City of Bellingham Lake Whatcom Stormwater Management Program:

Evaluation of Stormwater Phosphorus and Recommended Management Options

Prepared for

City of Bellingham Public Works Department
Bill Reilly
210 Lottie Street
Bellingham, WA 98255

Prepared by

Parametrix
411 108th Avenue NE, Suite 1800
Bellevue, WA 98004-5571
425-458-6200
www.parametrix.com

October 2007 | 215-2480-009

CITATION

Parametrix. 2007. City of Bellingham Lake Whatcom Stormwater Management Program:
Evaluation of Stormwater Phosphorus and Recommended Management Options.
Prepared by Parametrix, Bellevue, Washington. October 2007.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

µg/L	microgram per liter
BMP	best management practice
City	City of Bellingham
COB	City of Bellingham
CSO	Combined Sewer Overflow
DNR	Department of Natural Resources
Ecology	Washington State Department of Ecology
GIS	Geographic Information System
ISTS	Individual Sewage Treatment System
IWS	Institute for Watershed Studies
LID	low impact development
LWMP	Lake Whatcom Management Plan
mg/L	milligram per liter
MGD	million gallons per day
P	phosphorus
RCW	Revised Code of Washington
TDR	Transferable Development Rights
TMDL	Total Maximum Daily Load
TP	total phosphorus
TSS	total suspended solids
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WWTP	Wastewater Treatment Plant
WWU	Western Washington University

1. INTRODUCTION

Water quality in Lake Whatcom, a source of drinking water for 50 percent of Whatcom County residents, has been of concern for many years. A commonly identified contributor to the decline of the lake's water quality has been urban stormwater runoff and entrained constituents, such as suspended solids, metals, and nutrients (CH2M HILL 2007, Entranco 2002, HDR 1995, URS 1985). Phosphorus plays the largest role in contributing to lake water quality due to its role in stimulating lake algal productivity. Enhanced algal growth, which in turn lowers dissolved oxygen levels, can be associated with production of nerve and liver toxins (i.e., blue-green algae), and can effect the taste of drinking water (Hardy et al. 2000, Matthews et al. 2006, 2007).

To date, the methods used to manage stormwater have been selected from the usual suite of available best management practice (BMP) options–source controls, education, and treatment (both on-site and at "regional" levels) (Ecology 2005a, LWMP 2007). Given the challenges phosphorus presents to Lake Whatcom and the continuing decline of water quality (Matthews et al. 2006, 2007), the City of Bellingham initiated this review of phosphorus control approaches for those:

(1) Currently in use by the City

(2) Proposed by the County

(3) Used by other municipalities and counties in the US.

The approach involved reviewing studies conducted on Lake Whatcom by the City and County, City and County stormwater management plans, studies conducted elsewhere in Washington, and the general scientific and engineering literature. Based on this review, a series of recommendations have been developed for the City to consider in enhancing its existing (well developed) phosphorus management program.

The overall goals of this report are to:

- Present a current understanding of phosphorus in Lake Whatcom and the likely sources of phosphorus
- Review and comment on the City's stormwater management phosphorus control program
- Make recommendations for the City to enhance its existing program.

1.1 STRUCTURE OF THIS REPORT

The remainder of this introduction summarizes background information on Lake Whatcom and its watershed, discusses potential phosphorus sources and pathways to lakes and Lake Whatcom. Section 2 describes the current status of the City's phosphorus control program. Since treatment BMPs are such an integral component of any stormwater management program, Section 3 presents a discussion of treatment BMPs available for phosphorus and how well the City's BMPs are performing in controlling phosphorus. Section 4 explains the use of a simple loading analysis and City BMP performance data to support future phosphorus control strategies. Section 5 reviews available opportunities for improving the City's stormwater phosphorus control program and makes recommendations for enhancing and complimenting ongoing and proposed phosphorus control efforts by the City. Finally, Section 6 presents some concluding remarks, and all references are included in Section 7.

