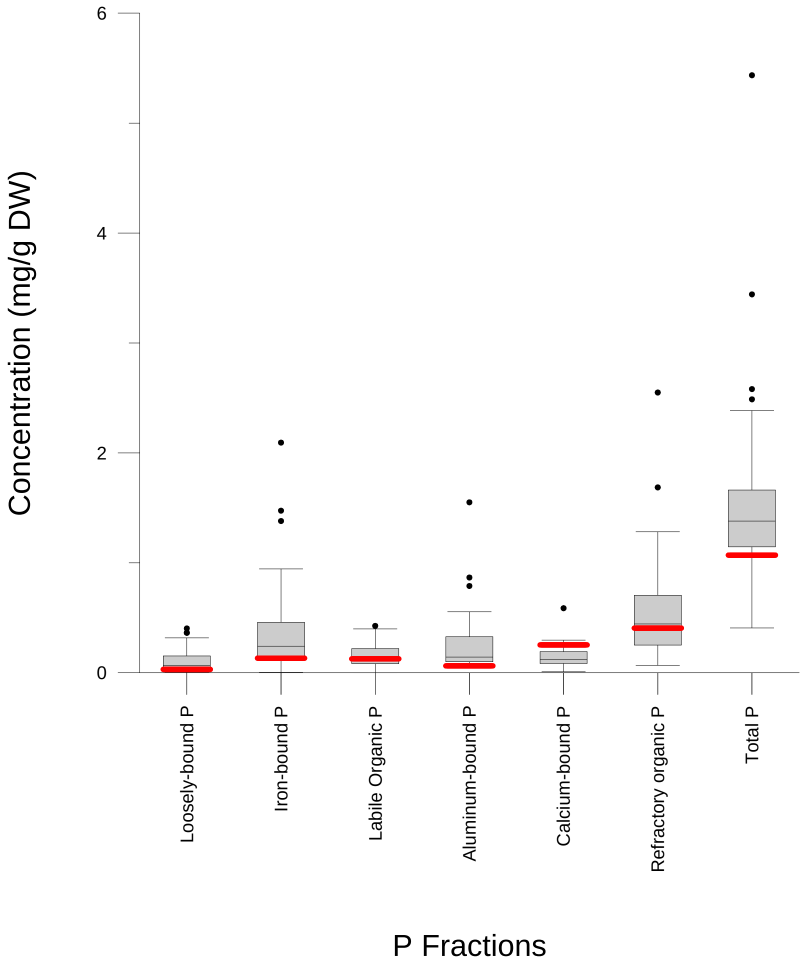

Figure 3. Box and whisker plots comparing various sediment phosphorus (P) fractions measured for Neill Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area. Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling) and aluminum-bound, calcium-bound, and refractory organic P are more are more inert to transformation (i.e., subject to burial). See Figure 2 for legend.

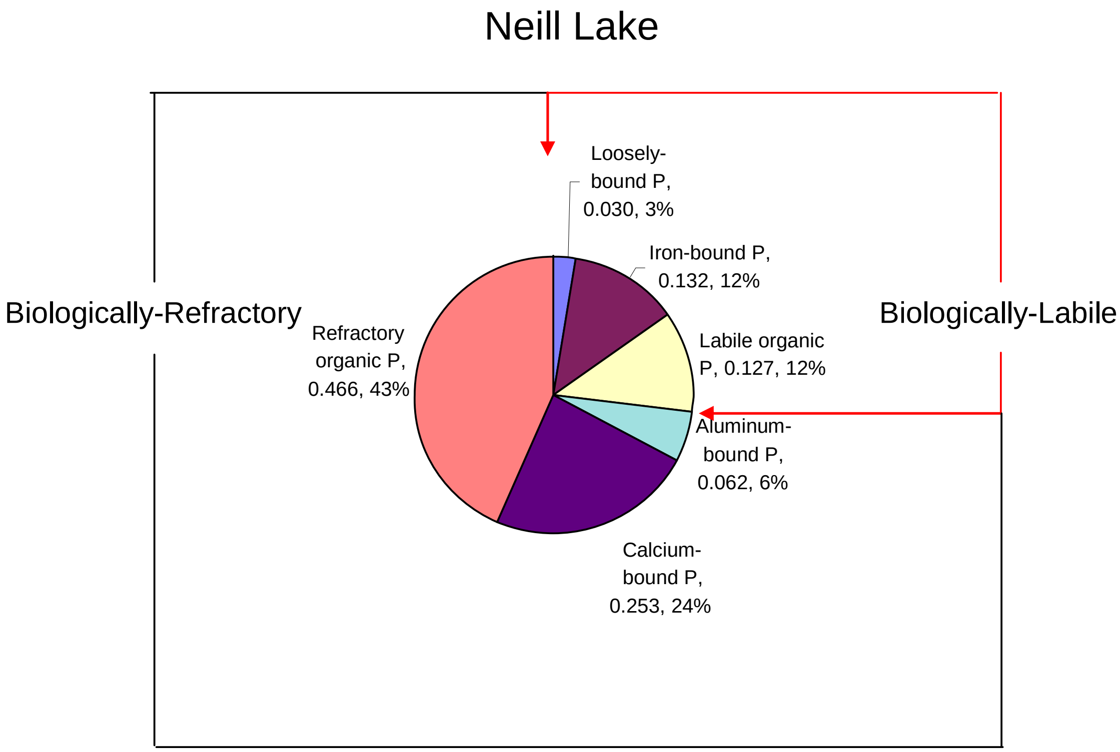

Figure 4. Total phosphorus (P) composition for sediment collected in Neill Lake. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration (mg·g^{-1}) and percent total P, respectively.

