# DRAFT FINAL REPORT

# Mill Creek (Otter Creek) Watershed Assessment

*November 22, 2002*

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From left to right, photographs of Mill Creek, Silver Lake, Magnolia Lake and Lake Caroline. Photographs taken by Aqua-Link in the Summer of 2002.

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# ***Acknowledgements***

The Mill Creek (Otter Creek) Watershed Assessment Project would not be possible without the financial support of the U.S. Environmental Protection Agency (U.S. EPA) and the Pennsylvania Department of Environmental Protection (PA DEP) through Section 319 (Nonpoint Source Pollution Program) of the Clean Water Act.

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# *Executive Summary*

Mill Creek is located in Lower Bucks County, Pennsylvania, and is a tributary to the Delaware River. This report describes the findings of a comprehensive lake and watershed assessment that was prepared by Aqua-Link, Inc. for the Bucks County Conservation District. Funding for this project was provided by the U.S. Environmental Protection Agency (U.S. EPA) and the Pennsylvania Department of Environmental Protection (PA DEP) through Section 319 (Nonpoint Source Program) of the Clean Water Act. As part of this assessment, a comprehensive lake and watershed management plan was developed to improve and further protect the water quality of streams and County-owned lakes within the Mill (Otter) Creek watershed.

The comprehensive lake and watershed management plan for this project was developed using watershed-specific data and information. Watershed data and information were compiled, analyzed and mapped using GIS (Geographical Information System) software. Stream and lake data were collected and analyzed. Both hydrologic and pollutant (nutrients and sediment) budgets were determined for the entire Mill Creek watershed. Water quality modeling was performed in order to predict phosphorus loading reductions that are needed to improve lake water quality. Watershed and stream corridor investigations were performed to identify major sources of nonpoint pollution to the study lakes and streams.

Based upon this assessment, Silver and Magnolia Lakes are classified as highly eutrophic or hyper-eutrophic. Therefore, both lakes contained very high amounts of nutrients and algae (phytoplankton), thereby resulting in very poor water clarity (transparency) throughout the entire study period. In addition, Magnolia Lake had very low dissolved oxygen levels, which are likely adversely affecting aquatic life including the lake's fishery, and Silver Lake is extremely shallow due to heavy siltation.

High levels of nutrients and sediments to the lakes are attributed to stormwater runoff from urban lands and streambank erosion and failure. The most significant nonpoint sources (NPS) of pollution to the lakes are Mill and Queen Anne's Creeks. Queen Anne's Creek is a major tributary to Mill Creek.

The comprehensive management plan offers a wide variety of in-lake restoration techniques, watershed best management practices (BMP's) and institutional practices to be implemented by vested watershed stakeholders. Recommended in-lake restoration techniques include the installation of an aeration system in Magnolia Lake, fish stockings in both Silver and Magnolia Lakes and sediment dredging for Silver Lake. Recommended watershed best management practices (BMP's) include stormwater retrofits, lake shoreline stabilization, streambank stabilization, stream channel reconstruction, establishing riparian buffers, parkland improvements at Magnolia Lake and floodplain

improvement projects along Black Ditch and Mill Creek. It was suggested that many of the recommended watershed BMP's first should be implemented in those priority subwatersheds that were determined as part of this assessment. Recommended institutional practices include stormwater management through stricter ordinances, riparian corridor protection, environmental education and baseline water quality monitoring of lakes and streams.

# 1. Introduction

Over the years, the water quality of Mill Creek (sometimes referred to as Otter Creek as describe below), its tributaries and three County-owned lakes has been severely degraded as a consequence of high loadings of nonpoint source (NPS) pollution. NPS pollution is primarily attributed to runoff from both urban and commercial land uses and previous land development activities. The above streams and lakes are considered extremely valuable natural resources for the residents of Bucks County and other surrounding counties.

The Mill Creek (Otter Creek) watershed is shown in Figure 1.1. Unfortunately, there is some confusion about the actually name of this watershed. The main tributary for this watershed is Mill Creek. The headwaters of Mill Creek begin in the northwestern portion of the watershed near Woodbourne and this stream generally flows southerly into Magnolia Lake (Figure 1.2). From Magnolia Lake, Mill Creek travels a very short distance and discharges into Silver Lake (Figure 1.3). The total distance of Mill Creek from its headwaters to Silver Lake is approximately 9 miles. From the lake's dam, the stream, now known as Otter Creek, flows only about 1mile into the Delaware River. Most local residents and state and county agency personnel refer to this watershed as the Mill Creek watershed. In light of the above, this watershed is referenced as the Mill Creek watershed throughout the remainder of this report.

Mill Creek is located in Lower Bucks County, Pennsylvania, and is a tributary to the Delaware River (Figure 1.1). This report describes the findings of a comprehensive lake and watershed assessment that was performed by Aqua-Link, Inc. for the Bucks County Conservation District. As part of this report, a comprehensive lake and watershed management plan was developed to improve and further protect the water quality of streams and County-owned lakes within the Mill Creek watershed.

The comprehensive lake and watershed management plan for this project was developed using watershed-specific data and information. Watershed data and information were compiled, analyzed and mapped using GIS (Geographical Information System) software. Stream and lake data were collected and analyzed. Hydrologic and pollutant (nutrients and sediment) budgets were determined for the entire Mill Creek watershed. Water quality modeling was performed in order to predict phosphorus loading reductions that are needed to improve lake water quality. Watershed and stream corridor investigations were performed to identify major sources of NPS pollution to the study lakes and streams.

The final product of the Mill Creek watershed assessment is this detailed report, which assesses the water quality of major streams and reservoirs throughout the watershed, identifies major NPS pollution to these waters and prioritizes the major subwatersheds on a NPS loading basis. Based

**Figure 1.1 Mill Creek Watershed**

**Figure 1.2 Photograph of Magnolia Lake**

**Figure 1.3 Photograph of Silver Lake**

upon the above, the final report contains a comprehensive lake and watershed management plan to reduce NPS pollution to streams and County-owned lakes and ultimately the Delaware River.

As part of this project, the District purchased a complete set of lake and stream monitoring equipment plus a NPS pollution watershed model. This equipment, the model and a lake and watershed curriculum, as developed by Aqua-Link, were turned over to Silver Lake Nature Center for integration into its existing environmental education program. Currently, volunteers of the Friends of Silver Lake organization are utilizing the above equipment to continue the stream monitoring program.

## 1.1. Project Funding and Administration

In May 1999, the Bucks County Conservation District (BCCD) applied for federal funding through the U.S. Environmental Protection Agency's (EPA) Section 319 (Nonpoint Source) Program to develop a comprehensive lake and watershed management plan for the Mill Creek watershed. The project was approved for funding by the Pennsylvania Department of Environmental Protection (PA DEP) in October 1999. The District served as the Project Sponsor, which in turn selected Aqua-Link, Inc. of Doylestown, Pennsylvania, to perform the watershed assessment.

## 1.2. Background Information

Mill Creek and its tributaries are entirely located within the lower portion of Bucks County, Pennsylvania (Figure 1.1). Mill Creek is classified as a Warm Water Fishery (WWF) under PA DEP's Chapter 93 Water Quality Standards. The lower Delaware River is listed on the PA DEP's 303(d) List of Impaired Waters.

The Mill Creek watershed is classified as a High Priority/Category I Watershed under PA DEP's Unified Watershed Assessment (HUC Code Number 02040201). In addition, Mill Creek lies within Subwatershed Area 2E, which is considered a degraded watershed under PA DEP's State Water Plan. The Mill Creek watershed consists of large tracts of urban, commercial and industrial lands, which are primarily intermixed with residential land uses.

The Mill Creek watershed contains three lakes (actually reservoirs), which are Silver Lake, Magnolia Lake and Lake Caroline. The three lakes are County-owned and maintained by the Bucks County Department of Parks and Recreation. These lakes serve as focal points for three different County-owned parks. The parks provide visitors with a wide-variety of outdoor recreational activities such as, fishing, nature walks and wildlife watching. In addition, the Silver Lake Nature Center, which is also part of the county park system, offers a variety of environmental education programs to the public for all ages. Lastly, many of the tributaries throughout the Mill

Creek watershed are an integral part of riparian parks owned and maintained by several different townships and the County.

Over the years, nonpoint source (NPS) pollution, namely sediments and nutrients, has degraded the water quality and aquatic habitats of both streams and lakes throughout the Mill Creek watershed. This fact has been recognized by the Pennsylvania Fish and Boat Commission (PA FBC), which in the recent past had only stocked Magnolia Lake with channel catfish. In general, channel catfish are considered a tolerant fish species with respect to pollution (i.e., lake eutrophication).

Due to heavy siltation, the Bucks County Department of Parks and Recreation (BCDPR) have dredged Silver Lake and Lake Caroline. In 1985, two-thirds of Silver Lake was dredged, while the remaining one-third was later dredged in 1994. The total cost of dredging Silver Lake to a water depth of 5 feet exceeded $600,000. Prior to the onset of dredging, Silver Lake only had an average water depth of 1½ feet. In 1995, a total of 29,000 cubic yards of sediment was dredged from Lake Caroline. The total cost of the Lake Caroline dredging project was nearly $750,000 (personal communication with Mr. James Burke, BCDPR, June 2000).

## 1.3. Past Studies and Investigations

Several other studies have recently been completed for the Mill Creek Watershed. As previously stated, the Mill Creek watershed is sometimes referred to as the “Otter Creek watershed”. These studies are briefly described below:

- *Otter Creek Watershed Stormwater Management and Flood Control Study* was performed by Pickering, Corts & Summerson, Inc. (PC&S, 2000) for the Bucks County Planning Commission. This study was funded in response to severe flooding that has occurred along Mill Creek and Queen Anne Creek, which is a tributary to Mill Creek. Hydrologic and hydraulic modeling was performed using computer software packages (HEC-1 and HydroCAD). The final report provided recommendations to alleviate or minimize the impacts of flooding using both constructed and institutional approaches.

- *Otter Creek Watershed Restoration & Protection Plan* was prepared by Borton Lawson Engineering (BLE 2002) for the Bucks County Planning Commission. This project was funded through PA DEP’s Growing Greener Grant Program. The plan summarizes existing characteristics of the Otter (Mill) Creek watershed and provides both structural and non-structural measures to primarily reduce flooding and to a lesser degree, improve water quality.

# 2. Lake and Watershed Characteristics

This section primarily discusses the physical characteristics of Silver and Magnolia Lakes and their surrounding watershed. The information provided below is frequently cited throughout the remainder of this report. Lake Caroline was not directly studied as part of this project due to funding constraints. Where appropriate, some limited information about this lake is provided below.

## 2.1. Lake Characteristics

Silver Lake and Lake Caroline are classified as reservoirs with dams constructed across Mill Creek and Queen Anne's Creek, respectively (Figure 1.1). Both lakes are considered elongated and narrow. Conversely, Magnolia Lake actually is classified a as reservoir, but does not contain a dam structure. In the 1970's, the site of this present lake was originally used as a soil borrow site for the construction of the nearby Pennsylvania Turnpike. Although uncertain, it appears that Mill Creek flowed just east of the lake and was separated by a levee. Shortly thereafter, the stream eventually breached the levee along the northeastern end of Magnolia Lake. Magnolia Lake is generally rectangular in geometry and contains a centrally located island.

In this report, the terms lake and reservoir are used interchangeable without any references to their actual origin or whether a water body contains a dam structure.

### *2.1.1. Lake Bathymetry and Morphological Characteristics*

Bathymetric surveys for Silver and Magnolia Lakes were performed on June 2, 2000. The surveys were conducted along established transects using a fathometer (Eagle Fish ID 128 sonar unit) to acquire water depth data and a GPS unit (Trimble Model Pro XR) to provide the locations where all water depth data were collected. Raw field data were analyzed using ESRI ArcView software (version 3.2a) with 3-D Analyst in order to determine lake water volumes, surface areas, mean water depths and maximum water depths. ArcView software also was used to generate bathymetric maps for the both study lakes. Aqua-Link determined the surface area of Lake Caroline using Maptech Terrain Navigator software (version 5.03).

The bathymetric maps of Silver and Magnolia Lakes are presented as Figures 2.1 and 2.2, respectively. The morphologic characteristics of the Silver and Magnolia Lakes are presented in Table 2.1. In this table, only the surface area of Lake Caroline is presented. It is anticipated that the maximum water depth of this lake is approximately 5 feet in depth (personal communication with Mr. James Burke, Bucks Co. Dept. of Parks and Recreation, May 2000).

**Figure 2.1 Bathmetric Map of Silver Lake**

**Figure 2.2  Bathymetric Map of Magnolia Lake**

**Table 2.1 Lake Morphologic Characteristics**

| Parameter | Silver Lake | Magnolia Lake | Lake Caroline* |
|---|---|---|---|
| **Lake Surface Area ($A_o$)** | 24.6 ac<br>(10.0 ha) | 26.0 ac<br>(10.5 ha) | 7.7 ac<br>(3.1 ha) |
| **Lake Volume** | $2.90 \times 10^6$ $ft^3$<br>($8.21 \times 10^4$ $m^3$) | $8.23 \times 10^6$ $ft^3$<br>($2.33 \times 10^5$ $m^3$) | -------- |
| **Mean Water Depth ($Z_{mean}$)** | 2.7 ft<br>(0.8 m) | 7.2 ft<br>(2.2 m) | -------- |
| **Max. Water Depth ($Z_{max}$)** | 5.6 ft<br>(1.7 m) | 15.9 ft<br>(4.8 m) | -------- |

* Limited data since this lake was not directly studied as part of this project

As shown, Silver and Magnolia Lakes are quite similar in surface area, while Lake Caroline is much small at 7.7 acres (3.1 hectares). Conversely, Magnolia Lake is considerably much deeper and therefore contains about 2.8 times more water than Silver Lake.

### 2.1.2. Lake Uses

Silver and Magnolia Lakes and Lake Caroline serve as the focal points for three different County-owned parks. All three lakes are used for aesthetics and to a lesser degree for fishing. Many people are often seen walking, walking their dogs, riding bicycles and jogging around Silver Lake and Lake Caroline. This is encouraged since both of these parks have improved trail systems around the lakes. Most of the recreational fishing generally is observed at Magnolia Lake and, to a lesser extent, at Silver Lake. Both boating and swimming are prohibited at all three lakes.

In addition, Magnolia Lake is used by motorized model boating enthusiasts. Aqua-Link has observed on several occasions persons on the shoreline maneuvering their model boats via remote control through an established course that was setup at the lake.

## 2.2. Watershed Characteristics

Specific data (hydrology, aerial photographs, topography, roadways, soils and land use) for the Mill Creek watershed were obtained from a variety of sources. These data were then analyzed using ArcView GIS (geographical information system) software (version 3.2a) and Spatial Analyst. For more information about all GIS data sets, refer to the metafile data files included as part of this report in Appendix A.

The Mill Creek watershed is approximately 19.7 square miles (12,583 acres) based upon the PA DEP Small Watersheds data file (Appendix A and Figure 2.3). The watershed encompasses eight different municipalities, which are Bristol Borough, Bristol Township, Falls Township, Langhorne Borough, Langhorne Manor Borough, Lower Makefield Township, Middletown Township and Penndel Borough as shown in Figure 1.1. Of these eight, three municipalities comprise 93 percent of the total watershed (Borton Lawson Engineering 2002): Bristol Township (40.6 percent), Middletown Township (38.4 percent), Falls Township (14.0 percent).

For the purposes of this assessment, the Mill (Otter) Creek watershed was subdivided into six major subwatersheds: Mill Creek Inlet (MCI), Queen Anne's Creek (QAC), Black Ditch (BD), Magnolia Lake (ML), Silver Lake (SL) and Delaware River (DR) as shown in Figure 2.3. The SL, ML and DR subwatersheds are not drained by any major streams and therefore are classified as direct drainage areas. These subwatersheds are referenced throughout the remainder of this report. In addition, the locations of the six stream and two lake monitoring stations are shown in Figure 2.3. Lake and stream data are presented in Sections 3 through 5 of this report.

### 2.2.1. Hydrology

Mill Creek is the main tributary within the Mill Creek watershed. The headwaters of Mill Creek begin in the northwestern portion of the watershed near Woodbourne and this stream generally flows southerly into Magnolia Lake (Figure 2.3). From Magnolia Lake, Mill Creek travels a very short distance and discharges into Silver Lake. The total distance of Mill Creek from its headwaters to Silver Lake is approximately 9 miles. From the lake's dam, the stream, now known as Otter Creek, flows only about 1mile into the Delaware River.

The Mill Creek has two major tributaries: Queen Anne's Creek and Black Ditch (Figure 2.3). The headwaters of Queen Anne's Creek are comprised of three different tributaries. These headwater streams are responsible for draining the northeast and north central portions of the watershed. Two of these tributaries begin in vicinity of Fairless Hills and eventually flow southwesterly into Lake Caroline. The discharge from Lake Caroline flows under Oxford Valley Road and is joined by its third tributary, which begins in Elmwood Terrace. At this point, the stream is now known as Queen Anne's Creek and flows into Mill Creek just south of the intersection of Newportville and Oxford Valley Roads. The headwaters of Black Ditch are located in Holly Hill. Black Ditch flows in a southwesterly direction through Levittown and eventually discharges into Mill Creek just north of Magnolia Lake.

As shown in Figure 2.3, Mill Creek at the point where it empties into Magnolia Lake consists of the Mill Creek Inlet, Queen Anne's Creek and Black Ditch subwatersheds. These three subwatersheds are discussed in detail in Section 6.0.

### 2.2.2. Topography

The topographic relief is described as fairly flat in the southern portion of the watershed and gently sloping in the central and northern portions. Elevations range from 0 feet at Mean Sea Level (MSL) near the confluence of Otter Creek and the Delaware River to $200^{+}$ feet in the northwestern section of the watershed (Figure 2.3).

### 2.2.3. Soils

A total of 49 different soil types are located throughout the Mill Creek watershed. Of this total, seventeen different soils types representing 87.5 of all soils are shown in Figure 2.4 (Appendix B). The most prevalent soils types are the Urban Land-Matapeake Complex (0 to 8 percent slopes), Urban Land (0 to 8 percent slopes) and Urban Land-Chester Complex (0 to 8 percent slopes) as noted in Table 2.2. These three soil types comprise 60 percent of all watershed soil types and are discussed below.

Urban land is highly built-up areas in Bucks County. Most urban land is on terraces of the uplands and the coastal plain, however, some is on the flood plain. The soils and foundation materials are highly variable. Urban structures and works cover so much of this land that identification of the soils is not practical. Most areas have been smoothed and the original soil material has been disturbed, filled over or otherwise destroyed prior to construction. Urban land is used for homes, shopping centers, schools, factories, roads, cemeteries, golf courses, railroads and other industrial facilities. The southern part of Bucks County has the highest concentration of urban land (U.S. Department of Agriculture, SCS 1975).

Urban Land-Matapeake Complex, 0 to 8 percent slopes, is composed of about 65 percent urban land, 25 percent Matapeake soil and similar inclusions and 10 percent contrasting inclusions. Urban Land is land covered by streets, parking lots, buildings and other structures that obscure the soils. Matapeake soils are yellowish brown silt loams underlain by gravelly loamy to coarse sands that are dark yellowish brown. Urban Land has rapid runoff rates due to highly impermeable surfaces and low levels of erosion. Matapeake soils are well drained with a seasonal high water table greater than 72 inches. Runoff from these soils is moderate and the potential for erosion is moderate. In those areas where slopes exceed 4 percent, the erosion potential is considered high (USDA 1996).

Urban Land-Chester Complex, 0 to 8 percent slopes, is composed of about 65 percent urban land, 25 percent Chester soil and similar inclusions and 10 percent contrasting inclusions. Urban Land is land covered by streets, parking lots, buildings and other structures that obscure the soils. Chester soils are brown to strong brown silt loams underlain by yellowish red silty clays and loams

**Figure 2.3 Topogrpahic Base Map of the Mill Creek Watershed**

**Table 2.2 Major Soil Types in the Mill Creek Watershed**

| Soil Type | Symbol | Percent |
|---|---|---|
| Urban land-matapeake complex, 0 to 8 percent slopes | Utb | 30.5 |
| Urban land, 0 to 8 percent slopes | Ufub | 14.6 |
| Urban land-chester complex, 0 to 8 percent slopes | Ukb | 14.6 |
| Hatboro silt loam | Ha | 5.7 |
| Othello silt loam | Ot | 2.9 |
| Udorthents, sandy | Ucb | 2.6 |
| Chester silt loam, 3 to 8 percent slopes | Cdb | 2.4 |
| Doylestown silt loam, 0 to 3 percent slopes | Dda | 2.1 |
| Alton gravelly loam, 0 to 3 percent slopes | Ala | 2.0 |
| Lawrenceville silt loam, 0 to 3 percent slopes | Lka | 1.5 |
| Delaware loam, 0 to 3 percent slopes | Daa | 1.4 |
| Glenville silt loam, 3 to 8 percent slopes | Grb | 1.4 |
| Urban land-doylestown complex, 0 to 8 percent slopes | Umb | 1.3 |
| Urban land-udorthents, sandy complex, 0 to 8 percent slopes | Uzbb | 1.2 |
| Udorthents, schist and gneiss | Ufb | 1.1 |
| Duncannon silt loam, 0 to 3 percent slopes | Dua | 1.0 |
| Udorthents, loamy | Ub | 1.0 |
| Others (remaining 32 soil types) | ------ | 12.5 |
| **Total** | **------** | **100.0** |

followed by reddish brown micaceous silt loam and loam. Urban Land has rapid runoff rates due to highly impermeable surfaces and low levels of erosion. Chester soils are well drained with a seasonal high water table greater than 72 inches. Runoff from these soils is medium and the potential for erosion is slight (USDA 1996).

In addition, Hatboro Silt Loam is the dominant soil type along intermittent and perennial streams throughout the watershed. It is composed of about 80 percent Hatboro soils and similar inclusions and 20 percent contrasting inclusions. Hatboro Silt Loam consists of dark grayish brown silt loam underlain by light brownish fray friable sandy clay loams and stratified friable sandy, clayey and gravelly sediments. The seasonal high water table is 0 to 10 inches. Runoff from these soils is slow and the potential for erosion is slight (USDA 1996).