1.2 THE LAKE AND ITS WATERSHED

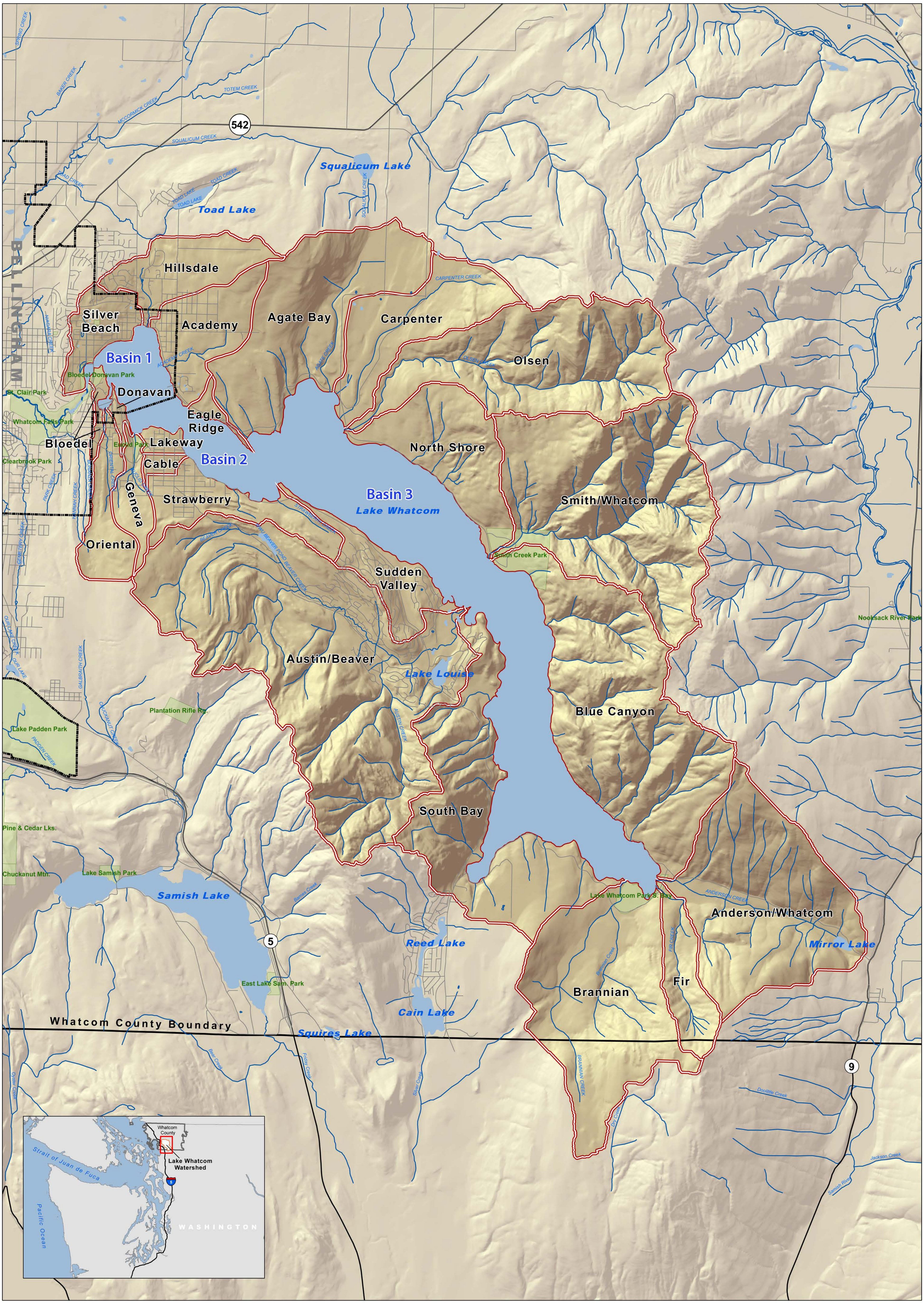
Lake Whatcom, a large lake located in Whatcom County, Washington, is divided into three basins (Basins 1, 2, and 3), which are separated by two sills (Figure 1). Basin 3, the largest and deepest of the three basins, is located the furthest upstream and contains approximately 96 percent of the lake's volume. Basin 3's watershed consists primarily of public and private forestland; very little is developed. Basins 1 and 2 are largely developed, with each containing 2 percent of the lake's volume (Entranco 2002).