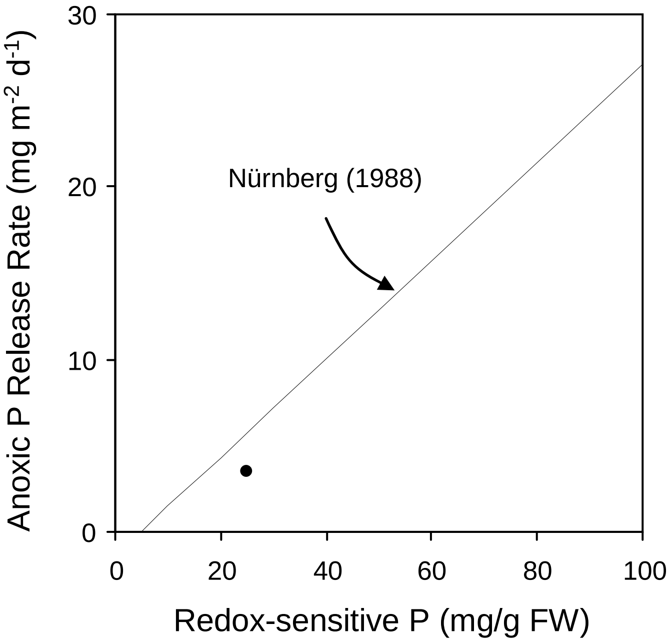

Figure 5. Regression relationships between iron-bound phosphorus (P; mg g^{-1} fresh sediment mass) and rates of P release from sediments under anoxic conditions developed by Nürnberg (1988). The black dot denotes Neill Lake sediment.

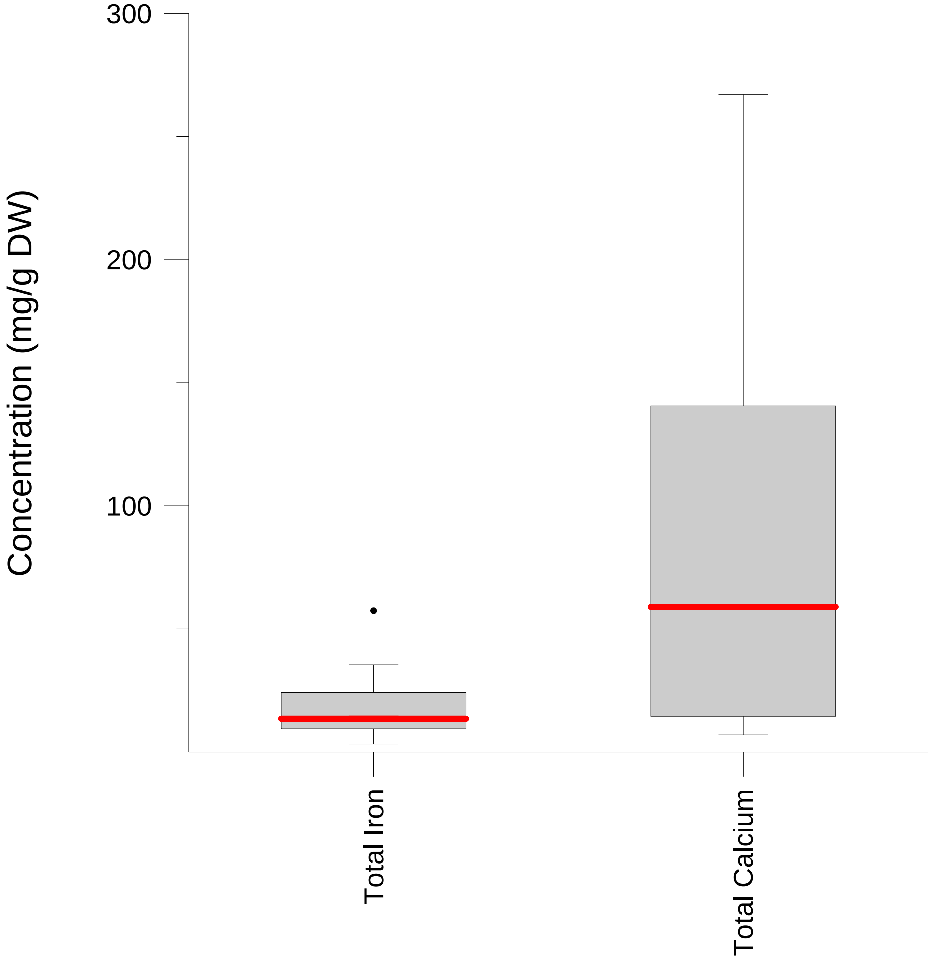

Figure 6. Box and whisker plots comparing sediment total iron and calcium concentrations measured for Neill Lake sediments (red line) with statistical ranges (n=40) for lakes in the Minneapolis-St. Paul area. See Figure 2 for legend.