**Figure 2.4 Soils in the Mill Creek Watershed**

### 2.2.4. Land Use

The Mill Creek watershed is highly urbanized as illustrated in Figure 2.5. Most of the commercial and industrial land uses occur in the northern and southern portions of the watershed in close proximity to the Route 1 Business and Route 13 corridors, respectively.

Urban land uses (low and high intensity residential plus commercial/industrial/transportation) account for nearly 67 percent of all land uses in the watershed (Table 2.3). Deciduous forested lands, which are second highest in acreage, only account for 16.9 percent of the total land use. Agricultural lands are very limited with only 6.5 and 0.7 percent occurring as hay/pasture and row crops, respectively.

**Table 2.3 Land Uses in the Mill Creek Watershed**

| Land Use | Area (acres) | Percent |
|---|---|---|
| Low Intensity Residential | 5,537.2 | 44.0 |
| Deciduous Forest | 2,126.6 | 16.9 |
| Commercial/Industrial/Transportation | 2,075.0 | 16.5 |
| Pasture/Hay | 811.7 | 6.5 |
| High Intensity Residential | 773.0 | 6.1 |
| Woody Wetlands | 377.0 | 3.0 |
| Mixed Forest | 267.7 | 2.1 |
| Transitional | 231.6 | 1.8 |
| Open Water | 145.7 | 1.2 |
| Evergreen Forest | 93.1 | 0.7 |
| Emergent Herbaceous Wetlands | 89.5 | 0.7 |
| Row Crops | 50.8 | 0.4 |
| Urban/Recreational Grasses | 4.4 | > 0.0 |
| **Total** | **12,583.1** | **100.0** |

Land use data for each of the six major subwatersheds (Figure 2.3) are presented in Table 2.4. The major subwatersheds of the Mill (Otter) Creek watershed are Mill Creek Inlet (MCI), Queen Anne's Creek (QAC), Black Ditch (BD), Magnolia Lake (ML), Silver Lake (SL) and Delaware River (DR). The subwatersheds ML, SL and DR are considered direct drainage to Magnolia Lake, Silver

Lake and the Delaware River, respectively. The term direct drainage implies at these subwatersheds do not contain any major tributaries; therefore runoff during storm events is conveyed primarily via overland flow.

**Table 2.4 Land Uses for Major Subwatersheds**

| Land Cover Type | Land Use per Subwatershed (ac) | | | | | |
|---|---|---|---|---|---|---|
| | MCI | QAC | BD | ML Direct | SL Direct | DR Direct |
| Commercial/Industrial/Transportation | 789.5 | 746.9 | 110.9 | 49.6 | 182.5 | 195.6 |
| Deciduous Forest | 971.4 | 860.8 | 130.9 | 40.0 | 109.4 | 13.9 |
| Emergent Herbaceous Wetlands | 30.1 | 17.6 | 3.0 | 2.4 | 25.3 | 11.0 |
| Evergreen Forest | 52.1 | 31.6 | 1.6 | 1.5 | 5.3 | 0.9 |
| High Intensity Residential | 271.6 | 298.4 | 202.4 | 0.6 | 0.0 | 0.0 |
| Low Intensity Residential | 2,335.7 | 1,639.6 | 1,133.1 | 107.1 | 249.2 | 72.6 |
| Mixed Forest | 140.1 | 82.6 | 19.5 | 3.4 | 20.8 | 1.3 |
| Open Water | 18.1 | 52.5 | 1.1 | 28.1 | 40.3 | 5.5 |
| Pasture/Hay | 355.4 | 288.0 | 100.3 | 18.3 | 31.8 | 18.0 |
| Row Crops | 33.8 | 14.8 | 2.2 | 0.0 | 0.0 | 0.0 |
| Transitional | 78.8 | 138.2 | 2.0 | 1.3 | 5.0 | 6.2 |
| Urban/Recreational Grasses | 1.9 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Woody Wetlands | 106.4 | 59.2 | 79.1 | 15.2 | 117.1 | 0.0 |
| **Total** | **5,184.9** | **4,232.7** | **1,786.1** | **267.4** | **786.9** | **325.1** |

### *2.2.5. Riparian Buffers*

The lack of adequate riparian, forested buffers in the Mill Creek watershed are shown in Figure 2.6. In this figure, yellow and red lines indicate one or both sides lacking sufficient forested buffers, respectively. Insufficient buffers, as defined by the Heritage Conservancy, are those riparian areas that lack trees within 50 feet from the top of the stream banks or have tree canopy cover less than 50 percent.

**Figure 2.5 Land Use in the Mill Creek Watershed**

**Figure 2.6 Riparian Forest Buffers in the Mill Creek Watershed**

# 3. Lake Assessments

## 3.1. Primer on Lake Ecology and Watershed Dynamics

A glossary of lake and watershed terms is provided in Appendix C (U.S. EPA 1980). This glossary is intended to serve as an aid to understanding this section and contains many of the technical terms used throughout the remainder of this report.

The water quality of a lake is often described as a "reflection" of its surrounding watershed. The term "lake" collectively refers to both reservoirs (man-made impoundments) and natural lake systems. Water from the surrounding watershed enters a lake as streamflow, surface runoff and groundwater. The water quality of these water sources is greatly influenced by the characteristics of the watershed such as, geology, soils, topography and land use. Of these characteristics, changes in land use (e.g., forested, agriculture, silviculture, residential, commercial, industrial) can significantly alter the water quality of lakes.

Nutrients (e.g., phosphorus, nitrogen, carbon, silicon, calcium, potassium, magnesium, sulfur, sodium, chloride, iron) are primarily transported to lakes via streamflow, surface runoff and groundwater, while sediments are mainly conveyed by streamflow and surface runoff. As streamflow and surface runoff enter a lake, their overall velocity decreases, which allow transported sediments to settle to the lake bottom. Many of these incoming nutrients may be bound to sediment particles and subsequently will also settle to the lake bottom. Very small sediment particles such as, clays, may resist sedimentation and subsequently pass through the lake without settling.

Once within the lake, water quality is further modified through a complex set of physical, chemical and biological processes. These processes are significantly affected by the lake's morphological characteristics (morphology). Some of the more important morphological characteristics of lakes are surface area, shape, depth, volume and bottom composition. In addition, the hydraulic residence time (i.e., the lake's flushing rate) also greatly affects these processes and is directly related to the lake's volume and the annual volume of water flowing into the lake.

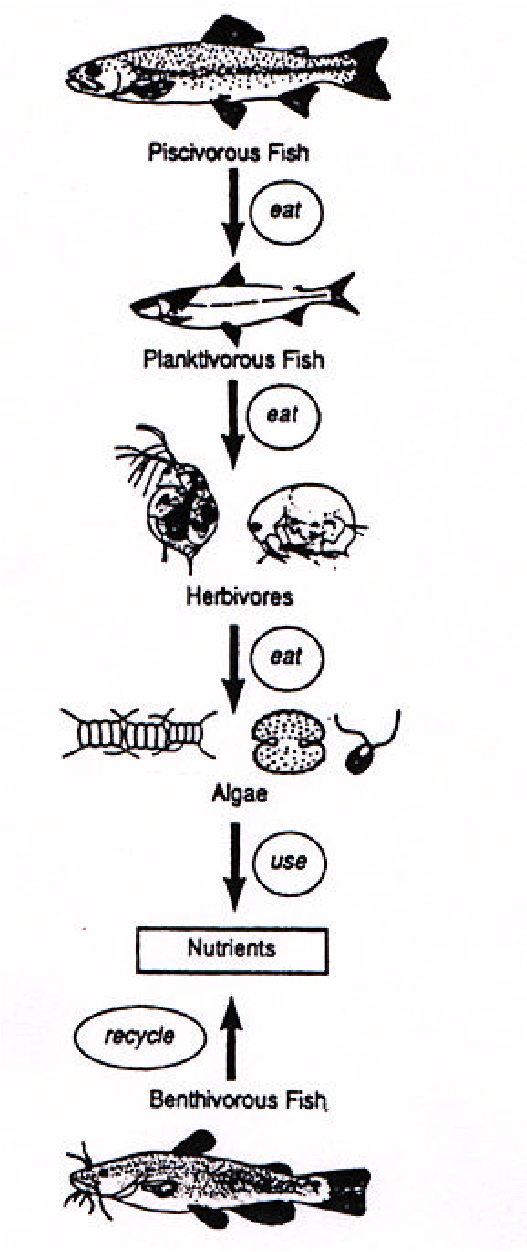
With respect to nutrients, phosphorus and nitrogen are generally considered the most important nutrients in freshwater lakes. Phosphorus and, to a lesser degree, nitrogen typically determine the overall amount of aquatic plants present. Aquatic plants adsorb and convert available nutrients into energy, which is then used for additional growth and reproduction. In lakes, aquatic plants are mainly comprised of phytoplankton (free-floating microscopic plants or algae) and macrophytes (higher vascular plants). The most readily available form of phosphorus is dissolved orthophosphate (analytical determined as dissolved reactive phosphorus), while ammonia ($NH_3$-N) and nitrate ($NO_3$-N) are the most readily available forms of nitrogen.

The transfer and flow of energy in lakes is ultimately controlled by complex interactions between various groups of aquatic organisms (both plants and animals). A simplistic diagram of these interactions among aquatic organisms is shown as Figure 3.1. In Figure 3.1, algae (phytoplankton) and aquatic macrophytes (plants) capture energy from the sun and convert this energy into chemical energy through the process known as photosynthesis. During photosynthesis, carbon dioxide, nutrients, water and captured sunlight energy are used to produce organic compounds (chemical energy), which are then used to support further growth and reproduction.

Energy continues to flow upward through the food chain. Algae are primarily grazed upon by zooplankton. Zooplankton are tiny aquatic animals that are barely visible to the naked eye. Next, zooplankton serve as prey for planktivorous (plankton-eating) fish and larger invertebrates (macroinvertebrates). In turn, plankitvores are consumed by piscivorous (fish-eating) fish. Overall, these aquatic organisms (zooplankton, macroinvertebrates and fish) derive energy by breaking down organic matter through the process known as respiration. During respiration, organic matter, water and dissolved oxygen are converted into carbon dioxide and nutrients.

At the bottom of the food chain (Figure 3.1), particulate organic waste products (excrement) from aquatic organisms along with dead aquatic organisms settle to the lake bottom and are subsequently feed upon by other organisms. Organisms that live or reside along the lake bottom are referred to as benthivores. After settling to the lake bottom, dead organic materials and organic waste products are now called detritus. Some benthivorous fish (catfish and carp) and microorganisms (bacteria, fungi and protozoans) feed upon detritus. Aquatic organisms that feed upon detritus in lakes are referred to as decomposers. Decomposers obtain energy by breaking down detritus (dead organic matter) via the process of respiration. During decomposition, some of the nutrients are recycled back into lake water and can now once again be used by algae and aquatic plants for growth and reproduction. Any unused detritus will accumulate and eventually become part of the lake sediments, thereby increasing the organic content of these sediments.

Ultimately, the amount of nutrients in lakes controls the overall degree of aquatic productivity (Figure 3.1). Lakes with low levels of nutrients and low levels of aquatic productivity are referred to as “oligotrophic”. Oligotrophic lakes are typically clear and deep with low quantities of phytoplankton and rooted aquatic plants. In these lakes, the deeper, colder waters are generally well-oxygenated and capable of supporting coldwater fish such as trout. Conversely, lakes with high nutrient levels and high levels of aquatic productivity are referred to as eutrophic. Eutrophic lakes are generally more turbid and shallower due to the deposition of sediments and the accumulation of detritus. If deep enough, the bottom waters of eutrophic lakes are generally less oxygenated or may be devoid of dissolved oxygen (anoxic). Eutrophic lakes are often capable of supporting warmwater fish such as bluegill and bass. Mesotrophic lakes lie somewhere in between oligotrophic and eutrophic lakes. These lakes contain moderate levels of nutrients and moderate levels of aquatic productivity. In some instances, the flow of energy through the food web may be disrupted. In



**Zooplankton plus others: macroinvertebrates (clams, snails & aquatic insects) & grazing minnows**

**Phytoplankton (def) : microscopic free-floating algae**

**Plus, microorganisms like bacteria, fungi & protozoans**

**Figure 3.1 Aquatic Food Chain**

hyper-eutrophic (highly eutrophic) lakes, aquatic productivity is extremely high and is dominated by very large numbers of a few, undesirable species. The phytoplankton community is typically comprised largely by blue-green algae during the summer months. Many species of blue-green algae are not readily grazed upon the zooplankton community. Under these conditions, the blue-green algae community is allowed to flourish due to the lack of predation, while the zooplankton community collapses. Decreases in zooplankton biomass in a lake may in turn adversely affect the lake's fishery. In addition, shallow lake areas may be completely infested with dense stands of aquatic macrophytes and dominated by common carp, catfish or other rough fish.

## 3.2. Study Design and Data Acquisition

The assessments of Silver and Magnolia Lakes consisted of the following major tasks: lake water quality monitoring and performing bathymetric surveys. The study design and how data were acquired for each of these tasks are described below.

For additional information, the approved *Quality Assurance – Quality Control Plan for the Mill Creek Watershed Assessment Project* dated May 28, 1999 (Aqua-Link, Inc. 1999) should be consulted. This document provides a thorough discussion of the study design along with the rationale behind the study design. In addition, this document provides specific information regarding the protocols used to collect field data and the analytical methods used by the contract laboratory.

### *3.2.1. Lake Water Quality Monitoring Program*

The lake water quality monitoring stations for this assessment were established at their deepest locations. The location of the lake monitoring stations, Stations SL1 and ML1 for Silver and Magnolia Lakes, respectively, are shown in Figure 2.3.

Lake Stations SL1 and ML1 were monitored once a month during the months of June, July, August and October 1999. All lake water quality samples were collected by boat, which is equipped with an outboard motor. On each study date, water samples for laboratory analysis were collected at a single depth of 1.0 meter below the lake's surface as recorded as SL1-S for Silver Lake and ML1-S for Magnolia Lake. All water samples were collected using a Kemmerer vertical sampler unit. Lake water collected in the vertical sampler was transferred directly into bottles supplied by the contract laboratory and preserved in the field accordingly. The contract laboratory, QC, Inc. of Southampton, Pennsylvania, analyzed all collected lake water samples for alkalinity, total phosphorus, dissolved reactive phosphorus (often referred to as soluble reactive phosphorus or orthophosphorus), total Kjeldahl nitrogen (TKN), ammonia, nitrate plus nitrite and total suspended solids. All samples for dissolved reactive phosphorus analysis were filtered in the field using a Nalgene filtration unit with 0.45 micron, 47 mm diameter filter paper.

The approved QA/QC plan was modified slightly to include limited deep water monitoring in Magnolia Lake. During the 1999 study period, the lake was thermally stratified, thereby indicating the potential release of phosphorus from anoxic in-lake sediments. To assess this phenomenon, water samples were collected 1.0 meter from the lake bottom at Station ML1 (recorded as ML1-B) once a month during the months of July, August and October 1999. Deep water samples (referred to as bottom samples) were analyzed for dissolved reactive phosphorus, total phosphorus and total suspended solids by the contract laboratory.

In addition, dissolved oxygen, temperature, pH, conductivity, specific conductance and transparency were monitored in the field on each study date. Dissolved oxygen, temperature, conductivity and specific conductance were measured in the field at 0.5 to 1.0 meter intervals throughout the water column using a YSI 600XL Sonde with a 610D data logger. Transparency was measured in the field using a 20 cm (8 inch diameter) freshwater Secchi disk, which was quartered black and white.

Lastly, lake samples for chlorophyll-a analysis and phytoplankton identification and enumeration also were collected on each study date. At Stations SL1 and ML1, three discrete water samples were collected throughout the photic zone of the lakes. The photic zone in this study was defined as a depth of twice the Secchi disk depth. Discrete samples were collected using the Kemmerer vertical water sampler unit at the upper, mid-point and lower end of the photic zone and then composited together for phytoplankton analysis. In addition, discrete water samples were collected at 1.0 meter below the surface of the lakes for the analysis of chlorophyll-a. Chlorophyll-a and phyotoplankton analyses were performed by QC, Inc. (Southampton, PA) and Dr. Kenneth Wagner (Northborough, Massachusetts), respectively.

### 3.2.2. Bathymetric Surveys

Bathymetric surveys for Silver and Magnolia Lakes were performed on June 2, 2000. The surveys were conducted along established transects using a fathometer (Eagle Fish ID 128 sonar unit) and a GPS unit (Trimble Model Pro XR). The bathymetric surveys were previously discussed at length in Section 2.1.1 of this report.

# 4. Lake Assessment Data and Results

The water quality data for Silver and Magnolia Lakes are presented and fully discussed in the following paragraphs. As noted in Section 3.2, Silver Lake is a shallow lake system, while Magnolia Lake is classified as moderately deep. One monitoring station was established at each of the study lakes and designated as SL1 and ML1 for Silver and Magnolia Lakes, respectively. Where indicated, water quality data are sometimes presented for different monitoring depths. Surface waters refer to sampling depth of 1.0 meter below the lake's surface (SL1-S and ML1-S) and bottom waters refer to a sampling depth of 1.0 meter above the lake's sediments (ML1-B).

For a complete listing of all data acquired and analyzed as part of this lake assessment, refer to Appendices D and E of this report. Refer to Section 3.2 for more information about the study design and data acquisition.

## 4.1. Lake Water Quality Data

### *4.1.1. Temperature and Dissolved Oxygen*

In late spring or the beginning of summer, many moderately deep to deep temperate lakes develop stratified layers of water. Under stratified conditions, warmer and colder waters are near the lake's surface (epilimnion) and the lake's bottom (hypolimnion), respectively. As the temperature differences become greater between these two water layers, the resistance to mixing increases. During lake stratification, the epilimnion is usually oxygen-rich due to photosynthesis and direct inputs from the atmosphere, while the hypolimnion may become depleted of oxygen due to the respiration of aquatic organisms. As previously discussed, aquatic organisms (e.g., bacteria, fungi, protozoans, zooplankton, macroinvertebrates, fish) consume dissolved oxygen in order to metabolize prey or detritus (U.S. EPA 1980, U.S. EPA 1990 and U.S. EPA 1993).

Conversely, shallow temperate lakes may only become weakly stratified during the summer months or some lakes may never stratify at all. The overall degree and duration of stratification in weakly stratified lakes are largely dependent upon local wind conditions and the morphological characteristics of the lake itself. During windy days, surface wave action may be sufficient to partially or completely destratify (mix) a lake. Conversely, a shallow lake may become partially stratified on windless days.

Overall, water temperatures and dissolved oxygen concentrations are very important with regards to a lake's fishery. In general, the optimal water temperature for salmonid fish (i.e., trout) is 55 to 60 °F (12.8 to 15.6 °C). Trout may withstand water temperatures above 80 °F (26.7 °C) for several hours, but if water temperatures exceed 75 °F (23.9 °C) for extended periods, high trout mortality is expected (Pennsylvania State University). Conversely, non-salmonid fish such as, golden shiners, bass, bluegills, can grow well even when water temperatures exceed 80 °F (26.7 °C). In general, safe minimum dissolved oxygen concentrations for adult salmonid and non-salmonid fish are 5.0 and 3.0 mg/L, respectively. When dissolved oxygen concentrations fall below these concentrations, production impairment of salmonid and non-salmonid fish can be expected.

In addition to impacting the lake's fishery, low dissolved oxygen levels in the bottom waters of a lake will often accelerate the release of nutrients such as, soluble orthophosphorus (analytically measured as dissolved reactive phosphorus) and ammonia nitrogen, from anoxic (oxygen depleted) in-lake sediments. In particular, the accelerated release rates of nutrients (referred to as internal loading) can represent a substantial portion of all incoming nutrients to a lake. Increased nutrient loadings via in-lake sediments may further degrade lake water quality by increasing the production of both phytoplankton and aquatic macrophytes (vascular plants).

### Silver Lake

Water temperature and dissolved oxygen profile data for Silver Lake are graphically presented in Figures 4.1 and 4.2, respectively. At Station SL1, the maximum water depth generally ranged from 1.1 to 1.4 meters (3.6 to 4.6 feet) throughout the study period, thereby indicating that Silver Lake is classified as a very shallow lake system.

At this station, water temperatures generally remained uniform throughout the water column during the entire study period (Figure 4.1). Uniform water temperatures indicate that the lake is shallow enough to remain thermally unstratified or destratified as a direct result from wind mixing. During the summer months, water temperatures frequently approached or exceeded 80° F. For example, lake water temperatures were 27° C (81° F) throughout the entire water column on June 29, 1999 (Figure 4.1).

Dissolved oxygen concentrations remained above 5.0 mg/l from 0.0 to 1.0 (0.0 to 3.28 feet) as shown in Figure 4.2. The lowest dissolved oxygen levels were observed on July 16th and August 18th near the sediments. For these study dates, the dissolved oxygen levels never fell below 1.0 mg/l.