The lake's outlet, Whatcom Creek, is located on the western edge of Basin 1. The City of Bellingham (City), which is located at the downstream end of Lake Whatcom, encompasses the majority of Basin 1's eastern and western shores and the entirety of its northern end.

Lake Whatcom **sills** are naturally existing, submerged rises or dams that limit water exchange and circulation between lake basins.

The entire Lake Whatcom watershed is 31,127 acres, of which 629 acres (2 percent) is located in the City. The remaining 98 percent of the watershed is located in Whatcom County. Approximately 13 percent of the entire watershed (4,007 acres) is currently developed; an additional 18 percent (5,552 acres) of the watershed is available for development under current zoning (3,208 additional homes) (City of Bellingham 2007c). The City is approaching full build-out, therefore the vast majority of the remaining developable land is located in Whatcom County.

Full build-out within the watershed would result in approximately 16,000 more residents living in the watershed than in 2000 (Entranco 2002). At the current development rate (approximately 270 new homes per year), the water shed will reach full build-out in approximately 12 years (City of Bellingham 2007c).



Legend

Subbasin Boundary
Road
Stream
Bellingham City Limt
Whatcom County Boundary
Park

Figure 1
Lake Whatcom Watershed, Subbasins, and Lake Basins.

Source: Lake Whatcom Comprehensive Stormwater Plan (CH2M Hill 2007)

File Path: \\simba\Proj\WhatcomWaCountyOf351768\GIS\Layouts\LakeWhatcomOverview2.mxd, Date: April 2, 2007 9:11:24 AM

1.3 LAKE PHOSPHORUS

Following a general description of phosphorus in lake ecosystems and current state water quality criteria for phosphorus, this section describes our current understanding of phosphorus in Lake Whatcom.

Typical Shoreline Development

1.3.1 Phosphorus and Lake Ecosystems

Healthy lake ecosystems contain low concentrations of nutrients, such that in most lakes, phosphorus is the limiting element for lake productivity (Moore and Hicks 2004). Because it is the element in greatest demand by aquatic life, even small increases in phosphorus concentrations can greatly increase vegetation growth, including algae. Therefore extra inputs of phosphorus disrupt the balance of a lake's ecosystem by fueling blooms of algae and aquatic weeds (*termed eutrophication*). When it dies, this vegetation sinks to the bottom of the lake where bacteria decompose them. During decomposition, these bacteria consume large amounts of dissolved oxygen, often depleting oxygen levels in the lower portion of a lake, which can lead to fish kills, foul odors, and poor tasting drinking water.

What is Eutrophication?

A major challenge facing Puget Sound lowland lakes is algal growth associated with increased fertilizer inputs from surrounding urban neighborhoods. High nutrient concentrations stimulate blooms of algae, clouding the water and blocking sunlight, leading to decreases in dissolved oxygen.

This process is called **eutrophication**.

1.3.2 Lake Phosphorus Water Quality Criteria

The Washington State Department of Ecology (Ecology) has adopted a specific set of lake phosphorus nutrient criteria based on region of the state and ambient total phosphorus (TP) levels (WAC 173-201A-230-Establishing lake nutrient criteria). This regulation sets criteria for TP levels for Puget Lowland lakes based on their trophic state (Table 1).