Based on the above data, Silver Lake is classified as a shallow, polymictic lake. Polymictic lakes are defined as those lakes, which never truly stratify or sometimes weakly stratify with respect to water temperature. In contrast, dimictic lakes are defined as those lakes that turn over (completely mixing) twice annually and typically remain thermally stratified throughout the entire growing season. Overall, water temperature and dissolved oxygen data for the study period indicate that the lake is suited to support and maintain a warmwater (non-salmonid) fishery. The greatest constraint for this lake is its overall lack of available fish habitat in terms of water volume. Low to moderate dissolved oxygen levels at the lake water-sediment interface suggest that in-lake sediments

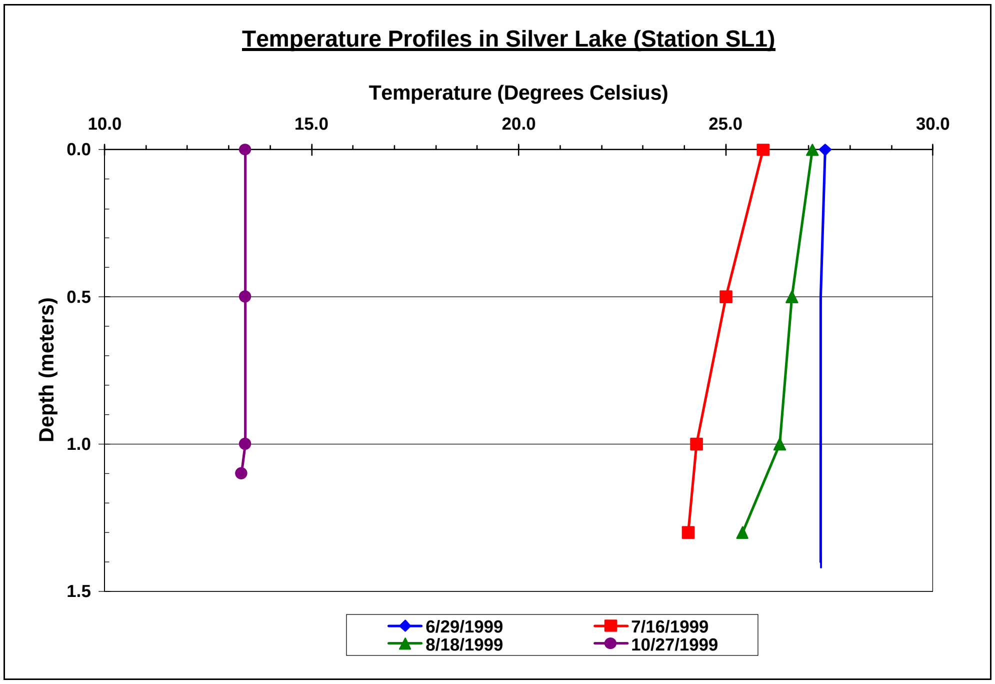


**Figure 4.1 Temperature Profiles in Silver Lake**

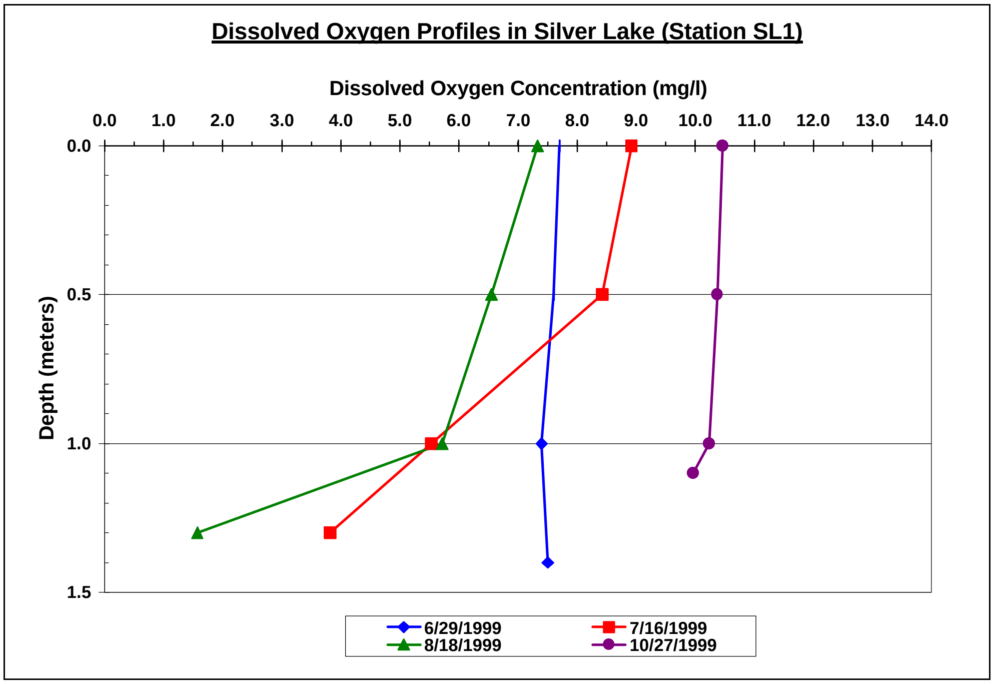


**Figure 4.2 Dissolved Oxygen Profiles in Silver Lake**

have low potential for promoting the internal release of nutrients, the buildup of hydrogen sulfide gas and the formation of toxic ammonium nitrogen. The release of soluble nutrients via sediments and the formation of hydrogen sulfide and ammonium nitrogen dramatically increase when dissolved oxygen levels in lake bottom waters are less than 1.0 mg/L.

### Magnolia Lake

Water temperature and dissolved oxygen profile data for Magnolia Lake are graphically presented in Figures 4.3 and 4.4, respectively. At Station ML1, the maximum water depth generally ranged from 4.0 to 4.4 meters (13.1 to 14.4 feet) throughout the study period, thereby indicating that Magnolia Lake is classified as a moderately deep lake system.

At this station, water temperatures were stratified during the months of June through August in 1999 (Figure 4.1). The greatest degree of thermal stratification occurred on June 29th where the surface and bottom water temperatures were 27.5° C (81.5° F) and 16.2° C (61.2° F), respectively. On October 27th, water temperatures were uniform throughout the water column due to wind mixing. Surface and bottom waters were 12.6° C (54.7° F) and 11.6° C (52.9° F), respectively (Figure 4.1).

Dissolved oxygen concentrations were strongly stratified when the lake was thermally stratified during the months of June through August (Figure 4.4). During this period, dissolved oxygen levels typically fell below 1.0 mg/l at water depths ranging from 2.0 to 4.4 meters (6.6 to 14.4 feet. In addition, dissolved oxygen concentrations fell below 3.0 mg/l at water depths ranging from 1.5 to 4.1 meters (4.9 to 13.4 feet), thereby indicating possible production impairment of non-salmonid fish.

Based on the above data, Magnolia Lake is classified as a moderately deep, dimictic lake. Dimictic lakes are those lakes that turn over (completely mixing) twice annually and typically remain thermally stratified throughout the entire growing season. Overall, water temperature and dissolved oxygen data for the study period indicate that the lake will likely result in production impairment of non-salmoid game fish species such as largemouth bass and bluegills. Very low dissolved oxygen levels at the lake water-sediment interface suggest that in-lake sediments have a high potential for promoting the internal release of nutrients, the buildup of hydrogen sulfide gas and the formation of toxic ammonium nitrogen. The release of soluble nutrients via sediments and the formation of hydrogen sulfide and ammonium nitrogen dramatically increase when dissolved oxygen levels in lake bottom waters are less than 1.0 mg/L.

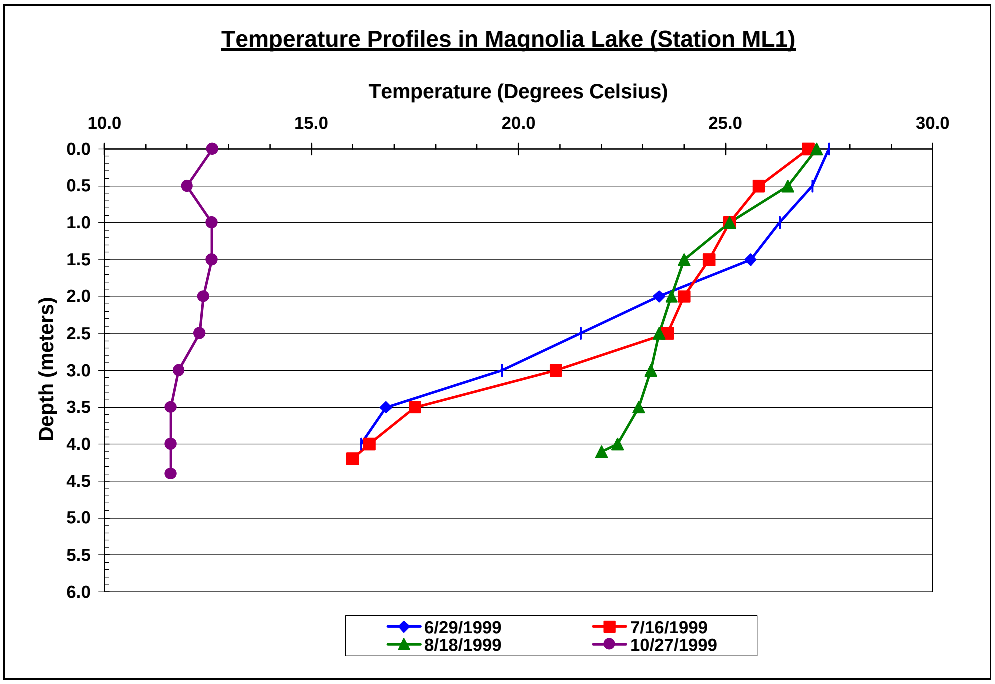


**Figure 4.3 Temperature Profiles in Magnolia Lake**

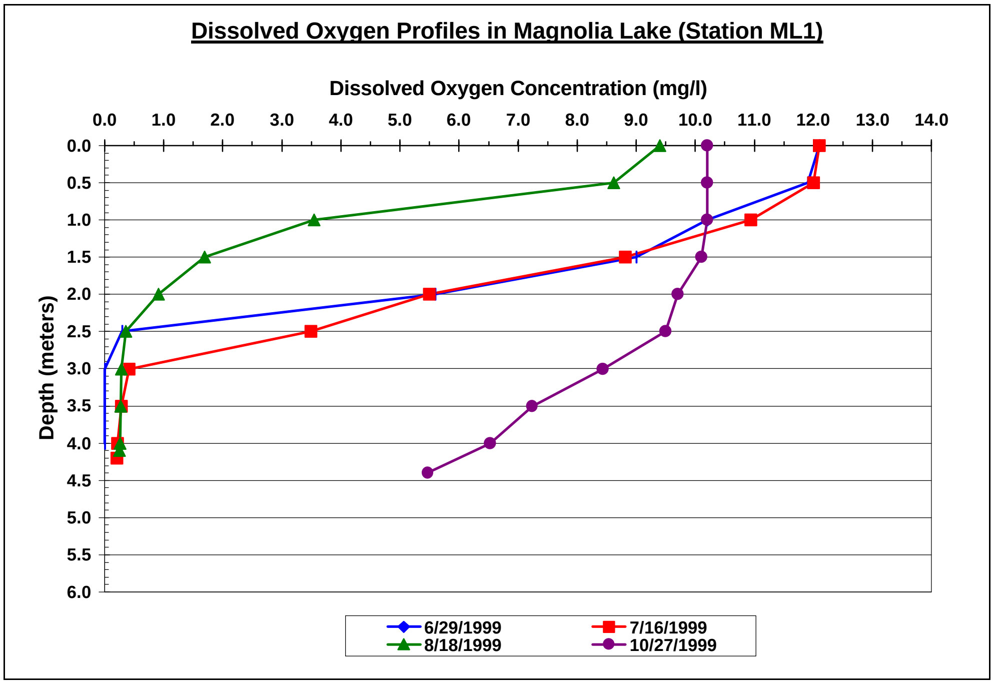


**Figure 4.4 Dissolved Oxygen Profiles in Magnolia Lake**

### 4.1.2. pH and Alkalinity

The pH and alkalinity of water are directly related to one another. In general, as alkalinity increases, the pH of the water also increases. The acidity or basicity of a solution is most often expressed as pH. The term pH is defined as the logarithm of the reciprocal (or its negative logarithm) of the hydrogen ion concentration. Therefore, a one unit change in pH represents a ten-fold increase or decrease in the hydrogen ion concentration (as pH decreases, the hydrogen ion concentration increases). The pH scale ranges 0 to 14 standard units where a value of 7 indicates neutral conditions. Water becomes more acidic when pH values fall below 7 and more basic when pH values rise above 7. In general, most natural waters usually have a pH values between 6.5 and 8.5.

Aquatic life in lakes can be adversely impacted when pH levels drop too low in lakes. When pH concentrations fall below 6.0 standard units, there is a greater risk to increase the concentration of heavy metals, in particular aluminum. High concentrations of hydrogen and aluminum ions are known to adversely affect the ion regulation of aquatic organisms, a condition referred to as "osmoregulatory failure". When osmoregulatory failure occurs, high hydrogen and aluminum concentrations induce the leaching of sodium and chloride ions from the body fluids of fish and other aquatic organisms (U.S. EPA, 1990). As summarized by J. Baker, pH values ranging from 5.5 to 6.0 standard units can result in the loss of sensitive minnows and dace, which may be important as forage fish for game fish. In addition, the above pH levels are also known to adversely affect the reproductive success rates of game fish, such as walleye (U.S. EPA, 1990).

Alkalinity refers to the capacity of water to neutralize acid inputs. Alkalinity of natural waters is due primarily to the presence of hydroxides, bicarbonates, carbonates and occasionally borates, silicates and phosphates. It is typically expressed in units of milligrams per liter (mg/l) of $CaCO_3$ (calcium carbonate). Waters having a pH below 4.5 contain no alkalinity. Low alkalinity is the main indicator of susceptibility of aquatic organisms to acidic inputs (e.g., acid rain and acidic dry fallout). Waters with pH values ranging from 6 to 9 are largely comprised of bicarbonate ($HCO_3^-$). At higher pH values, carbonate ($CO_3^{=}$) plays a more important role in the buffering capacity of the water. Lakes with watersheds that contain sedimentary carbonate rocks are high in dissolved carbonates (hard-water lakes). Conversely, lakes in granite or igneous rocks are low in dissolved carbonates (soft water lakes). In the Northeastern U.S., the alkalinity of natural surface waters typically ranges from 5 to over 200 mg/L as $CaCO_3$.

<u>Silver Lake</u>

The mean pH value in Silver Lake during the study period was 7.06 standard units as shown in Table 4.1. The highest pH value was observed during on July 16th when phytoplankton densities were at the highest. Therefore, this higher pH value on this date was likely due to increased levels of photosynthesis by phytoplankton (refer to Section 4.1.7). Overall, the pH values in Silver Lake indicate near neutral water conditions.

The mean alkalinity concentration in Silver Lake during the study period was 40.8 mg/l as $CaCO_3$ (Table 4.1). The mean alkalinity concentration is considered moderately low, but sufficient to regulate or maintain stable pH levels. Furthermore, the lake is not susceptible to acidic inputs such as, "acid rain", acidic runoff from snowmelt and acidic dry deposition. When acidic inputs are episodically high, it is expected that pH levels in the lake will remain stable, thereby protecting acid intolerant aquatic organisms.

**Table 4.1 Mean pH and Alkalinity Concentrations in the Study Lakes in 1999**

| Station | pH (standard units, s.u.) | Alkalinity (mg/l as $CaCO_3$) |
|---|---|---|
| Silver Lake (SL1-S) | 7.06 [6.71 – 7.37] | 40.8 [24.0 – 48.3] |
| Magnolia Lake (ML1-S) | 7.63 [6.81 – 8.26] | 42.5 [25.1 – 50.0] |
| Magnolia Lake (ML1-B) | 6.78 [6.38 – 7.16] | ---------- |

Note(s): Data presented as mean values along with ranges of values in brackets

### Magnolia Lake

The mean pH values in Magnolia Lake during the study period were 7.63 and 6.78 standard units for surface and bottom waters, respectively, as shown in Table 4.1. In general, surface pH values were higher than bottom water values due to increased levels of photosynthetic activity by phytoplankton. Overall, the pH values in Magnolia Lake indicate near neutral water conditions.

The mean alkalinity concentration for surface waters in Magnolia Lake during the study period was 42.5 mg/l as $CaCO_3$ (Table 4.1). Similar to Silver Lake, the mean alkalinity concentration is considered moderately low, but indicates that the lake has a sufficient capacity to regulate or maintain stable pH levels.

### *4.1.3. Specific Conductance*

Conductivity is a measure of the ability of water to conduct an electric current and is dependent on the number of dissolved ions in solution. Although directly correlated to the total amount of dissolved solids, conductivity provides no indication with regards to the relative quantities of the various types of dissolved solids present. Observed conductivities in lake waters vary widely and are largely a function of the geology and the soils in the watershed. Conductivity varies significantly with temperature and to a lesser extent with the nature of the individual ions present. Because temperature has a relatively large effect on conductivity, conductivity is typically corrected to 25°C and reported as specific conductance (in micro Siemens, $\mu$S/cm @ 25°C) to allow direct comparison of values that were measured at different temperatures.

Silver and Magnolia Lakes

The specific conductance values for Silver and Magnolia Lakes are presented in Table 4.2. Overall, these values in the lakes are considered high, thereby indicating the presence of large amounts of dissolved solids, which includes soluble forms of nutrients like phosphorus and nitrogen. The mean specific conductance values for the surface and bottom waters in Magnolia Lake (ML1-S and ML1-B) are quite similar, thereby indicating there is not a significant internal release of nutrients via anoxic in-lake sediments during thermal stratification.

**Table 4.2 Mean Specific Conductance Values in the Study Lakes in 1999**

| Station | Specific Conductance (ìS/cm) |
|---|---|
| Silver Lake (SL1-S) | 229 [130 – 285] |
| Magnolia Lake (ML1-S) | 240 [151 – 300] |
| Magnolia Lake (ML1-B) | 239 [141 – 331] |

Note(s): Data presented as mean values along with ranges of values in brackets

### *4.1.4. Total Suspended Solids*

The concentration of total suspended solids in a lake is a measure of the amount of particulate matter in the water column. Suspended solids include both organic matter including phytoplankton and inorganic materials like soil particles.

### Silver and Magnolia Lakes

The mean total suspended solids concentrations in Silver and Magnolia Lakes are presented in Table 4.3. These mean total suspended solids concentrations are considered high and attributed to high levels of phytoplankton biomass (Section 4.7.1) and high sediment loadings to the lakes via stormwater runoff.

**Table 4.3 Mean Total Suspended Solids Concentrations in the Study Lakes in 1999**

| Station | Total Suspended Solids (mg/l) |
|---|---|
| Silver Lake (SL1-S) | 16.0 [8.0 – 24.0] |
| Magnolia Lake (ML1-S) | 9.0 [1.0 – 13.0] |
| Magnolia Lake (ML1-B) | 10.3 [9.0 – 11.0] |

Note(s): Data presented as mean values along with ranges of values in brackets

## *4.1.5. Transparency*

The transparency, or clarity, of a lake is most often reported as the Secchi disk depth. This measurement is taken by lowering a circular black-and-white disk, which is 20 cm (8 inches) in diameter, into the water until it is no longer visible. Observed Secchi disk depths range from a few centimeters in very turbid lakes to over 40 meters in the clearest known lakes (Wetzel, 1975). Although somewhat simplistic and subjective, this field monitoring method probably best represents those lake conditions that are most often perceived by lake users and the general public.

Secchi disk transparency is related to the transmission of light in water, and depends on both the absorption and scattering of light. The absorption of light in dark-colored waters reduces light transmission. Light scattering is usually a more important factor than absorption in determining Secchi depths. Scattering can be caused by water color or by the presence of both particulate organic matter (e.g., algal cells) and inorganic materials (e.g., suspended clay particles).

In general, lakes are classified as oligotrophic and eutrophic when Secchi disk transparencies are greater than or equal to 3.0 to 5.0 meters, or less than or equal to 1.5 to 2.0 meters, respectively. Therefore, lakes are classified as mesotrophic when Secchi disk transparencies generally fall between those values that are reported above.

Silver and Magnolia Lakes

Secchi disk transparency values for Silver and Magnolia Lakes are presented in table 4.4. Based upon these mean values, both lakes are classified as either eutrophic (high levels of aquatic productivity) or hypereutrophic (extremely high levels of aquatic productivity) according to criteria established by U.S. EPA (1980) and Nurnberg (2001), respectively. Nurnberg classifies lakes as hypereutrophic when Secchi depth transparencies fall below 1.0 meter.

**Table 4.4 Mean Secchi Disk Values in the Study Lakes in 1999**

| Station | Secchi Disk Depth (meters) |
|---|---|
| Silver Lake (SL1) | 0.45 [0.38 – 0.60] |
| Magnolia Lake (ML1) | 0.69 [0.50 – 0.85] |

Note(s): Data presented as mean values along with ranges of values in brackets

## *4.1.6. Nutrient Concentrations*

Phosphorus and nitrogen are major nutrients required for the growth of phytoplankton (free floating, microscopic plants) and macrophytes (aquatic vascular plants) in lakes. The lake monitoring program for this study included the analysis of lake samples for both total and dissolved inorganic forms of both nutrients. The dissolved inorganic nutrients, namely dissolved reactive phosphorus, nitrate, and ammonia nitrogen, are regarded as the forms most readily available to support aquatic plant growth, while the total nutrient amounts provide an indication of the maximum growth potential that could be achieved in lakes.

### 4.1.6.1. Phosphorus

Total phosphorus represents the sum of all forms of phosphorus. Total phosphorus includes dissolved and particulate organic phosphates (e.g., algae and other aquatic organisms); inorganic particulate phosphorus as soil particles and other solids; polyphosphates from detergents and dissolved orthophosphates. Soluble (or dissolved) orthophosphate (determined analytically as “dissolved reactive phosphorus”) is the phosphorus form that is most readily available for algal uptake. Soluble orthophosphate is usually reported as dissolved reactive phosphorus because laboratory analysis takes place under acid conditions and may result in the hydrolysis of some other phosphorus forms. Total phosphorus levels are strongly affected by the daily phosphorus loadings to a lake, while soluble orthophosphate levels are largely affected by algal consumption during the growing season.

## Silver Lake

The total and dissolved reactive phosphorus concentrations measured in Silver Lake are presented in Table 4.5. Based on criteria established by the U.S. EPA (1980), a lake is classified as oligotrophic, when total phosphorus concentrations are less than or equal to 0.010 to 0.015 mg/l, and eutrophic, when total phosphorus concentrations are greater than or equal to 0.020 to 0.030 mg/l. According to Nurnberg (2001), lakes with total phosphorus concentrations between 0.031 and 0.100 mg/l are classified as eutrophic. Hypereutrophic lakes contain total phosphorus concentrations exceeding 0.100 mg/l. Based upon the above criteria, Silver Lake is classified as eutrophic.

Dissolved reactive phosphorus is reported as half the detection limit, which is 0.010 mg/l. Therefore, dissolved reactive phosphorus was not detected in Silver Lake, thereby indicating that this form of phosphorus is rapidly used by phytoplankton as soon as it becomes available.

**Table 4.5 Mean Phosphorus Concentrations in the Study Lakes in 1999**

| Station | Total Phosphorus (mg/l as P) | Dissolved Reactive Phosphorus (mg/l as P) |
|---|---|---|
| Silver Lake (SL1-S) | 0.085 [0.050 – 0.113] | 0.005 [0.005 – 0.005] |
| Magnolia Lake (ML1-S) | 0.065 [0.018 – 0.100] | 0.005 [0.005 – 0.005] |
| Magnolia Lake (ML1-B) | 0.093 [0.057 – 0.140] | 0.013 [0.005 – 0.030] |

Note(s): Data presented as mean values along with ranges of values in brackets

## Magnolia Lake

The total and dissolved reactive phosphorus concentrations for surface and bottom waters in Magnolia Lake are presented in Table 4.5. The total phosphorus concentrations for surface waters indicate that this lake is classified as eutrophic according the criteria. Higher total phosphorus concentrations in the bottom waters indicate the internal release of dissolved reactive phosphorus from anoxic in-lake sediments and the decay of organic matter such as, dead aquatic vegetation including phytoplankton, during periods of thermal stratification. This statement is substantiated by the fact that dissolved reactive phosphorus was only detected in the bottom waters at Station ML1.

Similar to Silver Lake, the dissolved reactive phosphorus concentrations for surface waters were not detected in Magnolia Lake.

### 4.1.6.2. Nitrogen

Nitrogen compounds are also important for the growth and reproduction of phytoplankton and aquatic macrophytes. The common inorganic forms of nitrogen in water are nitrate ($NO_3^-$), nitrite ($NO_2^-$) and ammonia ($NH_3$). The form of inorganic nitrogen present depends largely on dissolved oxygen concentrations. Nitrate is the form usually found in surface waters, while ammonia is only stable under anaerobic (low oxygen) conditions. Nitrite is an intermediate form of nitrogen, which is generally considered unstable. Nitrate and nitrite (referred to as total oxidized nitrogen) are often analyzed together and reported as $NO_3$ + $NO_2$-N, although nitrite concentrations are usually insignificant as noted previously. Total Kjeldahl nitrogen (TKN) concentrations include ammonia and organic nitrogen (both soluble and particulate forms). Organic nitrogen can be easily estimated by subtracting ammonia nitrogen from total Kjeldahl nitrogen concentrations. Total nitrogen is calculated by summing the nitrate-nitrite, ammonia and organic nitrogen fractions together.

<u>Silver Lake</u>

The total nitrogen, total Kjeldahl nitrogen, nitrate plus nitrite nitrogen and ammonia nitrogen concentrations in Silver Lake are presented in Table 4.7. With the exception of ammonia nitrogen, the mean concentrations for all forms of nitrogen are considered high and indicative of highly productive lake systems. According to Nurnberg (2001), lakes with total nitrogen concentrations between 0.65 to 1.20 mg/L are classified as eutrophic. Therefore, Silver Lake is classified as highly eutrophic based upon this criterion.

Total nitrogen is the sum of total Kjeldahl nitrogen (TKN), nitrate nitrogen and nitrite nitrogen. TKN is the sum of organic nitrogen and ammonia nitrogen. Therefore, it is surmised that most of the nitrogen in the lake consists of organic and nitrate nitrogen. This is because the ammonia concentrations were low and nitrite is generally very unstable in most freshwater systems.

<u>Magnolia Lake</u>

The total nitrogen, total Kjeldahl nitrogen, nitrate plus nitrite nitrogen and ammonia nitrogen concentrations in Magnolia Lake are presented in Table 4.7. Similar to Silver Lake, the mean concentrations for all forms of nitrogen except ammonia are considered high and indicative of highly productive lake systems. According to Nurnberg (2001), Magnolia Lake is classified as highly eutrophic.

**Table 4.6 Mean Nitrogen Concentrations in the Study Lakes in 1999**

| Station | Total Nitrogen (mg/l as N) | Total Kjeldahl Nitrogen (mg/l as N) | Nitrate + Nitrite (mg/l as N) | Ammonia (mg/l as N) |
|---|---|---|---|---|
| Silver Lake<br>(SL1-S) | 1.03<br>[0.80 – 1.59] | 0.68<br>[0.15 – 0.99] | 0.36<br>[0.05 – 0.72] | 0.045<br>[0.025 – 0.066] |
| Magnolia Lake<br>(ML1-S) | 1.02<br>[0.65 – 1.55] | 0.59<br>[0.15 – 0.84] | 0.43<br>[0.05 – 0.89] | 0.043<br>[0.025 – 0.066] |

Note(s): Data presented as a mean values along with a range of values in brackets

Once again, it is surmised that most of the nitrogen in the lake consists of organic and nitrate nitrogen. This is because the ammonia concentrations were low and nitrite is generally very unstable in most freshwater systems.

#### 4.1.6.3. Limiting Nutrient

Phytoplankton growth depends on a variety of nutrients. This includes macronutrients (phosphorus, nitrogen and carbon) as well as trace nutrients ( iron, manganese and many others). According to Liebig's law of the minimum, biological growth is limited by the substance that is present in the minimum quantity with respect to the needs of the organism. Nitrogen and phosphorus are usually the nutrients limiting algal growth in most natural waters.

Depending on the species, algae require approximately 15 to 26 atoms of nitrogen for every atom of phosphorus. This ratio converts to 7 to 12 mg of nitrogen per 1 mg of phosphorus on a mass basis. A ratio of total nitrogen to total phosphorus of 15:1 is generally regarded as the dividing point between nitrogen and phosphorus limitation (U.S. EPA, 1980). Identification of the limiting nutrient becomes more certain as the total nitrogen to total phosphorus ratio moves farther away from the dividing point, with ratios of 10:1 or less providing a strong indication of nitrogen limitation and ratios of 20:1 or more strongly indicating phosphorus limitation.

In many instances, inorganic nutrient concentrations provide a better indication of the limiting nutrient because the inorganic nutrients are the forms directly available for algal growth. Ratios of total inorganic nitrogen (TIN = ammonia, nitrate, and nitrite) to dissolved reactive phosphorus (DRP) greater than 12 are indicative of phosphorus limitation, ratios of TIN:DRP less than 8 are indicative of nitrogen limitation, and TIN:DRP ratios between 8 and 12 indicate either nutrient can be limiting.

### Silver and Magnolia Lakes

The total phosphorus to total nitrogen (TN:TP) and the total inorganic nitrogen to dissolved reactive phosphorus (TIN:DRP) ratios for Silver and Magnolia Lakes are presented in Table 4.7. The TN:TP ratios indicate that Magnolia Lake is more phosphorus limiting than Silver Lake although both lakes indicate some tendency for nitrogen limitation. Conversely, the TIN:DRP ratios strongly suggest that phosphorus is limiting in both of the study lakes.

**Table 4.7 Mean Nitrogen to Phosphorus Ratios in the Study Lakes in 1999**

| Station | Nitrogen to Phosphorus Ratios | |
|---|---|---|
| | TN:TP | TIN:DRP |
| Silver Lake (SL1-S) | 12.7<br>[7.6 – 16.0] | 79.9<br>[15.0 – 157.2] |
| Magnolia Lake (ML1-S) | 19.7<br>[10.2 – 36.1] | 93.5<br>[15.0 – 191.2] |

Note(s): Data presented as a mean values along with a range of values in brackets

## 4.1.7. Plankton and Chlorophyll-a

The quantity of phytoplankton (free floating, microscopic aquatic plants commonly referred to as “algae”) and macrophytes (vascular aquatic plants) are primary biological indicators of lake trophic conditions. Small aquatic animals, namely zooplankton and macroinvertebrates, graze upon algae and fragments of aquatic plants. Larger invertebrates and fish then consume the above grazers and to a lesser extent, some aquatic plants.

Information about the plankton community composition and succession is extremely useful when attempting to gain a better understanding about various lake problems. For example, eutrophic lakes often support unbalanced phytoplankton communities characterized by very large numbers of relatively few species. The number of larger zooplankton will tend to decrease during periods when blue-green algae are dominant. Conversely, oligotrophic lakes and acidic lakes often have small populations of both phytoplankton and zooplankton, which typically consist of only a few different species.

### 4.1.7.1. Phytoplankton

Phytoplankton are free floating, microscopic aquatic plants that have little or no resistance to currents and live suspended in open water. Their forms may be unicellular, colonial or filamentous. As photosynthetic organisms (primary producers), phytoplankton form the base of aquatic food chain and are grazed upon by zooplankton and herbivorous fish.

A healthy lake should support a diverse assemblage of phytoplankton, in which many algal species are represented. Excessive growth of a few species is usually undesirable. Such growth can result in dissolved oxygen depletion during the night, when the algae are respiring rather than photosynthesizing. Dissolved oxygen depletion also can occur shortly after a massive "algal bloom" due to increased levels of respiration by bacteria and other microorganisms that are metabolizing dead algal cells. Excessive growth of some species of algae, particularly members of the blue-green group, may cause taste and odor problems, release toxic substances to the water, or give the water an unattractive green soupy or scummy appearance.

Planktonic productivity is commonly expressed in terms of density and biomass. Phytoplankton densities are most frequently expressed as cells per milliliter (cells/ml). Biomass is commonly expressed on a mass per volume basis as micrograms per liter (ìg/l). Of the two, biomass provides a better estimate of the actual standing crop of phytoplankton in lake systems.

<u>Silver Lake</u>

The phytoplankton biomass in Silver and Magnolia Lakes are shown in Figures 4.5 and 4.6. Overall, the phytoplankton community of Silver Lake was represented by genera from seven different taxa: Bacillariophyta (diatoms), Chlorophyta (green algae), Chrysophyta (golden-brown algae), Cryptophyta (cryptomonads), Cyanophyta (blue-green algae), Euglenophyta (euglenoids) and Pyrrhophyta (red-brown dinoflagellates). As shown in Figure 4.5, phytoplankton biomass ranged from 3,818 to 10,609 ug/l during the study period. The highest and lowest biomass levels were observed in June and August, respectively.

In June, the phytoplankton assemblage was rather diverse and consisted of numerous genera represented by the following taxa: Chlorophytes, Bacillariophytes, Euglenophytes and Cyanophytes as shown in Figure 4.5. By July, Cyanophytes were the dominant taxon and largely represented by the genus *Anabaena* followed by *Oscillatoria* and *Aphanizomenon*. Cryptophytes and Euglenophytes were most prevalent in August. The most dominant species were *Cryptomonas* (Cryptophyte) and *Euglena* and *Trachelomonas* (Euglenophytes). In October, the phytoplankton community became somewhat more diversified and largely represented by the Cryptophytes and to lesser extent by the Chrysophytes and the Euglenophytes. The most dominant genera were *Cryptomonas* (Cryptophyte), *Dinobryon* (Chrysophyte) and *Trachelomonas* (Euglenophytes).

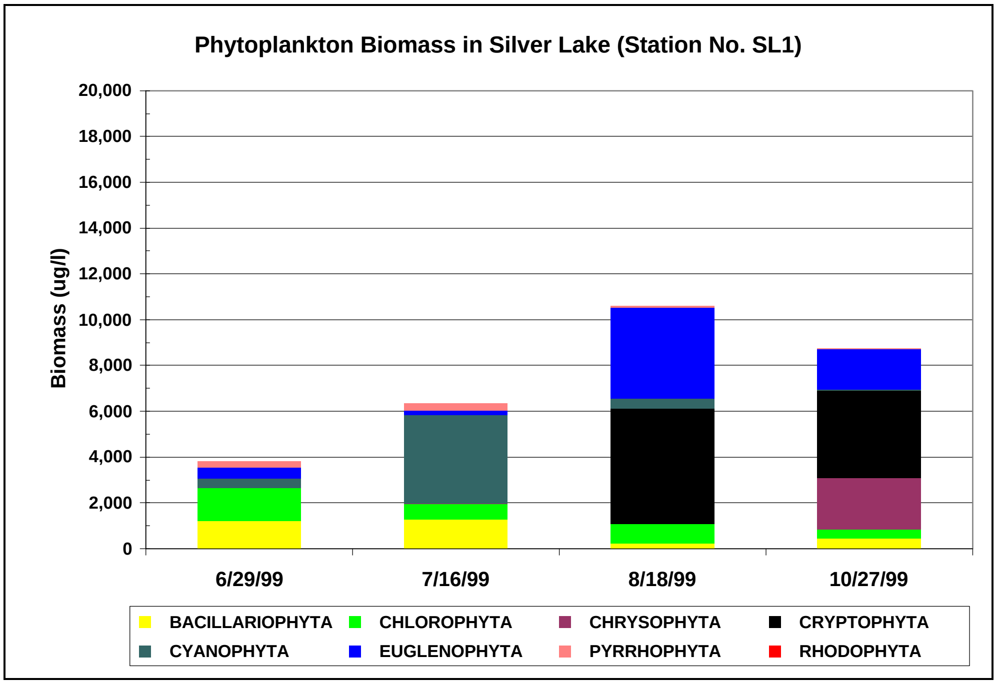


**Figure 4.5 Phytoplankton Biomass in Silver Lake**

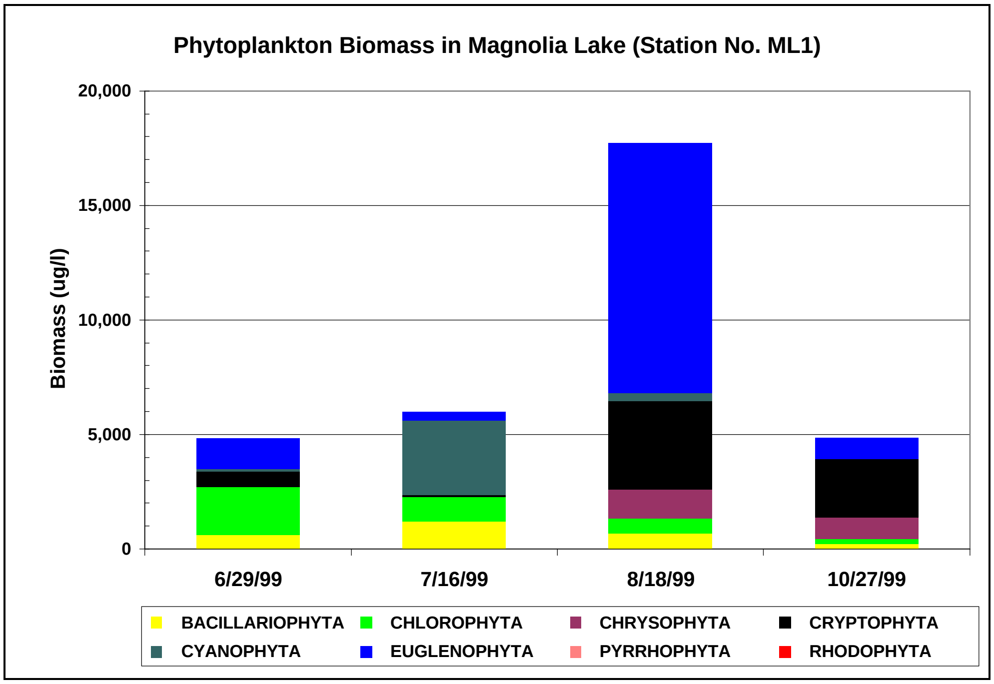


**Figure 4.6 Phytoplankton Biomass in Magnolia Lake**

### Magnolia Lake

Overall, the phytoplankton community of Magnolia Lake was represented by genera from seven different taxa: Bacillariophyta (diatoms), Chlorophyta (green algae), Chrysophyta (golden-brown algae), Cryptophyta (cryptomonads), Cyanophyta (blue-green algae), Euglenophyta (euglenoids) and Pyrrhophyta (red-brown dinoflagellates). As shown in Figure 4.6, phytoplankton biomass ranged from 4,821 to 17,728 ug/l during the study period. The highest and lowest biomass levels were observed in June and August, respectively.

In general, the phytoplankton communities of Magnolia and Silver Lakes were quite similar. In Magnolia Lake, the phytoplankton assemblage for June was rather diverse and consisted of numerous genera of the following taxa: Chlorophytes, Euglenophytes, Cryptophytes and Bacillariophytes as shown in Figure 4.6. By July, Cyanophytes were the dominant taxon and largely represented by the *Aphanizomenon* and *Anabaena*. Euglenophytes and Cryptophytes were most prevalent in August. The most dominant genera were *Trachelomonas* (Euglenophyte) and *Cryptomonas* (Cryptophyte). In October, the Cryptophytes become most dominant followed by the Chrysophytes and the Euglenophytes. The most dominant genera were *Cryptomonas* (Cryptophyte), *Dinobryon* (Chrysophyte) and *Trachelomonas* (Euglenophytes).

### Silver and Magnolia Lakes

The phytoplankton biomass data for Silver and Magnolia Lakes suggest eutophic conditions. Phytoplankton biomass levels in the lakes were considered moderately high and were especially high in August 1999. Wetzel (1983) and Amand and Wagner (1999) describe the dominance of nitrogen-fixing genera of blue-green algae, namely *Aphanizomenon* and *Anabaena*, and Euglenophytes in some types of eutrophic lake systems. Euglenophytes are often prevalent in organically-enriched or polluted waters (Wetzel 1983, Amand and Wagner 1999, U.S. Department of Health, Education and Welfare 1962).

## 4.1.7.2. Chlorophyll-a

Chlorophyll-a is a pigment that gives all plants their green color. The function of chlorophyll-a is to convert sunlight to chemical energy in the process known as photosynthesis. Because chlorophyll-a constitutes about 1 to 2 percent of the dry weight of planktonic algae, the amount of chlorophyll-a in a water sample is an indicator of phytoplankton biomass. Based on criteria established by the U.S. EPA (1980), a lake is classified as eutrophic when its chlorophyll-a concentrations are equal to or greater than 6 to 10 ug/l. When chlorophyll-a concentrations are equal to or less than 2 to 4 ug/l, a lake can be classified as oligotrophic. According to Nurnberg (2001), lakes are classified as eutrophic when chlorophyll-a concentrations fall between 9.1 to 25 ug/l and hypereutrophic when these concentrations exceed 25 ug/l (micrograms per liter).

#### Silver and Magnolia Lakes

The chlorophyll-a concentrations in Silver and Magnolia Lakes are presented in Table 4.8. The mean chlorophyll-a concentration for Silver Lake indicates highly eutrophic and hypereutrophic conditions according to the U.S. EPA and Nurnberg criteria, respectively. Conversely, the mean chlorophyll-a concentration for Magnolia Lake indicates highly eutrophic conditions according to the U.S. EPA and Nurnberg criteria.

**Table 4.8 Mean Chlorophyll-a Concentrations in the Study Lakes in 1999**

| Station | Chlorophyll-a (ìg/L) |
|---|---|
| Silver Lake (SL1-S) | 34.9 [20.0 – 55.9] |
| Magnolia Lake (ML1-S) | 21.7 [11.6 – 31.5] |

Note(s): Data presented as mean values along with ranges of values in brackets

### *4.1.8. Trophic State Index*

The Trophic State Index (TSI) developed by Carlson (1977) is among the most commonly used indicators of lake trophic state. This index is actually composed of three separate indices based on measurements of total phosphorus concentrations, chlorophyll-a concentrations, and Secchi disk depths for many lakes. Total phosphorus was chosen for the index because phosphorus is often the nutrient limiting for phytoplanktonic growth in lakes. Chlorophyll-a is a plant pigment present in all algae and is used to provide an indication of the biomass of phytoplankton and Secchi disk depth is a common measure of lake transparency.

As part of this study, TSI values were determined for total phosphorus, chlorophyll-a, and Secchi depth data for each of the study dates. Total phosphorus concentrations, chlorophyll-a concentrations, and Secchi disk depths were logarithmically converted to a trophic state scale ranging from 1 to 100. Increasing values for the Trophic State Index are indicative of increasing lake trophic states. In general, index values less than 35 to 40 are indicative of oligotrophic conditions, while index values greater than 50 to 55 are indicative of eutrophic lake conditions.

### Silver and Magnolia Lakes

The calculated TSI values for Secchi depth, chlorophyll-a and total phosphorus are presented in Table 4.9 and Figures 4.7 and 4.8. Overall, the three mean TSI values in Table 4.9 indicate that both Silver and Magnolia Lakes are classified as highly eutrophic or hypereutrophic. Based upon these values, Silver Lake is slightly more eutrophic than Magnolia Lake.