Table 1. Trophic-state action values for establishing Puget Lowland lake phosphorus criteria: (Reproduced from Table 230(1), WAC-123-210A-230)

Coast Range, Puget Lowlands, and Northern Rockies Ecoregions:

Trophic State	If Ambient TP (µg/l) Range of Lake is:	Then criteria should be set at:
Ultra-oligotrophic	0-4	4 or less
Oligotrophic	>4-10	10 or less
Lower mesotrophic	>10-20	20 or less
Action value	>20	Lake-specific study may be initiated

A **Trophic State** is the general level of nutrients in a water body. Lakes are typically categorized into one of three states:

- **Oligotrophic -** lakes poor in nutrient with little aquatic life
- **Mesotrophic -** lakes with moderate levels of nutrient and aquatic life
- **Eutrophic** – lakes with high nutrient concentrations, often experiencing periods of oxygen deficiency which limit aquatic life

1.3.3 Phosphorus in Lake Whatcom

Western Washington University's (WWU) Institute for Watershed Studies (IWS) monitors water quality in Lake Whatcom and at certain locations in its watershed. Recent data from this and other sources have shown negative trends in the lake's water quality, specifically increases in phosphorus and *Chlorophyll a* concentrations, decreased dissolved oxygen levels, and a subsequent shift in characterization from oligotrophic towards mesotrophic (Matthews et al. 2005, 2006, 2007). Lake phosphorus levels have exceeded 20 µg/L on at least an annual basis since 2003 at the lowest depths measured in Basins 1 and 2 (Basin 1 being nearest to developed properties within the City of Bellingham limits (See Figures B101 and B102 in Matthews et al. 2007).

Ecology has placed Lake Whatcom on its 303(d) list of impaired water bodies for dissolved oxygen and total phosphorus and completed a groundwater TMDL in 2005 (Ecology 2005b). Monitoring for the TMDL indicated that at some locations, elevated levels of phosphorus in groundwater discharging to the lake were associated with upgradient development. In general, this TMDL, IWS monitoring data, and other reports suggest that a significant portion of the surface water and groundwater phosphorus loading to Lake Whatcom originates from human sources and activities. These data and reports point to the importance of controlling phosphorus from human sources, including urban development.

The situation faced by Lake Whatcom and the City of Bellingham is not unusual. Based on survey results from 45 states, the Environmental Protection Agency's National Water Quality Inventory 2000 Report to Congress identified nutrients (specifically phosphorus and nitrogen) as the primary group of pollutants affecting lakes in the country (USEPA 2002).[1]

This is particularly true for Washington, where nutrients were reported as the primary pollutant in all lakes surveyed (USEPA 2002). A review of Washington State waters conducted by Ecology found 34 percent (or 29 lakes) at least partially impaired by nutrients (Ecology 2004).

- ☐ **Lake Whatcom is considered impaired for dissolved oxygen and total phosphorus.**
- ☐ **Lake Whatcom is now showing decreased water quality due to excess phosphorus.**
- ☐ **People are the major source of phosphorus in City of Bellingham stormwater.**

---

[1] The states reported metals as the second most common pollutant in assessed lake acres, impairing 3.2 million lake acres (19% of the assessed lake acres and 42% of impaired lake acres). This is significant because many of the BMPs and treatment methodologies proposed in this report also are very effective for metals treatment.

1.4 PHOSPHORUS SOURCES

Understanding sources of phosphorus and how phosphorus moves through the environment is critical to identifying source controls, optimizing selection and location of treatment controls, and for future land development purposes. This section provides an overview of typical phosphorus sources and pathways to lakes and then describes our current understanding of phosphorus sources to Lake Whatcom.

1.4.1 Typical Sources and Pathways of Phosphorus to Lakes

Sources of phosphorus and other pollutants to a lake can be divided into two categories: internal and external. External sources originate from outside the lake (the watershed and atmosphere) or from upstream portions of a lake. Internal sources of phosphorus are derived from the lake's ecological processes, e.g., decomposing plant material, resuspension during lake-turnover, and release to the water column during periods of hypolimnetic oxygen deficits. Since the purpose of this report is to evaluate phosphorus control in stormwater runoff, it only addresses external sources of phosphorus from the City's portion of the watershed (i.e., Basin 1 only). Common sources, pathways, and transport mechanisms for phosphorus to lake systems are illustrated in Figures 2 and 3.