**Table 4.9 Mean Carlson's Trophic State Index Values for the Study Lakes in 1999**

| Station | TSI Values | | |
|---|---|---|---|
| | Secchi Depth | Chl-a | Total P |
| Silver Lake (SL1) | 72 [67 – 74] | 65 [60 – 70] | 68 [61 – 72] |
| Magnolia Lake (ML1) | 65 [62 – 70] | 61 [55 – 64] | 64 [46 – 71] |

Note(s): Data presented as mean values along with ranges of values in brackets

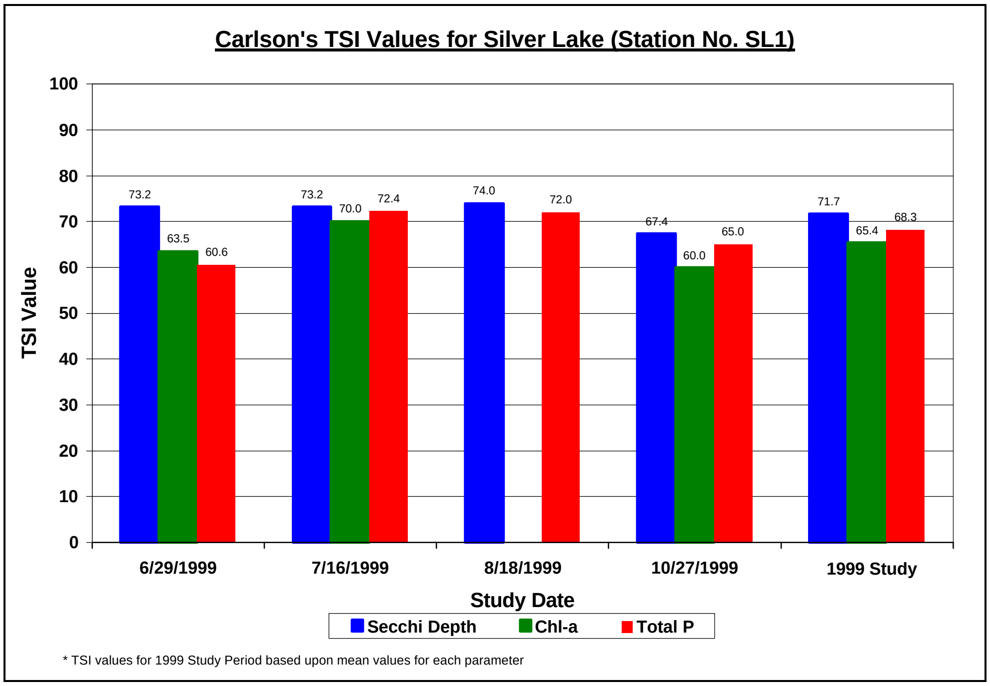
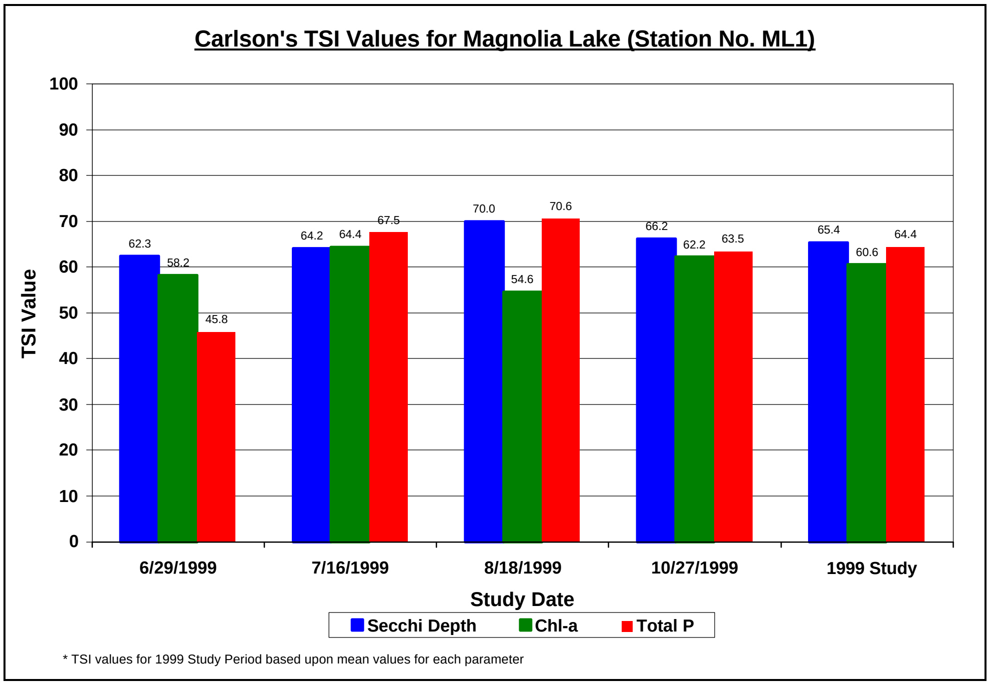


**Figure 4.7 Carlson's TSI Values for Silver Lake**



* TSI values for 1999 Study Period based upon mean values for each parameter

**Figure 4.8 Carlson's TSI Values for Magnolia Lake**

## 4.2. Summary of Lake Water Quality Data

The lake water quality data for the 1999 study period is presented below. For additional information, refer to Section 4.1 of this report.

### *4.2.1. Silver Lake*

1. The lake is classified as a shallow, polymictic lake. Polymictic lakes are defined as those lakes, which never truly stratify or sometimes weakly stratify with respect to water temperature. The maximum lake water depth is 5.6 feet.

2. Lake water temperatures frequently approached or exceeded 80° F. On June 29, 1999, lake water temperatures were 27° C (81° F) throughout the entire water column.

3. Dissolved oxygen concentrations remained above 5.0 mg/l from 0.0 to 1.0

(0.0 to 3.28 feet) throughout the 1999 study period. The lowest dissolved oxygen levels were observed on July 16th and August 18th near the sediments. For these study dates, the dissolved oxygen levels never fell below 1.0 mg/l.

4. The mean pH value of the lake was 7.06 standard units. The highest pH value was observed on July 16th when phytoplankton densities were at the highest. This elevated pH value was likely due to increased levels of photosynthesis by phytoplankton. Overall, lake pH values indicate near neutral water conditions.

5. The mean alkalinity concentration was 40.8 mg/l as $CaCO_3$. This value is considered moderately low, but sufficient to regulate or maintain stable pH levels.

6. The mean Secchi disk transparency value of 0.45 meters is low and indicates eutrophic (high levels) or hypereutrophic (extremely high levels of aquatic productivity) lake conditions according to criteria established by U.S. EPA (1980) or Nurnberg (2001), respectively.

7. The mean total phosphorus concentration was 0.085 mg/l as phosphorus and indicates eutrophic conditions. Dissolved reactive phosphorus was not detected, thereby indicating that this form of phosphorus is rapidly used by phytoplankton as soon as it becomes available.

8. With the exception of ammonia nitrogen, the mean concentrations for all forms of nitrogen are considered high and indicative of highly productive lake systems. According to Nurnberg (2001), total nitrogen concentrations suggest highly eutrophic lake conditions.

9. Total nitrogen to phosphorus ratios provides no clear distinction whether nitrogen or phosphorus is the limiting nutrient, while total inorganic nitrogen to dissolved reactive phosphorus ratios strongly indicate that phosphorus is limiting.

10. Phytoplankton biomass levels suggest eutrophic lake conditions. The biomass levels were considered moderately high and were especially high in August

1999. Nitrogen-fixing genera of blue-green algae, namely *Aphanizomenon* and *Anabaena*, and Euglenophytes were most prevalent. Euglenophytes are most often observed in organically enriched or polluted waters.

11. The mean chlorophyll-a concentration of 34.9 ug/l indicates highly eutrophic or hypereutrophic conditions.

12. The Carlson's Trophic State Index (TSI) values for Secchi depth, total phosphorus and chlorophyll-a indicate that the lake is classified as highly eutrophic or hypereutrophic. Based upon these values, Silver Lake is slightly more eutrophic than Magnolia Lake.

### 4.2.2. Magnolia Lake

1. The lake is classified as a moderately deep, dimictic lake. Dimictic lakes are those lakes that turn over (completely mixing) twice annually and typically remain thermally stratified throughout the entire growing season (May through September). The maximum lake water depth is 15.9 feet.

2. Lake water temperatures were stratified during the months of June through August in 1999 (Figure 4.1). The greatest degree of thermal stratification occurred on June 29th where the surface and bottom water temperatures were 27.5° C (81.5° F) and 16.2° C (61.2° F), respectively.

3. Dissolved oxygen concentrations were strongly stratified when the lake was thermally stratified during the months of June through August. During this period, dissolved oxygen levels typically fell below 1.0 mg/l at water depths ranging from 2.0 to 4.4 meters (6.6 to 14.4 feet). In addition, dissolved oxygen concentrations fell below 3.0 mg/l at water depths ranging from 1.5 to 4.1 meters (4.9 to 13.4 feet), thereby indicating possible production impairment of non-salmonid fish.

4. The mean pH values were 7.63 and 6.78 standard units for surface and bottom waters, respectively. In general, surface pH values were higher than bottom water values due to increased levels of photosynthetic activity by phytoplankton. Overall, the pH values in the lake indicate near neutral water conditions.

5. The mean alkalinity concentration was 42.5 mg/l as $CaCO_3$. This value is considered moderately low, but sufficient to regulate or maintain stable pH levels.

6. The mean Secchi disk transparency value of 0.69 meters is low and indicates eutrophic (high levels) or hypereutrophic (extremely high levels of aquatic productivity) lake conditions according to criteria established by U.S. EPA (1980) or Nurnberg (2001), respectively.

7. The mean total phosphorus concentration was 0.065 mg/l as phosphorus and indicates eutrophic conditions. Higher total phosphorus concentrations in the bottom waters indicate the internal release of dissolved reactive phosphorus from anoxic in-lake sediments and the decay of organic matter such as, dead aquatic vegetation including phytoplankton, during thermal stratification.

8. With the exception of ammonia nitrogen, the mean concentrations for all forms of nitrogen are considered high and indicative of highly productive lake systems. According to Nurnberg (2001), total nitrogen concentrations suggest highly eutrophic lake conditions.

9. Total nitrogen to phosphorus ratios suggest that phosphorus is limiting, while total inorganic nitrogen to dissolved reactive phosphorus ratios strongly indicate that phosphorus is limiting.

10. Phytoplankton biomass levels suggest eutrophic lake conditions. The biomass levels were considered moderately high and were especially high in August 1999. Nitrogen-fixing genera of blue-green algae, namely *Aphanizomenon* and *Anabaena*, and Euglenophytes were most prevalent. Euglenophytes are most often observed in organically enriched or polluted waters.

11. The mean chlorophyll-a concentration of 21.7 ug/l indicates highly eutrophic conditions.

12. The Carlson's Trophic State Index (TSI) values for Secchi depth, total phosphorus and chlorophyll-a indicate that the lake is classified as highly eutrophic or hypereutrophic. Based upon these values, Magnolia Lake is slightly less eutrophic than Silver Lake.

# 5. Watershed Assessment

The stream monitoring program and the watershed investigation for the Mill (Otter) Creek watershed assessment project are discussed below in Sections 5.1 and 5.2, respectively.

## 5.1. Streams Monitoring Program

The stream monitoring program for this project extended from December 2000 through August 2002. In Section 5.1.1, the study design and how stream data were acquired are briefly discussed. In addition, stream data and results are presented in Section 5.1.2. For additional information about the stream monitoring program, refer to the approved *Quality Assurance – Quality Control Plan for the Mill Creek Watershed Assessment Project* (Aqua-Link, Inc. 1999) and the *Stream Monitoring Manual: Mill Creek Watershed Assessment* (Aqua-Link, Inc. 2000).

### *5.1.1. Study Design and Data Acquisition*

In 2000, Aqua-Link and the District selected six different locations to establish stream stations within the Mill Creek watershed as shown previously in Figure 2.3 (refer to Appendix A for actual GPS coordinates). Written descriptions and photographs of these stations are provided below in Table 5.1 and Figure 5.1, respectively. At these selected sites, Aqua-Link installed staff gages and established cross sectional areas where incremental stream velocity and water depth data were to be collected. Aqua-Link provided training to several volunteer monitors representing the Friends of Silver Lake and the District. In addition, copies of the stream monitoring manual were provided to all volunteer monitors. This manual provided a comprehensive set of instructions ranging from collecting field data and water samples to shipping these samples to the contract laboratory for analysis.

**Table 5.1 Descriptions of Stream Monitoring Stations**

| Station | Stream | Description |
|---|---|---|
| MC1 | Mill (Otter) Creek | Mill Creek (Otter Creek) below the outlet of Silver Lake |
| MC2 | Mill Creek | Mill Creek above Magnolia Lake |
| MC3 | Mill Creek | Mill Creek above Oxford Valley Road bridge crossing |
| MC4 | Mill Creek | Mill Creek near the Frosty Hollow Road bridge crossing |
| BD1 | Black Ditch | Black Ditch near the Green Lane bridge crossing |
| QAC1 | Queen Anne's Creek | Queen Anne's Creek near Cobalt Road at the pedestrian bridge crossing |

## Figure 5.1 Photographs of Stream Monitoring Stations

These six stream stations were monitored three times during baseflow (low flow) and five times during stormflow (high flow) conditions. During a sampling event, discrete water samples were collected and subsequently shipped to the contract laboratory (QC, Inc. of Southhampton, PA) for analysis. All collected stream samples were analyzed for total phosphorus, total Kjeldahl nitrogen, nitrate plus nitrite nitrogen and total suspended solids. At the time of sample collection, staff gage readings were recorded on designated field data sheets. Lastly, incremental stream water depths and velocities were measured and recorded at the established cross sections at the stream monitoring stations (Figure 5.2).

**Figure 5.2 Collecting Stream Velocity and Water Depth Data**

### 5.1.2. Stream Data and Results

The mean concentrations of total phosphorus (TP), total nitrogen (TN, sum TKN and nitrate-nitrite nitrogen) and total suspended solids for all six stations during both baseflow and stormflow conditions are summarized in Table 5.2. For easy comparison, a numerical ranking system was applied for each water quality parameter. For example, mean total phosphorus concentrations during baseflow conditions ranked from 1 to 6 (best to worst in terms of water quality). The same ranking system was applied to total nitrogen and total suspended solids. The assigned points were tallied and evaluated for all stream stations during baseflow and stormflow conditions.

**Table 5.2 Mean Nutrient and Suspended Solids Concentrations for All Stream Stations**

| Station | Flow Regime | TP (mg/l as P) | TN* (mg/l as N) | TSS (mg/l) | Ranking | | | Total Pts |
|---|---|---|---|---|---|---|---|---|
| | | | | | TP | TN* | TSS | |
| BD1 | Base | 0.07 | 1.62 | 3.67 | 5 | 1 | 5 | 11 |
| MC1 | Base | 0.08 | 1.87 | 17.00 | 6 | 3 | 6 | 15 |
| MC2 | Base | 0.04 | 1.74 | 2.00 | 3 | 2 | 2 | 7 |
| MC3 | Base | 0.03 | 2.01 | 2.00 | 1 | 4 | 2 | 7 |
| MC4 | Base | 0.03 | 2.05 | 2.00 | 2 | 5 | 2 | 9 |
| QAC1 | Base | 0.05 | 2.15 | 2.33 | 4 | 6 | 4 | 14 |
| | | | | | | | | |
| BD1 | Storm | 0.11 | 1.57 | 24.60 | 1 | 4 | 2 | 7 |
| MC1 | Storm | 0.38 | 1.53 | 14.20 | 6 | 2 | 1 | 9 |
| MC2 | Storm | 0.26 | 1.99 | 154.80 | 5 | 6 | 6 | 17 |
| MC3 | Storm | 0.19 | 1.97 | 101.80 | 4 | 5 | 5 | 14 |
| MC4 | Storm | 0.13 | 1.48 | 45.40 | 3 | 1 | 4 | 8 |
| QAC1 | Storm | 0.12 | 1.56 | 37.80 | 2 | 3 | 3 | 8 |

The best water quality occurring during baseflow conditions was observed at Stations MC2 and MC3 and then followed by Station MC4. The baseflow point ranking totals for these stations were 7, 7 and 9, respectively, as shown in Table 5.1. The worse water quality occurred at Stations MC1 and QAC1 and then followed by Station BD1. The baseflow point ranking totals for these stations were 15, 14 and 11, respectively as shown in Table 5.1. Both Stations MC1 and QAC1 are located below County-owned lakes. Station MC1 is directly below the dam of Silver Lake, while Station QAC1 is located a greater distance below Lake Caroline. Station BD1 is located within a typical stream reach of Black Ditch. Black Ditch is a very slow moving, low gradient stream that contains vast amounts of aquatic vegetation commonly found in wetlands and lakes. It is believed that these three stations are significantly influenced by the upstream lakes or in the case of Station BD1, where the stream “behaves” more like a wetland or a very shallow lake system. In general, lakes and wetlands generate high levels of phytoplankton, which translates into elevated levels of total suspended solids. In addition, lakes and wetlands often release soluble forms of nutrients from anoxic (low dissolved oxygen) sediments.

Aqua-Link determined the instantaneous loadings of total phosphorus, total nitrogen and total suspended solids for all six streams stations as shown in Table 5.3. These loadings were determined by utilizing both water quality data reported by the contract laboratory and calculated instantaneous discharge data collected under baseflow and stormflow conditions. Instantaneous discharges were determined by Aqua-link using field data (incremental stream velocity and water depth data) that were measured and recorded by volunteers during the time of stream sample collection (refer to Appendix F). The instantaneous loadings for total phosphorus, total nitrogen and total suspended solids were calculated for the individual study dates and subsequently averaged together in order to obtain the mean loading values presented in Table 5.3. These mean loading values reported in this table are expressed on a mass per day basis (kilograms per day, kg/d).

**Table 5.3 Mean Nutrient and Suspended Solids Loadings for All Stream Stations**

| Station | Flow Regime | Mean Q (cfs) | TP (kg/d as P) | TN (kg/d as N) | TSS (kg/d) | Ranking TP | Ranking TN* | Ranking TSS | Total Pts |
|---|---|---|---|---|---|---|---|---|---|
| BD1 | Base | 0.8 | 0.18 | 3.0 | 5 | 2 | 1 | 1 | 4 |
| MC1 | Base | 8.8 | 1.71 | 39.8 | 371 | 6 | 5 | 6 | 17 |
| MC2 | Base | 9.8 | 1.00 | 40.5 | 48 | 5 | 6 | 5 | 16 |
| MC3 | Base | 6.3 | 0.35 | 32.0 | 31 | 3 | 4 | 4 | 11 |
| MC4 | Base | 2.3 | 0.15 | 11.6 | 11 | 1 | 2 | 2 | 5 |
| QAC1 | Base | 3.3 | 0.40 | 16.5 | 18 | 4 | 3 | 3 | 10 |
| | | | | | | | | | |
| BD1 | Storm | 17.1 | 4.74 | 65.5 | 915 | 1 | 1 | 1 | 3 |
| MC1 | Storm | 90.9 | 13.96 | 371.1 | 3,702 | 3 | 4 | 2 | 9 |
| MC2 | Storm | 106.4 | 119.70 | 714.9 | 82,686 | 6 | 6 | 6 | 18 |
| MC3 | Storm | 104.2 | 86.88 | 630.4 | 51,632 | 5 | 5 | 5 | 15 |
| MC4 | Storm | 27.9 | 10.69 | 105.2 | 4,604 | 2 | 2 | 3 | 7 |
| QAC1 | Storm | 59.5 | 21.77 | 246.2 | 7,732 | 4 | 3 | 4 | 11 |

Aqua-Link was required to eliminate some data and estimate others in order to determine the mean loading values that are presented in Table 5.3. First, no loadings were determined for the December 18, 2000 study date. Unfortunately, insufficient field data (staff gage readings plus incremental water depth and stream velocity data) were collected at all stations. Without these data, no instantaneous discharge data could be determined or even estimated. On this same study date, two of the stations lost their staff gages as a result of a previous storm event. These staff gages were later reinstalled by Aqua-Link. Aqua-Link also had to estimate some missing data for the May 22, 2002 storm event. In summary, a missing staff gage readings at Stations MC2 and BD1 were estimated using statistical regression analysis for staff gage readings at Stations MC2 and MC3 and Stations MC4 and BD1, respectively. Thereafter, regression analysis between staff gage readings and discharge were performed for all six stations in order to obtain discharge estimates for the May 22, 2002 study date. Refer to Appendix F for more information about how staff gage readings and stream discharge were estimated using statistical regression analysis.

As shown in Table 5.3, the most significant loadings occurred at Stations MC1 and MC2 during baseflow conditions. The baseflow point ranking totals for these stations were 17 and 16, respectively. The lowest loadings during baseflow conditions were determined for Stations BD1 and MC4. The baseflow point ranking totals for these stations were 4 and 5, respectively. As seen previously, Station BD1 ranked third worst in terms of baseflow water quality (Table 5.1), but now ranks the lowest in terms of loading (mass per time basis). This is primarily attributed to the fact that Station BD1 had the lowest mean discharge under baseflow conditions, which was only 0.8 cfs (cubic feet per second).

Conversely, the most significant loadings during stormflow conditions were reported for Stations MC2 and MC3, while the lowest loadings were noted again for BD1 and MC4 (Table 5.3). Station MC3 includes flow from both Mill Creek and Queen Anne's Creek. Based upon the data presented in Table 5.3, Station QAC contributes approximately 15, 25 and 39 percent of the sediment (suspended solids), phosphorus and nitrogen loadings that were estimated at Station MC3. Therefore, it appears that the MCI subwatershed contributes the highest nutrient and sediment loadings to Magnolia Lake followed secondly by the QAC subwatershed (refer to Figure 2.3).

## 5.2. Watershed Investigation

Aqua-Link, Inc. toured the Mill Creek watershed during the summer of 2002 in order to identify major problem areas contributing significant amounts of NPS (nonpoint source) pollution. Our investigation primarily focused on the NPS pollutants, namely nutrient and sediments. In excess, these pollutants result in lake water quality degradation in terms of eutrophication.

In the field, Aqua-Link toured lake and stream riparian corridors via truck; therefore most of our field surveillance targeted those areas generally accessible by roads and near bridge crossings. A GPS receiver (Garmin Model GPS 76S) linked to a portable notebook computer provided field personnel with real-time location and topographic data. In addition, field personnel walked riparian areas that were identified by others as significant watershed problems.

The locations of all significant NPS watershed problems (e.g., streambank erosion, lake shoreline erosion, sediment bars) were recorded using a GPS receiver. Digital photographs were taken and written descriptions of the problem areas were prepared using field survey data sheets. In the field, all GPS data and digital photographs were saved to a portable notebook computer. Later, GPS data were uploaded into ArcView GIS software in order to create a map showing all identified major NPS problems. Digital photographs were cropped and reformatted for inclusion into this final report.

The major NPS problems that were identified by Aqua-Link, Inc. during this assessment are described below. Refer to Figures 5.3 and 5.4 for the locations and photographs of these identified watershed problem areas. Appendix A includes the GPS coordinates of these locations.

Major NPS Problems Identified in the Mill Creek Watershed

1. Lake bank erosion at Silver Lake due to heavy pedestrian foot traffic. In addition, this shoreline lacks adequate riparian vegetation and lake margin areas contain invasive exotic plant species such as, purple loosestrife.

2. Severe lake bank erosion at Magnolia Lake due to heavy pedestrian foot traffic and lack of adequate riparian vegetation.

3. Lake bank erosion at Magnolia Lake due to heavy pedestrian foot traffic and lack of adequate riparian vegetation.

4. Illegal dumping of excavated soils within the Black Ditch flood plain at the Mill Creek Road bridge crossing.

5. Severe lake bank erosion at Lake Caroline due to heavy pedestrian foot traffic and lack of adequate riparian vegetation. Other noted problems are the lack of woody riparian vegetation around most of the lake's perimeter and the illegal feeding of waterfowl. Water feeding still routinely occurs even though the surrounding parkland is posted with "Do Not Feed the Waterfowl" signs in accordance to Ordinance No. 95, Section 38.b.

6. Moderate streambank erosion occurring along Queen Anne's Creek. Bank erosion primarily due to an inadequate riparian buffer, which lacks woody plant materials.

7. Moderate streambank erosion occurring along unnamed tributary to Lake Caroline. Bank erosion primarily due to inadequate riparian buffer, which lacks woody plant materials. Other noted problems were excessive sedimentation below the bridge crossing.

8. Apparent placement of excavated cobble from stream channel into the adjacent flood plain of Mill Creek at Station MC3. Placed cobble materials (acting as a man-made levee) appear to limit flood waters from naturally flowing into the flood plain. This portion of the flood plain is located within County-owned parkland. Under current conditions, accelerated rates of streambank erosion and downstream flooding may result due to the creation of this levee.

9. Severe streambank erosion occurring along Mill Creek due to an inadequate riparian buffer, which lacks woody plant materials. Streambank height is estimated at 6 to 8 feet.

10. Severe streambank erosion occurring along Mill Creek due to an inadequate riparian buffer, which lacks woody plant materials. Streambank height is estimated at 6 to 8 feet.

11. Severe stream channel down cutting along unnamed tributary (sometimes referred to as Samuel's Creek) to Mill Creek. This section of stream is effectively disconnected from its adjacent flood plain, thereby exacerbating downstream flooding and streambank erosion.

12. Very severe streambank erosion occurring along the outside bend of a meander along Mill Creek. The vertical cut along this bank is estimated at 6 to 10 feet, thereby creating a very dangerous situation during storm events. In addition, this stream reach is contributing very high quantities of nutrients and sediments to downstream waters.

13. Inadequate riparian buffers along an unnamed tributary to Mill Creek.

14. Extremely high levels of aggradation (sedimentation) within the stream channel of Mill Creek. Apparent source of sediments are uncontrolled stormwater runoff from Route 1 and to a lesser extent, streambank erosion.

15. Highly eroded intermittent stream channel through forested area near Route 1. This problem area is likely attributed to uncontrolled highway stormwater runoff that is discharged into a forested woodlot.

In addition to the above field investigation, all potential riparian areas lacking adequate buffers were identified using digital watershed data and ArcView GIS software as discussed in Section 2.2.5. This information was visually illustrated in Figure 2.6. Insufficient buffers along riparian areas are often highly susceptible to bank erosion and failure, thereby contributing excessive amounts of nutrients and sediments to streams and lakes.

**Figure 5.3 Locations of Watershed Problems**

## Figure 5.4 Photographs of Watershed Problems

# 6. Hydrologic and Pollutant Budgets

Hydrologic and pollutant budgets were determined for Silver and Magnolia Lakes. Hydrologic information was used to determine the hydraulic residence times (HRT) of the study lakes. HRT is an important variable that is used in phosphorus modeling and when evaluating various in-lake restoration techniques. The pollutant budgets were determined for nutrient and sediments, which are the focus of this study with respect to lake eutrophication. In addition, the pollutant budget data were used in the lake phosphorus modeling exercises.

## 6.1. Hydrologic Budget

A hydrologic budget balances the amount of water to and from a lake system. Water inputs to a lake are from tributaries, direct runoff from lands immediately surrounding the lake (i.e., the direct drainage area), precipitation to the surface of the lake and groundwater. Water outputs are via the lake's outlet, evaporation from the surface of the lake and groundwater. The hydrologic budget for any lake system is generally presented as an input-output type equation as listed below:

1. $V_{\text{outlet}} = V_{\text{tributaries}} + V_{\text{direct drainage}} + V_{\text{precipitation}} - V_{\text{evaporation}} \pm V_{\text{groundwater}} \pm V_{\text{storage}}$

Where,

| | |
|---|---|
| $V_{\text{outlet}}$ | volume of water released from the lake at the outlet, |
| $V_{\text{tributaries}}$ | volume of water entering the lake via major tributaries, |
| $V_{\text{direct drainage}}$ | volume of water entering the lake from lands adjacent to the lake and unmonitored tributaries to the lake, |
| $V_{\text{precipitation}}$ | volume of precipitation to the surface of the lake, |
| $V_{\text{evaporation}}$ | volume of water evaporated from the surface of the lake, |
| $V_{\text{groundwater}}$ | net volume exchange of groundwater through the lake bottom, and |
| $V_{\text{storage}}$ | change in storage capacity of the lake. |

In order to simplify this equation, the following assumptions were made for this report. Shallow groundwater to the lake is assumed to be included as part of the estimates for $V_{\text{tributaries}}$ and $V_{\text{direct drainage}}$. The $V_{\text{groundwater}}$ variable is assumed to be negligible since the lakes have very large watersheds and subsequently most of the water to the lakes will be from inflowing tributaries. The $V_{\text{storage}}$ variable is assumed to be negligible since the study period extends for a one-year period. Based on these assumptions, Equation No. 1 is simplified to the following equation:

2. $V_{\text{outlet}} = V_{\text{tributaries}} + V_{\text{direct drainage}} + V_{\text{precipitation}} - V_{\text{evaporation}}$

In the following paragraphs, each of these four variables in Equation No. 2 was determined. In addition, hydrologic budget summaries for Magnolia and Silver Lakes were prepared and are discussed in the following sections.

### 6.1.1. Major Tributaries

The annual contributions of water from Mill Creek and its major tributaries were estimated using historical stream discharge data as reported by the United States Geological Survey for a nearby stream monitoring station. Aqua-Link, Inc. used the above information in order to estimate the stream flow characteristics of Mill Creek and its tributaries.

For this assessment, the USGS Station No. 01464645, which is located along the North Branch Neshaminy Creek in Bucks County, PA, was selected to estimate stream flow contributions via major tributaries. Historical discharge data at this station were obtained via the internet using the USGS NWIS-W Data Retrieval System (Appendix H). The annual mean discharge at this station was determined to be 28.2 cfs (cubic feet per second). The calculated mean discharge was next expressed on a cfsm (cubic feet per second per square mile) basis by dividing the above value by its total drainage area, which is 16.2 square miles. A summary of the above information is presented in Table 6.1.

**Table 6.1 Hydrologic Characteristics of North Branch Neshaminy Creek**

| USGS Station No. | Period of Record | Mean Discharge (cfs) | Drainage Area (sq. mile) | Mean cfsm Ratio |
|---|---|---|---|---|
| 01464645 | 1986 – 2000 | 28.2 | 16.2 | 1.74 |

Source: USGS. Water resources data obtained via internet @ http://waterdata.usgs.gov.nwis.

Using the cfsm value shown in Table 6.1, the mean discharge for Mill Creek as it flows directly into Magnolia Lake was estimated. In addition, the annual mean discharge for Queen Anne's Creek and Black Ditch were estimated using the above approach. Queen Anne's Creek and Black Ditch are major tributaries to Mill Creek. All annual mean discharge values were also expressed on an annual basis in billion gallons per year (Bgal/yr) as shown in Table 6.2 (refer to Appendix H). Refer to Figure 2.3, which shows the subwatershed boundaries for the Mill Creek Inlet (Mill Creek flowing into Magnolia), Queen Anne's Creek and Black Ditch.

**Table 6.2 Hydrologic Characteristics of Mill Creek**

| Tributary | Subwatershed Area (sq. miles) | Annual Mean Discharge (cfs) | Annual Volume (Bgal/yr) |
|---|---|---|---|
| **Mill Creek (into Magnolia Lake)** | **17.5** | **30.45** | **7.18** |
| Mill Creek Inlet Subwatershed | 8.10 | 14.10 | 3.32 |
| Queen Anne's Creek Subwatershed | 6.61 | 11.50 | 2.71 |
| Black Ditch Subwatersehd | 2.79 | 4.85 | 1.15 |

### 6.1.2. Direct Drainage

Similar to Section 6.1.1, the annual volumes of water contributed by the direct drainage areas to Magnolia Lake, Silver Lake and the Delaware River were estimated using the cfsm approach. The direct drainage areas of Magnolia Lake, Silver Lake and the Delaware River are 0.42, 1.23 and 0.51 square miles, respectively as previously shown in Figure 2.3. Based upon the above, the estimated annual water volumes contributed by the Magnolia Lake, Silver Lake and the Delaware River direct drainage areas are 0.17, 0.50 and 0.21 billion gallons per year (Bgal/yr). For additional information, refer to Appendix H. As previously discussed Section 6.1, water contributions from the direct drainage areas occur via stream flow, overland flow and shallow groundwater.

### 6.1.3. Precipitation and Evaporation

The amount of precipitation and evaporation directly to and from Silver and Magnolia Lakes were estimated by using historical climatological data reported by the Pennsylvania State Climatologist (http://www.ems.psu.edu/pa_climatologist). The mean annual precipitation occurring at the City of Philadelphia, Pennsylvania is 41.41 inches per year. Evaporation from the lakes was estimated using a mean annual open pan evaporation rate of 31.72 inches per year as reported for Landisville, Pennsylvania. The Landisville Station represents evaporation rates for the southeastern portion of the state. Refer to Appendix H for all precipitation and evaporation data present above.

Based upon the surface areas of the lakes, Silver and Magnolia Lakes receive approximately 0.03 billion gallons of water due to precipitation and lose 0.02 billion gallons of water as a result of evaporation annually. As noted in Section 2.1.1, the study lakes are very similar with respect to surface areas.

### 6.1.4. Hydrologic Budget Summaries

The normalized hydrologic budget for Magnolia and Silver Lakes are presented below in Tables 6.3 and 6.4. For more information, refer to Appendix H of this report.

The most significant source of water to the Magnolia Lake is Mill Creek, which includes Queen Anne's Creek and Black Ditch subwatersheds. Mill Creek accounts for 7.18 billion gallons per year to the lake and this amount represents 97.3 percent of all incoming lake water as shown in Table 6.3.

**Table 6.3 Hydrologic Budget for Magnolia Lake**

| Input/Output | Annual Volume | | Percent of Total Input |
|---|---|---|---|
| | Cubic Feet ($ft^3$) | Billion Gallons (Bgal) | |
| Mill Creek[1] | 960,271,200 | 7.18 | 97.3 |
| Direct Drainage | 23,046,509 | 0.17 | 2.3 |
| Precipitation to Lake | 3,908,276 | 0.03 | 0.4 |
| Evaporation from Lake | -2,993,734 | -0.02 | ------ |
| Total | 984,232,251 | 7.36 | 100.0 |

[1] Mill Creek directly into Magnolia Lake; therefore includes Queen Anne's Creek and Black Ditch subwatersheds

The most significant source of water to Silver Lake is the outlet of Magnolia Lake. As previously discussed, Magnolia Lake empties almost directly into Silver Lake via a small segment of Mill Creek. The outlet of Magnolia Lake accounts for 7.36 billion gallons per year to Silver Lake and this amount represents 93.2 percent of all incoming lake water as shown in Table 6.4.

Lastly, it is estimated that Mill (Otter) Creek contributes approximately 8.08 billon gallons of water (Bgal) annually to the Delaware River. This annual water volume represents 7.87 Bgal directly from the outlet of Silver Lake (Table 6.4) and 0.21 Bgal via direct drainage. For more information, refer to Appendix H.

**Table 6.4 Hydrologic Budget for Silver Lake**

| Input/Output | Annual Volume | | Percent of Total Input |
|---|---|---|---|
| | Cubic Feet ($ft^3$) | Billion Gallons (Bgal) | |
| Mill Creek (outlet of Magnolia Lake) | 984,232,251 | 7.36 | 93.2 |
| Direct Drainage | 67,493,347 | 0.50 | 6.4 |
| Precipitation to Lake | 3,697,830 | 0.03 | 0.4 |
| Evaporation from Lake | -2,832,533 | -0.02 | ------ |
| Total | 1,052,590,896 | 7.87 | 100.0 |

### *6.1.5. Estimated Lake Hydraulic Residence Times*

The hydraulic residence times of Magnolia Lake were estimated using lake water volume data presented in Section 2.1.1 and hydrologic data presented in Section 6.1.4. Based upon this information, the mean hydraulic residences times for Silver and Magnolia Lakes were estimated to be 3.1 days and 1.0 day, respectively. Therefore, the lakes, if completely drained, would only require this many days to refill with water.

These hydraulic residences times are extremely low due to relatively very large drainage areas to lake volumes. To illustrate this point, Magnolia Lake has a total drainage area of 17.9 square miles (approximately 11,456 acres) and lake surface area of 26.0 acres. Therefore, the drainage area to lake surface area ratio for this lake is 440. Silver Lake has a total drainage area of 19.15 square miles (approximately 12,256 acres) and a lake surface area of 24.6 acres. Therefore, the drainage area to lake surface area ratio for Silver Lake is 498. Overall, ratios less than 25 to 50 are considered low, while ratios greater than 150 are classified as high. In general, the extremely low hydraulic residence times and extremely high drainage area to surface area ratios indicate that Magnolia and Silver Lakes function like “run-of-the-river” type lake systems. In general, these types of lakes often receive high pollutant loadings from their surrounding watersheds, which frequently results in the lake water quality degradation.

## 6.2. Pollutant Budgets

Pollutant budgets for phosphorus, nitrogen and suspended solids (sediments) were determined for Magnolia and Silver Lakes. In general, sources of nutrients and sediments to lakes are either from point or nonpoint sources. Point sources of pollution are direct (piped) discharges to streams and lakes from industrial and wastewater treatment facilities. All point source discharges require a NPDES (National Pollution Discharge Elimination System) permit, which is issued by the appropriate state agency. These permits thereby allow approved facilities to discharge treated process waters to nearby surface waters. Conversely, nonpoint sources (NPS) of pollution to lakes generally consist of runoff from different watershed land uses, septic systems, waterfowl, atmospheric deposition and the internal loading via in-lake sediments. NPS pollutant loadings are often estimated by using the unit areal loading (UAL) approach. For this approach, export coefficients from the literature are used to estimate pollutant loadings from various watershed sources. The UAL approach has been widely accepted to estimate both nutrient and sediment loadings to lakes where either no or limited stream monitoring data have been collected.

### *6.2.1. Point Sources*

There are no known point sources within the boundaries of the Mill (Otter) Creek watershed. Generated wastewater from all businesses and residential homes in the watershed are treated by either the Lower Bucks Joint Municipal Authority facility or the Northeast Philadelphia wastewater treatment facility. Raw wastewater is pumped to the Philadelphia facility via the Neshaminy Interceptor, which is owned and maintained by Bucks County.

### *6.2.2. Flow from Magnolia Lake to Silver Lake*

Water from Magnolia Lake flows almost immediately into Silver Lake. The two lakes are interconnected by a very short segment of Mill Creek. As noted in Section 6.1.4, Silver Lake annually receives 93.2 percent (7.36 billion gallons) of its water from the outlet of Magnolia Lake.

The nutrient and sediment loadings from Magnolia Lake into Silver Lake were estimated by multiplying the mean total phosphorus, total nitrogen and total suspended solids in Magnolia Lake by the water volume of 7.36 billion gallons. The mean phosphorus, nitrogen and suspended solids concentrations were 0.079 mg/l as P, 1.02 mg/l as N and 9.65 mg/l, respectively (refer to Section 5.1.2). The mean concentrations for phosphorus and suspended solids were based upon the mean concentrations for surface and bottom waters (epilimnion and hypolimnion), while the mean nitrogen concentration was only based upon lake surface water quality data. As previously discussed, no bottom water samples were collected for the analysis of any forms of nitrogen.

Based upon the above, it was estimated that Magnolia Lake contributed 2,201 kg (kilograms), 28,415 kg and 268,826 kg of phosphorus, nitrogen and suspended solids directly into Silver Lake. It is recognized that these values may be lower than what is actually delivered to Silver Lake. This is due to the fact that Magnolia Lake has an extremely large drainage area to lake surface area ratio and subsequently a very low hydraulic residence time. Under such circumstances, lake water quality can significantly change during storm events. In this study, lake water quality was only monitored during dry periods. Therefore, it is expected that the nutrient and suspended concentrations in Magnolia Lake increased during storm events.

### 6.2.3. Land Uses

Pollutant export coefficients reported by Reckhow et al. (1980) and the U.S. Environmental Protection Agency (1980) were evaluated and the most applicable export coefficients were selected to estimate the annual loading of phosphorus, nitrogen, and suspended solids to the study lakes. The following watershed characteristics were used in selecting the most applicable export coefficients: geography, topography, soil characteristics and precipitation characteristics (frequency, duration, intensity, and quantity).

The selected export coefficients for total phosphorus, total nitrogen, and total suspended solids and land use data (Section 2.2.4) were used to determine loadings for the six major subwatersheds (Figure 2.3). The total phosphorus, total nitrogen and total suspended solids loadings for the major subwatersheds are presented in Table 6.5. For a complete listing of all land use export coefficients and calculations, refer to Appendix I of this report.

By far, the most significant source of nutrients and sediments (suspended solids) in the entire watershed is Mill Creek above Magnolia Lake. At this point, Mill Creek consists of the Mill Creek Inlet (MCI), Queen Anne’s Creek (QAC) and Black Ditch (BD) subwatersheds. Of these three, the MCI subwatershed followed by the QAC subwatershed contributed the highest quantities of nutrients and sediments as shown in Table 6.5. This last statement is supported by the stream water quality and calculated loading data presented in Section 5.1.

### 6.2.4. Atmospheric Inputs

The phosphorus and nitrogen loadings from the atmosphere to the study lakes were estimated using the selected export coefficients of 0.25 kilograms per hectare per year (kg/ha/yr) for phosphorus and 10.0 kg/ha/yr for nitrogen (U.S. EPA 1980). These export coefficients account for nutrient loadings for both wet (precipitation) and dry fallout. Based on the above export coefficients and the lake surface areas, Magnolia Lake receives 3 and 105 kilograms per year of phosphorus and nitrogen, respectively, and Silver Lake receives 3 and 100 kilograms per year of phosphorus and nitrogen.

**Table 6.5 Nutrient and Solids Loadings for Major Subwatersheds**

| Subwatersheds | Area (ha) | Total Load (kg/yr) | | |
|---|---|---|---|---|
| | | TP | TN | TSS |
| MCI | 2,098 | 1,000 | 11,927 | 793,588 |
| QAC | 1,713 | 828 | 9,580 | 655,789 |
| BD | 723 | 368 | 4,547 | 283,915 |
| ML Direct | 108 | 46 | 546 | 36,921 |
| SL Direct | 318 | 138 | 1,553 | 108,028 |
| DR Direct | 132 | 83 | 825 | 77,532 |
| **Totals** | **5,092** | **2,463** | **28,978** | **1,955,772** |

### 6.2.5. On-Lot Septic Systems

On-lot septic tanks can be a significant source of nutrients to lakes. In the Mill Creek watershed, all businesses and residential homes are connected to public sewers as noted in Section 6.2.1. Therefore, no phosphorus or nitrogen loadings for on-lot septic systems were determined as part of this assessment.

### 6.2.6. Waterfowl

Large quantities of waterfowl on a lake can become problematic. Excessive amounts of droppings near the lake may become a nuisance and adversely affect the lake's aesthetics. Furthermore, droppings that are washed into the lake can also adversely affect lake water quality. Waterfowl droppings, which are high in nutrients and fecal coliform bacteria, may accelerate the process of lake eutrophication and can result in unhealthy lake conditions for contact recreational activities such as swimming.

Phosphorus and nitrogen loadings for waterfowl were estimated by using loading coefficients cited by Bland (1996). These values are 0.44 and 1.43 grams per waterfowl-use day for phosphorus and nitrogen, respectively. Based upon field observations, waterfowl were only observed on Silver Lake where the resident geese population is estimated at 50. Based upon the above, phosphorus and nitrogen loadings that are contributed by waterfowl are estimated at 8 and 26 kg/year (kilograms per year).

### 6.2.7. Internal Release via In-Lake Sediments

In-lake sediments release nutrients, namely dissolved reactive phosphorus and ammonia nitrogen, to the overlying lake waters. The internal release of these nutrients dramatically increases when dissolved oxygen concentrations fall below 1 mg/l near the sediments. Under such conditions, phosphorus and nitrogen are released to overlying lake waters and then consequently become available for increased production of aquatic plants (i.e., phytoplankton, filamentous algae, and macrophytes).

As discussed in Section 4.1, Magnolia Lake was thermally stratified during the months of June through August. During this period, dissolved oxygen levels for the bottom waters (the hypolimnion) of the lake were below 1 mg/l. Conversely, Silver Lake, which is very shallow, never thermally stratified during the study period and generally remained aerobic at all water depths.

The internal release of phosphorus via aerobic and anaerobic (anoxic) lake sediments was estimated by using export coefficients cited in the literature. The selected export coefficients for the internal release of phosphorus from in-lake sediments were 2 and 10 $mg/m^2$/day for aerobic and anaerobic conditions, respectively. The selected export coefficients for the internal release of nitrogen were 22 and 32 $mg/m^2$/day for aerobic and anaerobic conditions, respectively (Thomann and Mueller 1987). It was assumed that the bottom waters of Magnolia Lake were anoxic for 215 days and remained aerobic for 150 days. Conversely, it was assumed that Silver Lake remained aerobic for the entire year.

Based upon the above, the estimated phosphorus and nitrogen loadings from in-lake sediments were 203 and 1,003 kg/yr for Magnolia Lake. The estimated phosphorus and nitrogen loadings from in-lake sediments were 73 and 799 kg/yr for Silver Lake.

### 6.2.8. Pollutant Budget Summaries

The annual pollutant budget summaries for Magnolia and Silver Lakes are presented in Tables 6.6 and 6.7. These budgets were estimated based upon the calculations presented in Sections 6.2.1 through 6.2.7. The most significant source of nutrients and sediments to Magnolia Lake was Mill Creek (Table 6.6). As noted in Section 6.2.3, the MCI and QAC subwatersheds contributed the highest quantities of pollutants and this information corroborates with the nutrient and sediment loading data presented in Section 5.1.2. The major source of nutrients and sediments to Silver Lake is Mill Creek via the outlet of Magnolia Lake (Table 6.7).