Differences in water temperature and density cause lakes to stratify (divide into layers) during summer and winter, with lower density, warmer water overlaying higher density, colder water. Cooling temperatures in the fall cause the upper layers to become more dense and sink, causing the "layers" to **turnover**. This results in mixing of the lake waters and resuspension sediments into the water column.

The **hypolimnion** is the bottom layer of water in a thermally stratified lake. This layer is typically low or lacking in dissolved oxygen in eutrophic lakes.

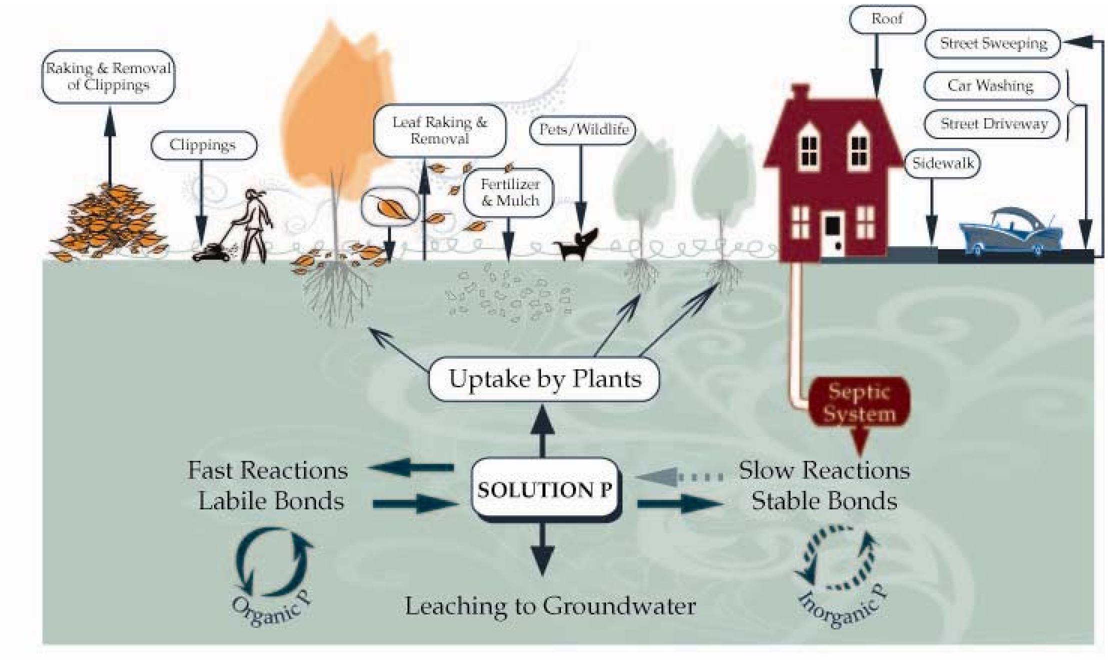


Figure 2. Common phosphorus sources and pathway to groundwater

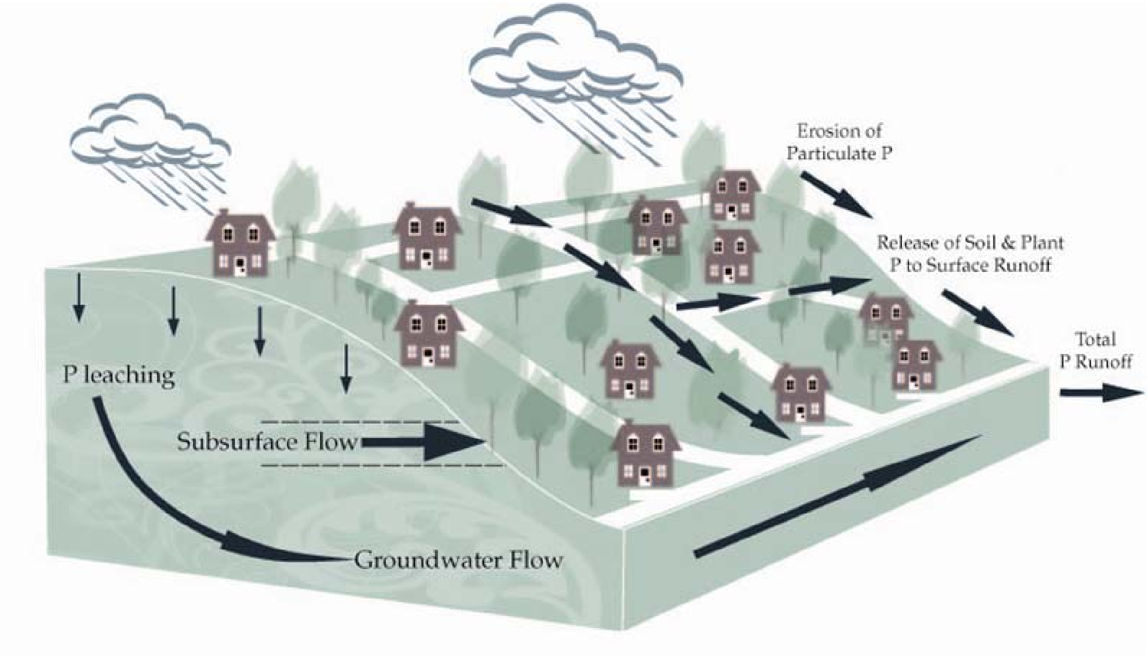


Figure 3. Phosphorus transport mechanisms

1.4.2 Phosphorus Sources to Lake Whatcom

Understanding the phosphorus sources within city limits is an important first step in evaluating the City's control program and identifying options for future improvements.

A common approach to prioritizing the stormwater pollutant contribution of different land uses is the application of the Simple Method (Schueler 1987; Horner et al. 1994). This modeling approach estimates stormwater runoff pollutant loads for urban areas from (1) annual runoff (in inches), (2) pollutant concentration, and (3) area (in acres). Pollutant concentrations can either be measured locally, or estimated from national data sets, such as those presented in Table 2.