**Table 6.6 Pollutant Budget for Magnolia Lake**

| Source | Pollutant (kg/yr) | | |
|---|---|---|---|
| | TP | TN | TSS |
| Mill Creek (MLI, QAC & BD Subwatersheds) | 2,196 | 26,054 | 1,733,291 |
| Direct Drainage (ML Subwatershed) | 46 | 546 | 36,921 |
| Atmospheric | 3 | 105 | -------- |
| Internal Release by Sediments | 203 | 1,003 | -------- |
| **Total** | **2,448** | **27,708** | **1,770,212** |
| External Load Only (TP Model) | 2,245 | | |

**Table 6.7 Pollutant Budget for Silver Lake**

| Source | Pollutant (kg/yr) | | |
|---|---|---|---|
| | TP | TN | TSS |
| Magnolia Lake Outlet (via Mill Creek) | 2,201 | 28,415 | 268,826 |
| Direct Drainage (SL Subwatershed) | 138 | 1,553 | 108,027 |
| Atmospheric | 3 | 100 | -------- |
| Waterfowl | 8 | 26 | -------- |
| Internal Release by Sediments | 73 | 799 | -------- |
| **Total** | **2,423** | **30,893** | **376,853** |
| External Load Only (TP Model) | 2,350 | | |

## 6.3. Phosphorus Modeling

Based on the water quality data collected during this study, phosphorus was identified as the "limiting" nutrient in Magnolia and Silver Lakes. Therefore, it is phosphorus that controls the overall degree or level of eutrophication in these lakes. If phosphorus concentrations were to decrease, overall water quality of these lakes is expected to improve.

Simply stated, the amount of phosphorus in the lake is a function of the amount of phosphorus flowing into the lake minus the amount of phosphorus flowing out of the lake minus the amount of phosphorus settling to the bottom of the lake. This simple input-output principle has been used to develop a large number of models to predict the lake phosphorus concentration if the input (load) and the basin's hydrology are determined. The major difference between various models is in their method of calculating their sedimentation term. Since it is not practical to measure phosphorus sedimentation directly, it must be estimated empirically based on a lake's morphometric and hydrologic characteristics.

These models are most commonly used as a tool to predict changes in lake water quality. Lake managers commonly increase and decrease the external phosphorus loads (lake phosphorus inputs) in order to predict changes in lake water quality. In addition, lake managers frequently rely on models to corroborate the overall accuracy of selected export coefficients for various point and nonpoint sources.

## Study Period

Lake and watershed data that were acquired as part of this assessment served as input variables for phosphorus modeling. First, phosphorus modeling was performed to predict the phosphorus concentrations in Magnolia and Silver Lake. Next, predicted concentrations were compared to the actual mean concentrations for the study period. Lastly, the selected model was rearranged in order to determine the necessary phosphorus loading reductions that would be required to achieve mesotrophic lake conditions.

Numerous phosphorus models were evaluated for their applicability to the study lakes. The most critical stage in performing any modeling exercise is to select the most appropriate model. Models developed by Vollenweider (1969), Kirchner and Dillon (1975), Chapra (1975), Larsen and Mercier (1975), Jones and Bauchman (1975), Canfield and Bauchman (1981), Prairie (1988), Prairie (1989), Reckhow (1977) and Walker (1977) were evaluated as part of this assessment.

After reviewing over fifteen different models, the Reckhow Quasi-General Model (1980) was selected as a suitable model for the study lakes. This Reckhow Quasi-General model, which tends to be a rather robust model, is as follows:

$$TP = L/[11.6 + 1.2Q_s]$$

Where,

$TP$ = annual average phosphorus concentration (g/m3 or mg/l)
$L$ = areal phosphorus loading ($g/m^2$-yr)
$Q_s$ = areal water loading (m/yr) = $Q/A_o$
$Q$ = inflow of water to the lake ($m^3$/yr)
$A_o$ = lake surface area ($m^2$)

L was obtained from the phosphorus budgets that were developed and summarized in Tables 6.5 and 6.6. Q was obtained from the hydrologic budgets that were developed and summarized in Tables 6.3 and 6.4 and the lake surface areas were determined and presented in Table 2.1. For all modeling results, refer to Appendix I.

By substituting the appropriate values, the Reckhow model predicts in-lake concentrations of 0.065 and 0.068 mg/l as phosphorus (P) for Magnolia and Silver Lakes. The actual mean phosphorus concentrations in Magnolia and Silver Lakes for the study period were 0.065 and 0.085 mg/l as P, respectively. The concentration for Magnolia Lake represents the mean concentration for surface waters (epilimnion).

Based upon the above, the predicted and actual concentrations for Magnolia Lake are equal. Conversely, the predicted concentration for Silver Lake is slightly less than actual mean concentration for the study period. This lower predicted value possibly may be attributed to under estimating the actual phosphorus loading from Magnolia Lake to this lake. In any event, the predicted model value for Silver Lake is consider good and meets the overall goals and objectives of this assessment.

The phosphorus loading reductions were determined in order to achieve mesotrophic conditions in the study lakes. The above equation was rearranged to solve for L when P was set equal to 0.030 mg/l as P. According to criteria established by the U.S. Environmental Protection Agency (1980), a lake with a total phosphorus concentration of 0.030 g/m3 (0.030 mg/L) is classified as highly mesotrophic. Thereafter, the predicted L values were compared to the calculated L values in order to determine the required phosphorus reductions to achieve mesotrophy.

Based upon the above, it was estimated that calculated phosphorus loadings to Magnolia and Silver Lakes have to be reduced by 53 and 55 percent in order to achieve mesotrophy. As noted previously, the calculated external phosphorus loadings to Magnolia and Silver Lakes were 2,245 and 2,350 kg/yr, respectively. It should be noted that the external phosphorus loadings do not include any internal loadings from in-lake sediments.

# 7. Evaluation of Restoration Alternatives & Practices

The primary goal of any lake and watershed management plan is to improve the overall quality of incoming waters (e.g., streams, stormwater runoff) to a lake and to improve both the water quality and aquatic habitats of the lake itself. Management plans are typically developed by carefully evaluating all potential in-lake restoration alternatives, watershed management best management practices and institutional (non-structural) practices to achieve this goal.

Below is a list of restoration alternatives and practices that are commonly evaluated when developing a comprehensive lake and watershed management plan:

In-lake Management Alternatives

1. Lake Aeration
    a. Aeration (destratification, hypolimnetic)
    b. Mechanical Circulation
2. Lake Deepening
    a. Sediment Dredging
    b. Water Level Drawdown for Sediment Consolidation
    c. Raise Lake Surface Elevation
3. Other Physical Controls
    a. Harvesting of Nuisance Aquatic Plant Biomass
    b. Water Level Fluctuation
    c. Habitat Manipulation (Improvements)
    d. Covering Bottom Sediments to Control Macrophytes
4. Chemical Controls
    a. Algicides
    b. Herbicides
5. Biological Controls
    a. Bio-Manipulation for Phytoplankton Control
    b. Insects for Nuisance Aquatic Vegetation
6. In-Lake Schemes to Accelerate Nutrient Outflow or Prevent Recycling
    a. Sediment Dredging for Nutrient Control
    b. Nutrient Inactivation/Precipitation

   c. Dilution and Flushing
   d. Biotic Harvesting for Nutrient Removal
   e. Selective Discharge from Impoundments
   f. Sediment Exposure and Desiccation
   g. Lake Bottom Sealing

7. In-Lake Deacidification
   a. Limestone Additions
   b. Base Material Injection into Sediments

## Watershed Management

1. Wastewater
   a. Upgrade Facilities to Improve Effluent Quality
   b. Diversion of Wastewater from Lakes or Watersheds
   c. Connecting On-Lot Septic Systems to Public Sewers
2. Land Management Practices
   a. Agriculture (Crop and Feedlot)
   b. Forest (Silviculture)
   c. Urban (Stormwater)
   d. Riparian Corridors
3. Stream and Lake Bank Stabilization & Restoration
   a. Soft Approach (Plant Materials Only)
   b. Soil Bio-Engineering Approach
   c. Natural Stream Channel Design (Streams Only)
   d. Hard Approach (Conventional Armoring)
4. Homeowner Management Practices
   a. Lawn Maintenance
   b. On-Lot Septic System Maintenance
5. Deacidification
   a. Watershed Liming
   b. Limestone Additions to Streams

## Institutional

1. Model Ordinances
    a. Stormwater Management
    b. Riparian and Sensitive Area Protection
2. Education
    a. Lake Ecology and Management
    b. Watershed Dynamics and Management
    c. Homeowner Best Management Practices
3. Establishing a Lake and Watershed Steering Committee
4. Water Quality Monitoring
    a. Lakes
    b. Streams

The following criteria should be considered when evaluating potential restoration alternatives and practices (U.S. EPA 1980):

| | |
|---|---|
| Effectiveness | how well a specific management practice meets its goal |
| Longevity | reflects the duration of treatment effectiveness |
| Confidence | refers to the number and quality of reports and studies supporting the effectiveness rating given to a specific treatment |
| Applicability | refers to whether or not the treatment directly affects the cause of the problem and whether it is suitable for the region in which it is considered for application |
| Potential for Negative Impacts | an evaluation should be made to insure that a proposed management practice does not cause a negative impact on the lake ecosystem |
| Capital Costs | standard approaches should be used to evaluate the cost-effectiveness of various alternatives |

| | |
|---|---|
| Operation and Maintenance | these costs should be evaluated to help determine the cost-effectiveness of each management alternative |

By way of this assessment, it has been determined that Silver and Magnolia Lakes are considered very eutrophic or hypereutrophic (Section 4). The major source of pollution to these lakes is classified as nonpoint source (NPS) pollution and is primarily attributed to stormwater runoff from urbanized areas and streambank erosion (Sections 5 and 6). Nutrient and sediment budgets for the study lakes indicate the highest levels of NPS pollution are generated within the MCI and QAC subwatersheds as shown in Figure 2.3. In addition, stream data for storm events further suggest that the MCI subwatershed contributes high quantities (loadings) of nutrients and sediments, which have and continue to severely degrade the aquatic habitats and water quality of both streams and lakes. Therefore, any recommended watershed management practices should first be implemented within these two subwatersheds to increase their overall cost-effectiveness.

Overall, Silver and Magnolia Lakes have extremely high drainage area to lake surface area ratios as discussed in Section 6.1.5. The ratios for Magnolia and Silver Lakes are 440 and 498, respectively. These ratios suggest that it will be very difficult to dramatically improve lake water quality. Significant lake water quality improvements will only be recognized when NPS loadings of nutrients and sediments are dramatically decreased.

## 7.1. In-Lake

### *7.1.1. Aeration*

Aeration has been widely used in the restoration of lakes, where summer hypolimnetic oxygen depletion and/or winter kill are of major concern. Aeration can be divided into two categories: those methods, which destratify the lake water column and circulate the entire lake, and those methods, which only aerate the hypolimnion (deep water layer) without destratification. Both methods are based on the principle that increased dissolved oxygen concentrations will increase the availability of deep water habitats for fish while decreasing the release of phosphorus from the anoxic (low dissolved oxygen containing) sediments. The major difference between the two techniques is that destratifying aerators mix the entire water column resulting in uniform water temperatures from surface to bottom. Conversely, hypolimnetic aerators do not mix the entire lake, but instead only aerate the bottom waters (hypolimnion), thereby allowing the lake to remain thermally stratified.

Aeration by destratification works by bubbling air from the lake bottom, thereby causing the water column to circulate. In order for complete mixing to occur the temperature difference from the top to the bottom of the lake should generally be less than 5 degrees Celsius. Hypolimnetic aerators operate by lifting and aerating hypolimnetic water in a closed chamber and circulating the aerated water back into the hypolimnion. When properly used, hypolimnetic aerators do not destratify warmer surface waters and colder bottom waters in a lake during the summer months. One drawback to hypolimnetic aeration is that sometimes there is oxygen depletion within the metalimnion (between the epilimnion and hypolimnion). It is uncertain if this oxygen depletion creates a significant barrier for fish migration. In general, hypolimnetic aeration is more expensive and can be about three to five times more than destratification.

Based upon the data presented in Section 4.1.1, aeration is only recommended for Magnolia Lake since Silver Lake remained well oxygenated throughout the study period. In this study, Magnolia Lake was thermally stratified in June through August. The lake's bottom waters contained very low levels of dissolved oxygen and elevated levels of phosphorus (Section 4.1.6.1).

Aeration via destratification for Magnolia Lake is expected to increase dissolved oxygen throughout the water column, thereby improving habitat for the lake's fishery and decreasing the internal release of phosphorus from in-lake sediments. The phytoplankton levels in the lake are not expected to change significantly because of high NPS nutrient loadings from its surrounding watershed. Based on similar projects, the estimated cost for the above aeration system will likely range from approximately $15,000 to $25,000. This cost estimate includes installation but does not include the cost for bringing electric power to the lake and annual operational and maintenance costs.

### 7.1.2. Sediment Dredging

The physical removal of lake sediments can be used to achieve one or more objectives and is often referred to as a lake's "ultimate face lift". The most obvious advantage of dredging is the removal of accumulated sediments and deepening of the lake. An additional benefit is that virtually all of the plants are removed from the lake. The entire macrophyte would be eliminated, including the seeds and roots, thereby preventing a quick recurrence of nuisance growths. Costs for dredging are high, but the benefits are long-term, as long as control measures are implemented to minimize the amount of sediments entering the lake.

Some of the problems associated with dredging are the re-suspension of sediments and nutrients, the disturbance of the benthic (lake bottom) community, and the disturbance of both fishery nesting and refuge areas. During the dredging operation, sediments and nutrients are often re-suspended, which may result in algal blooms, increased turbidity, and decreased dissolved oxygen concentrations. In removing in-lake sediments, many of the residing aquatic organisms will be physically removed or smothered by the settling sediments in areas adjacent to the actual operation.

However, the continued improvements of dredging equipment and dredging methods have helped to minimize these adverse impacts.

Lake sediments can be removed by mechanical or hydraulic methods. Mechanical dredging can be performed in-lake or after draining the lake. In-lake dredging is generally performed using a clamshell bucket operated from a crane, which is located on shore or mounted to a barge. If the lake is drawn down, lake sediments are excavated using bulldozers (or other excavation equipment) after the lake sediments are sufficiently de-watered. Once the sediment is removed, this material must be loaded into trucks and hauled to the disposal site. If sediments cannot be sufficiently dewatered on site, water tight trucks will be needed. This adds to the volume that must be transported thereby increasing hauling costs of the project. In hydraulic dredging, a dredging barge is unloaded from a trailer into the lake. The barge is equipped with a cutterhead that which dislodges the sediments. Dislodged sediments are then pumped as a slurry from the barge to the disposal site via a pipeline. Because the sediments are transported as a slurry, a larger disposal/de-watering area is required. After drying, the sediments may be regraded into the existing topography and restabilized with vegetative cover (i.e. grasses), thereby returning the disposal sites to their former undisturbed condition. Another option is to transport these dewatered sediments to an offsite location for disposal.

Sediment removal is only required at Silver Lake, which is significantly shallower than Magnolia Lake. The mean and maximum water depths of Silver Lake are only 2.7 and 5.6 feet, respectively, as determined and discussed in Section 2.1.1. Therefore, the largest constraint for the lake's fishery is the lack of aquatic habitats, namely in the form of water volume.

In the past, Silver Lake has been dredged using mechanical equipment. As discussed in Section 1.2, two-thirds of Silver Lake was dredged in 1985, while the remaining one-third was eventually dredged in 1994. The total cost of dredging Silver Lake to a water depth of 5 feet exceeded $600,000. Prior to the onset of dredging, Silver Lake only had an average water depth of 1½ feet. The above information indicates that sediment dredging has not been a very cost-effective restoration technique for this lake. This is primarily attributed to very high NPS sediment loadings to the lake from its surrounding watershed, particularly from Magnolia Lake via Mill Creek.

At this time, dredging is not recommended for Silver Lake until watershed sediment loadings have been substantially decreased. This is primarily based upon the overall longevity of past dredging projects for this lake and the pollutant budgets as determined in Section 6 of this report. The Bucks County Department of Parks and Recreation should only consider dredging Silver Lake if there is interest in dramatically improving the fishery or permitting some limited boating activities on the lake for park visitors. If so, the County should retain a qualified consultant in order to perform a lake dredging feasibility study.

### *7.1.3. Fishery Management*

Fishery management programs should be implemented at Silver and Magnolia Lakes. Properly managed lake fisheries will improve the recreational value of these lakes for park visitors. During this assessment, Aqua-Link has observed anglers fishing both lakes, but unfortunately all of these anglers only reported either little or no success.

A fishery management program in Magnolia Lake should only begin after the implementation of aeration. Overall, the morphological (physical) and water quality characteristics (excluding low dissolved oxygen levels) of this lake make it a good candidate for supporting a good warmwater fishery. For example, this lake would be well suited for a largemouth bass-bluegill-channel catfish type fishery. Silver Lake is less suited as a warmwater fishery since this lake has a limited amount of available fish habitat due to shallowness. Without dredging, Silver Lake should only be stocked with more tolerant fish species like channel catfish.

It is recommended that the Bucks County Department of Parks and Recreation consider improving the fisheries at the study lakes. The Department should contact the Pennsylvania Fish and Boat Commission (PA FBC) and request for fishery surveys to be performed and subsequent fish stockings to be implemented. This request should only occur after lake aeration has been implemented in Magnolia Lake. If the PA FBC declines, the Department may retain a private lake management company to perform these fishery surveys and stockings.

## 7.2. Watershed Best Management Practices

### *7.2.1. Stormwater Retrofits*

Urbanization has a profound influence on stream and lake water quality. These impacts are more readily observed in older urban settings without any or inadequate stormwater controls as compared to newer urban areas (Schueler 1987). In general, stormwater management systems in older urban areas were designed to quickly capture surface runoff from impervious areas (roof tops, sidewalks, roadways, parking lots) and pipe it directly to receiving streams. In addition, increased imperviousness in a watershed subsequently results in less rainfall infiltration and percolation resulting in lower levels of groundwater recharge.

Urbanization allows for changes in watershed hydrology, changes in stream geometry, the degradation of aquatic ecosystems and pollutant export during construction and after site stabilization. Watershed hydrology is significantly altered after urbanization. Peak stream discharges are increased about 2 to 5 times higher than pre-development levels. The volume of stormwater runoff produced by individual storms is increased. For example, a moderately developed watershed many produce 50 percent more runoff than a forest watershed. The time required for runoff to reach a stream (time of concentration) is significantly decreased by as much as 50 percent. In addition, changes in watershed hydrology result in increased frequency and severity of flooding, reduced streamflow during prolonged periods of dry weather (due to decreased rates of soil infiltration) and greater runoff velocities during storm events (Schueler 1987).

Streams now must readjust (change in geometry) to the new hydrologic conditions in urban areas. The primary adjustment for increased stormwater volumes is channel widening. Stream channels may widen 2 to 4 times their original size if post-development runoff is not effectively controlled. The elevation of the stream's floodplain also will increase to accommodate higher post-development peak discharge rates; therefore property and structures not previously at risk to flooding now may be at risk. Streambanks are gradually undercut and slump into the stream channel. Trees that previously protected the banks are now exposed at the roots and sometimes become windthrown, thereby triggering a second phase of bank erosion. Eroded soils from streambanks and upland areas are temporarily stored in the stream channel as sand bars and other sediment deposits. Gradually, these sediments migrate throughout the stream network as bedload, but unfortunately the stream channel will inevitably be covered by shifting deposited mud and coarse sands for many years to come (Schueler 1987).

In addition, urbanization adversely affects the overall composition of aquatic ecosystems. Increase levels of pollutants to receiving waters often result in lower levels of species diversity and the dominance of more tolerate, less desirable aquatic insects and fish. Pollutants are exported during construction and after site stabilization. There is a very high potential for large quantities of sediment with attached nutrients and organic matter to be transported to streams and lakes from active construction sites. This potential is greatly reduced when adequate erosion and sediment controls are properly installed and maintained. After construction, pollutants rapidly accumulate on impervious surface and are readily transported to receiving waters via stormwater runoff. These pollutants include sediments, nutrients, bacteria, oxygen consuming substances, oil and grease, metals, toxic chemicals and chlorides. In addition, increased temperatures of stormwater runoff (thermal pollution) will result in increased temperatures of receiving waters (Schueler 1987).

Land development (urbanization) prior to the 1970's had little to no stormwater management practices. Stormwater systems were primarily built only to transport runoff rapidly to receiving waters. In the 1970's, efforts began to address runoff induced flooding. Stormwater control structures including detention basins were generally designed to accommodate only peak rates of runoff. Therefore, these structures only held runoff for a few hours until it was deliberately discharged to receiving waters and did not address the loss of groundwater recharge, poorer runoff water quality or increased runoff volumes over pre-development conditions (Delaware Riverkeeper 2001).

The primary problem with the peak rate of runoff design for stormwater control structures (detention basins) is that receiving waters receive increased stormwater volumes for longer periods of time. Structures of this design throughout a watershed have a cumulative net effect of actually increasing the instream peak discharge rates and water volumes for extended periods. Therefore, the final result is that downstream flooding is exacerbated since flood flow is increased and extended (Delaware Riverkeeper 2001).

In addition, most detention basins are designed to control only 10 to 100-year frequency storms and fail to impact the 2 to 5-year storms. Many detention basins are designed to pass these smaller storm runoff volumes directly to streams. In general, the 2-year storm in a natural watershed produces bankfull discharge. Bankfull discharge is that amount of flow that fills the stream to the top of its banks. In urban areas, smaller, more frequent storms can result in bankfull conditions because of increased runoff volumes. Bankfull discharge is considered the effective discharge for stream channel formation (channel widening, channel downcutting and bank erosion) as later described in Section 7.2.3.

Stormwater best management practices (BMP's) that are later incorporated into existing developments and urban areas is referred to as stormwater retrofitting. Retrofitting may only require minor modifications to existing control structures like detention basins or the construction of new control structures or devices. The underlying goal of retrofitting is to correct many of the problems that were described above. Below is a list of common retrofits that may be employed for existing stormwater detention basins (CH2MHill et. al. 1998):

- Modifying the outfall to create a two-stage release to better control smaller storms while not significantly compromising the major detention required for flood control

- Eliminating paved low-flow channels and replacing them with meandering vegetated swales

- Eliminating low-flow bypasses

- Incorporating low berms to lengthen the flow path and eliminate short-circuiting

- Incorporating stilling and settling basin at inlets

- Regrading the basin bottom to create a wetland area near the outlet or revegetating parts of the basin bottom with wetland vegetation to enhance pollutant removal, reduce mowing and improve aesthetics

- Creating a wetland shelf along the periphery of a wet basin to improve shoreline stabilization, enhance pollutant filtering and enhance esthetic habitat functions

In addition, filter strips and infiltration devices can be retrofitted into urbanized areas. Filter strips can be readily incorporated into some existing developments if relatively large vegetated surface can be utilized. Runoff from paved and grasses areas can be regraded to route drainage to and across the vegetated areas. In some instances, rerouting may only require the removal of curbs or slotting the curbs along the edge roads and parking lots. Infiltration devices such as, infiltration trenches, permeable pavement and bio-retention should also be considered to promote additional groundwater recharge and pollutant removal. Infiltration trenches may be installed down gradient of existing parking lots and permeable pavement is often installed in low traffic areas like parking lots and fire lanes. Bio-retention facilities are typically installed in natural depressions and roadside swales (CH2MHill et. al. 1998).

Based upon the above, Aqua-Link recommends that the municipalities perform a stormwater retrofitting assessment within the MCI and QAC subwatersheds (Figure 2.3). All existing detention basins should be identified and evaluated for retrofits. These structures should then be prioritized and upgraded accordingly with either state or federal funding. During the field investigations, it is recommended that any good candidate sites for filter strip and infiltration device retrofits be identified for future implementation.

## *7.2.2. Bank Stabilization*

Bank erosion is a major source of nutrients and sediments to lakes and streams. Excessive nutrients may result in accelerated rates of eutrophication such as, algal blooms in lakes and depleted dissolved oxygen levels in both streams and lakes. Excessive sediments in streams and lakes will adversely affect aquatic life and their habitats. In addition, high levels of sedimentation in lakes will result in loss of lake water volumes and shallowness, which will impair desirable and/or designated lake uses.

### 7.2.2.1. Lake Shoreline Stabilization

In Section 5.2, isolated areas of shoreline erosion were observed along Silver, Magnolia and Caroline Lakes. These problems are shown in Figures 5.3 and 5.4 as Sites 1-3 and 5. Overall, lake bank instability is primarily due to heavy pedestrian traffic and the lack of adequate riparian buffers consisting of woody plant species. The worst bank erosion was observed along Magnolia Lake. In general, the slope of this bank is steeper than what occurs at the other two lakes.

It is recommended that the above four problems be stabilized using soil bio-engineered principles, thereby providing good stabilization while maintaining a natural looking appearance. At Silver Lake and Lake Caroline, either biologs or rock should be placed at the toe of the bank (edge of water) for added protection. Clean soils should be placed over the existing highly compacted soils and seeded with grasses. Woody plant materials, which are approved for soil bioengineering in riparian areas, should be installed adjacent to the biologs or placed rock. Live stakes from willow trees (e.g., black willow, basket willow or purple osier willow) should be installed into the biologs or in between the placed rocks for additional stability and enhancing the projects overall appearance. Conversely, the existing banks at Magnolia Lake should be cut back to a 2:1 to 3:1 slope. It is anticipated that no fill soils will be needed for the two project sites at this lake. The same methods employed above should be used at Magnolia Lake. In addition, live fascines (bundles of live branch cuttings generally from willow trees) may be installed at mid-bank for additional support and stabilization.

For these projects, it will be necessary to obtain the proper permits from the Pennsylvania Department of Environmental Protection (PA DEP). In general, a general permit (GP-3) is commonly issued for projects that are less than 500 linear feet and an Individual Permit for Small Projects is issued for projects greater than 500 linear feet.

#### 7.2.2.2. Streambank Stabilization

In Section 5.2, several areas of streambank erosion are good candidates for restoration using soil bio-engineering principles. These problems are shown in Figures 5.3 and 5.4 as Sites 6, 7, 9 and 10. Overall, streambank instability is primarily due to the lack of adequate riparian buffers consisting of woody plant species.

At Sites 6, 9 and 10, the existing bank should be cut back and regarded to a 2:1 to 3:1 slope. Rock should be placed at the toe of the bank (edge of water) for added protection. The re-graded soils should be seeded with grasses. Woody plant materials, which are approved for soil bioengineering in riparian areas, should be installed adjacent to the placed rock. Live stakes from willow trees (e.g., black willow, basket willow or purple osier willow) should be installed in between the placed rocks for additional stability and enhancing its overall appearance. This practice is commonly referred to as “joint planting”. In addition, live fascines (bundles of live branch cuttings generally from willow trees) may be installed at mid-bank for additional support and stabilization.

The same approach should be applied to Site 7 except that the existing bank does not need to be re-graded and no live fascines are required. The existing bank at this site is very flat as shown in Figure is 5.4.

Once again, it will be necessary to obtain the proper permits from the Pennsylvania Department of Environmental Protection (PA DEP) for these projects. In general, a general permit (GP-3) is commonly issued for projects that are less than 500 linear feet and an Individual Permit for Small

Projects is issued for projects greater than 500 linear feet.

#### 7.2.2.3. Establishing Riparian Buffers

Riparian buffers are undisturbed vegetative strips that are adjacent to surface waters. Established vegetation along streams and lakes provide numerous benefits such as, filtering out sediments transported by surface runoff, nutrient uptake, wildlife habitat, shading and soil binding via plant roots. Grasses and herbaceous vegetation are best suited as filters, while woody vegetation (shrubs and trees) provide excellent protection against bank erosion.

Riparian buffers should consist of various layers of vegetation (grasses, herbaceous vegetation, shrubs and trees) to achieve optimal benefits. Undisturbed riparian buffers should extend a minimum of 25 feet wide from the top of the bank along lakes and streams. This minimum distance should be increased if adjacent slopes are steeper (Georgia Soil and water Conservation Commission).

Aqua-Link encourages all townships and the Bucks County Department of Parks and Recreation to immediately stop all lawn mowing activities within 25 feet of all lakes and streams. By doing so, these riparian parkland areas will become passively re-vegetated with both herbaceous and woody vegetation.

In addition, Aqua-Link recommends that active riparian buffer restoration be targeted first in the MC1 and QAC subwatersheds, which includes the entire perimeter of Lake Caroline (Figure 2.3). In these subwatersheds, potential areas that are lacking adequate riparian buffers are presented in Figure 2.6. Once again, all lawn mowing activities should be discontinued along streams and lakes. At a minimum, a 25-foot buffer should be maintained from the top of bank for streams or from the edge of water for lakes. Shrubs (e.g., willows, dogwoods, alder, nannyberry, winterberry) and trees that are approved for soil bio-engineering stabilization should be planted throughout the newly created buffer zone. Many species of willow and dogwoods reproduce well from live cuttings and therefore may be installed as live stakes as opposed to rooted plants.

### *7.2.3. Stream Channel Restoration*

Severe stream channel and bank erosion are occurring along a segment of Mill Creek and one of its tributaries near Red Rose Drive. These problem areas are shown as Sites 11 and 12 in Figures 5.3 and 5.4. This reach of Mill Creek and its unnamed tributary are considered highly incised or entrenched. In general, the potential for erosion for these types of streams increases as streambank height increases. The primary causes of stream channel incision are changes in the watershed or streamside vegetation. For these streams, the major cause for incision is apparently related to increased stormwater runoff volumes and velocities as a direct result of urbanization. Based upon field observations, these stream segments are contributing large quantities of sediments and attached nutrients to downstream waters and represent a serious risk to nearby residents.

The unnamed tributary, Site 11, exhibits signs of severe channel downcutting. This incised stream channel has very steep, vertical banks, which have effectively allowed for the stream channel to be disconnected from its adjacent flood plain. Mill Creek, Site 12, is an incised stream segment that has migrated up against a steep sided slope. The outer bend of the stream meander has a vertical cut of 6 to 10 feet.

One possible solution for stabilizing these two stream segments is stream channel reconstruction using natural stream channel design (NSCD) principles. For example, the existing streambanks may be regraded to include a bankfull bench. A bankfull bench is a type of terrace designed to accommodate bankfull stage. Bankfull discharge is the flow that transports the majority of the stream's sediment load over time and thereby forms the channel. On average, bankfull discharge occurs approximately every 1.5 years or conversely, there is a 67 percent chance of having a bankfull streamflow event. Bankfull stage, during bankfull discharge, is the point at which flooding occurs on the floodplain (NC State University Cooperative Extension). Riparian vegetation commonly used in soil bio-engineering type projects should be installed throughout the newly created bankfull benches. In addition, NSCD structures, such as J hooks or rock vanes, may be installed along the outer bend of the stream channel meander at Site 12. These structures will allow streamflow to be redirected away from the streambank towards the center of channel.

Stream reconstruction projects typically occur in three phases: assessment, design and permitting and construction. The first phase requires a fluvial geomorphological (FGM) assessment to be performed for the subject stream. This assessment involves the collection and analysis of stream and watershed data; the critical evaluation of various design options and the identification of all permitting requirements. Once completed, the second phase begins where the final project design is completed and all necessary permit applications are prepared and submitted to the appropriate agencies for approval. After all permits have been fully secured, the third phase, stream reconstruction, may commence after selecting a qualified contractor to construct the project.

At this time, Aqua-Link recommends that limited stream channel reconstruction be performed in those areas posing an immediate risk to property or the public at large. Stream channel reconstruction on a watershed-wide basis should not occur until other key elements of this management plan are implemented. This includes retrofitting of existing stormwater control structures and the adoption of stricter stormwater management ordinances.

Based upon the above, Aqua-Link encourages Middletown Township apply for state or federal funding to perform a FGM assessment of Mill Creek and its unnamed tributary in the vicinity of Red Rose Drive. These stream reaches are considered a high hazard for the public due to the severe extent of streambank erosion and stream channel downcutting.

### 7.2.4. Soil Erosion Due to Highway Runoff

Stormwater runoff from highways may be a significant source of sediments and attached nutrients to receiving streams. As shown in Figure 5.3 and 5.4, Site 15 is a highly eroded intermittent stream channel that receives stormwater runoff from Route 1. Eroded soils from this stream channel in turn are then deposited directly into Mill Creek as previously shown as Site 14 in Figures 5.3 and 5.4.

At a minimum, Aqua-Link recommends that this intermittent stream channel be lined with rock (rip rap) in order to reduce stormwater velocities and soil erosion. In addition, Aqua-Link encourages all of the municipalities and the Pennsylvania Department of Transportation (Penn DOT) to survey all major stormwater discharges from highways and stabilize accordingly.

### 7.2.5. Parkland Improvements

Aqua-Link encourages the Bucks County Department of Parks and Recreation to implement several park improvement projects at Magnolia Lake. This recommendation is not NPS pollution based, but is offered since Aqua-Link provided recommendations to improve lake water quality (aeration), the lake’s fishery and lake shoreline erosion.

Aqua-Link recommends that the Department should establish a designated parking lot off of Oxford Valley Road. Currently, many visitors park their vehicles along the shoulder of Lakeland Road to gain access to Magnolia Lake. In addition, Aqua-Link recommends that a trail system be installed along Oxford Valley Road and Lakeland Road. This trail system would provide pedestrian access from the designated parking lot to the northern and southern ends of the lake. During this assessment, all anglers were observed fishing along the northern and southern shorelines of the lake due to better access.

### 7.2.6. Floodplain Improvements

Any excavated soils that were illegally placed or dumped into any floodplain areas should be removed and properly disposed of elsewhere. These soils may decrease the overall carrying capacity of the floodplains to accommodate floodwater during larger storm events and may increase the likelihood of downstream flooding and downstream bank erosion. In addition, these unstabilized soils may be readily transported via surface runoff to nearby streams, thereby resulting in stream habitat and water quality degradation.

Site 4 appears to be an area where excavated soils were routinely dumped into the floodplain of Black Ditch (refer to Figures 5.3 and 5.4). Site 8 (Figures 5.3 and 5.4) is an area along Mill Creek where it appears that excavated cobble from the stream channel was placed on top of the bank. It is speculated that cobble was removed from the stream channel to increase its overall storage capacity during storm events. In any event, these cobble materials on top of the streambank presently have disconnected the stream channel from its adjacent floodplain.

## 7.3. Institutional

### *7.3.1. Stormwater Management*

The Bucks County Planning Commission and its consultant, Borton Lawson Engineering, are preparing a Stormwater Management Plan for the Delaware River South watershed in accordance with Pennsylvania Stormwater Management Act 167. The Mill (Otter) Creek watershed is a subwatershed of the Delaware River South watershed. Under this act, each county must prepare stormwater management plans for all of its designated watersheds with consultation of the municipalities.

The primary object of Act 167 is to manage stormwater runoff on a watershed-wide basis rather than on a site-by-site basis. Historically, individual municipalities have managed stormwater runoff by reviewing subdivision and land development plans in light of established ordinances. A key component of the Act 167 plan will be that municipalities will manage stormwater runoff using newly created ordinances. These ordinances will be developed from a model stormwater ordinance for the entire watershed. The Delaware River South watershed will be divided into stormwater management districts and assigned development and predevelopment runoff rates for each district. The Act 167 plan is scheduled for completion by June 30, 2003 (Borton Lawson Engineering 2002).

Aqua-Link recognizes the need for stricter ordinances to properly manage stormwater runoff in the Mill (Otter) Creek watershed. At this time, Aqua-Link recommends that the Planning Commission and its consultant should consider language in its Act 167 plan to promote groundwater recharge to its fullest extent and to provide specific requirements for designing new control structures for smaller sized storms (1-year, 24 hour storm) and water quality.

### *7.3.2. Riparian Corridor Protection*

Riparian corridors are those areas immediately surrounding surface waters. When properly maintained, riparian corridors aid in protecting water quality by filtering out pollutants from surface runoff and overland flow, stabilizing streambank and lake shoreline areas from erosion, providing shade to adjacent waters, providing critical habitats for wildlife and enhancing aesthetics.

At this time, Aqua-Link recommends that all municipalities in the watershed develop and adopt a riparian corridor protection ordinance. The ordinance is based upon establishing a riparian corridor conservation district, which applies to all lands that are adjacent to waterways in a municipality. The district may consist of several different zones, where permitted uses are specified for each zone. As an example, a copy of the riparian corridor protection ordinance developed and enacted by Doylestown Township in Central Bucks County is included as Appendix J of this report.

### *7.3.3. Education*

As part of this grant, the Bucks County Conservation District purchased lake and stream monitoring equipment and a nonpoint source watershed model from the Terrene Institute. This equipment and the watershed model were turned over to the Silver Lake Nature Center. In addition, Aqua-Link developed a lake ecology and watershed concepts PowerPoint presentation that will be integrated into the highly successful environmental education program at the nature center.

Aqua-Link recommends that Silver Lake Nature Center with the assistance of the municipalities and a water resources consultant develop educational materials about homeowner best management practices and the results of this assessment. These materials can be developed as tri-fold brochures (fact sheets) and distributed at the municipal buildings and the nature center and possibly by mail. Some suggested homeowner best management practices that may be presented are:

- Proper Lawn Mowing Methods
- Use of Low Phosphorus Lawn Fertilizers
- Limiting the Use of Lawn Fertilizers
- Establishing Low Maintenance Landscapes
- Limiting the Use of Pesticides
- Establishing & Maintaining Riparian Buffers
- Use of Rain Barrels to Collect Roof Top Runoff
- Illegal Disposal to Storm Sewer Drains

In addition, the Silver Lake Nature Center may elect to work with local middle or high school student in stenciling stormwater sewer drains. This type of project, in conjunction with local newspaper press releases, will provide an excellent opportunity to educate the public about the Mill (Otter) Creek watershed and its drainage patterns.

### 7.3.4. Water Quality Monitoring

Baseline water quality monitoring programs for both lakes and streams are often implemented after a comprehensive assessment has been completed. Newly acquired data are routinely entered into the existing water quality database and analyzed. The comparison of newly acquired data to past data is commonly referred to as "water quality trend analysis". Water quality trend analysis is an invaluable tool in assessing water quality improvements or degradation over time. Hence, water quality trend analysis provides water resource professionals and watershed stakeholders the opportunity to carefully evaluate the overall success of any implemented in-lake and watershed restoration measures.

Aqua-Link strongly recommends that the water quality of streams and lakes continue to be monitored annually or biannually. Monitoring should be performed at the established stream and lake monitoring stations that were used during this assessment. All stream stations should be monitored once again during both baseflow and stormflow conditions. All collected lake and stream samples should be analyzed for the same parameters as described in Section 3.2 by a certified laboratory. It is highly recommended that the certified laboratory use the same analytical procedures and detection limits as cited in the approved *Quality Assurance – Quality Control for the Mill Creek Watershed Assessmen*t (Aqua-Link, Inc. 1999).

In addition, Aqua-Link recommends that the water quality of Lake Caroline be assessed. The same monitoring protocols of this assessment should be used for the Lake Caroline assessment. The water quality data for Lake Caroline would then be compared to Silver and Magnolia Lakes. Presently, Aqua-Link has no knowledge of any existing water quality data for this lake.

# 8. Comprehensive Lake and Watershed Management Plan

The comprehensive lake and watershed management plan for the Mill (Otter) Creek watershed consists of the implementation of in-lake restoration, watershed best management practices and institutional practices. The primary goal of this management plan is to reduce nonpoint source pollutants, namely nutrients and sediments, to streams and County-owned lakes. This management plan is quite extensive and therefore will require a strong commitment by all watershed stakeholders to ensure success.

Based upon information and data acquired and assessed as part of this project (Sections 1 through 6), the following recommendations are offered to the watershed stakeholders in order to improve and further protect stream and lake water quality in the Mill (Otter) Creek watershed. These recommendations were ranked according to priority from 1 to 3 (highest to lowest priority).

## 8.1. In-Lake Restoration

Recommended in-lake restoration techniques for Silver and Magnolia Lakes are (refer to Sections 7.1.1 through 7.1.3):

- Aeration via destratification for Magnolia Lake (1)
- Sediment Dredging of Silver Lake (3)
- Fishery Management of Magnolia and Silver Lakes (2)

It should be noted that sediment dredging for Silver Lake is expected not to be cost-effective until nonpoint source sediment loadings are significantly reduced. This will only be accomplished through the implementation of both watershed best management and institutional practices. Therefore, sediment dredging of Silver Lake is listed as conditional and should be carefully evaluated by the Bucks County of Parks and Recreation.

## 8.2. Watershed Best Management Practices

Recommended watershed best management practices for the Mill (Otter) Creek watershed are (refer to Sections 7.2.1 through 7.2.6):

- Stormwater Retrofits in MCI and QAC Subwatersheds (1)
- Lake Shoreline Stabilization (1)
- Streambank Stabilization using Soil Bio-Engineering Principles (2)
- Establishing Riparian Buffers (2)
- Stream Channel Reconstruction of Mill Creek near Red Rose Drive (2)

- Parkland Improvements at Magnolia Lake (3)
- Floodplain Improvements at Mill Creek and Black Ditch (3)

Stormwater retrofits first require an assessment of the Mill Creek Inlet and Queen Anne's Creek subwatersheds as shown in Figure 2.3. As part of this assessment, all existing detention basins should be identified and evaluated for retrofitting. These structures should then be prioritized and upgraded accordingly with either state or federal funding. During the field investigations, it is recommended that any good, candidate sites for filter strip and infiltration device retrofits be identified for future implementation.

Stream channel reconstruction should only be performed on a limited basis for those areas posing an immediate risk to property or the public at large. Stream channel reconstruction on a watershed-wide basis should not occur until other key elements of this management plan are implemented. This includes retrofitting of existing stormwater control structures and the adoption of stricter stormwater management ordinances. Based upon the above, it is recommended that a fluvial geomorphological (FGM) assessment of Mill Creek and its unnamed tributary in the vicinity of Red Rose Drive be performed as fully discussed in Section 7.2.3.

## 8.3. Institutional

Recommended institutional practices for the Mill (Otter) Creek watershed are (refer to Sections 7.3.1 through 7.3.4):

- Stormwater Management (1)
- Riparian Corridor Protection (2)
- Environmental Education (2)
- Water Quality Monitoring of Lakes and Streams (1)

## 8.4. Funding Sources

Many of the recommendations offered in the comprehensive management plan are eligible for state or federal funding. State funding may be obtained through the Pennsylvania Department of Environmental Protection's Growing Greener Grant Program. Federal funding may be obtained through U.S. Environmental Protection Agency's Section 319 (Nonpoint Source) Program and/or National Oceanic and Atmospheric Administration's (NOAA) Coastal Zone Management (CZM) Program.

If funding is not available, the watershed stakeholders are strongly encouraged to implement some of the recommendations using their own financial resources. This type of watershed stakeholder commitment is viewed highly by the above agencies and can greatly improve the success of receiving state and federal funding for other lake and watershed projects.

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# APPENDIX A

## GIS Metadata Files &
## GPS Coordinate Data

# APPENDIX B

# Soils and Land Use GIS Data

# APPENDIX C

# Glossary of Lake and Watershed Management Terms

Source: U.S. EPA. 1980. Clean lakes program guidance manual. Report No. EPA-440/5-81-003. U.S. EPA, Washington, D.C.

# APPENDIX D

## Lake Water Quality Data

## Summarized by Aqua-Link, Inc.

# APPENDIX E

## Original Laboratory Lake Water Quality Data

### Reported by Laboratory

# APPENDIX F

## Stream Water Quality & Discharge Data

### Summarized by Aqua-Link, Inc.

# APPENDIX G

## Original Stream Water Quality Data

## Reported by Laboratory

# APPENDIX H

## Hydrologic Budget Information
## & Calculations

# APPENDIX I

## Pollutant Budget & Modeling Calculations

# APPENDIX J

## Example Riparian Corridor Protection Ordinance