Table 2. Dissolved Phosphorus Concentrations for various Land Use Categories (shaded land uses are *not* present in the City of Bellingham subbasins discharging to Lake Whatcom).

	Dissolved Phosphorus (mg/L)		
Land Use Category	**Pitt et al. 2005**	**Waschbusch et al. 1999**	**Barr 2005**
Lawns/Landscape Areas	1.35	0.37-0.77	0.79
Industrial Streets	0.46	-	1.30
Residential Streets	0.30	0.03-0.16	0.66
Driveways	0.29	0.07	0.24
Industrial Parking Lots	0.09	-	0.39
Freeways	0.08	-	0.24
Residential roofs	0.07	0.02-0.08	0.17
Commercial Roofs	0.06	-	0.18
Commercial Streets	0.06	-	0.31
Commercial Parking Lots	0.06	0.02	0.20
Industrial Roofs	0.02	-	0.13
Undeveloped Areas	0.01	-	0.08

Of the land uses that *are* present in the City of Bellingham subbasins, Table 2 shows that the highest phosphorus concentrations are generated by lawns/landscaped areas followed by streets and driveways. However, land use concentrations are only one part of any loading estimation. Equally important is the area of each land use present in these subbasins, as well as the overall level of imperviousness (which determines the volume of stormwater generated by each land use class). In evaluating studies of phosphorus loadings in the Lake Whatcom watershed as well as those reported for other locales, it is critical to consider the comparability of land use types, the amount of each, and the overall levels of imperviousness.

A number of local studies have attempted to identify phosphorus sources and estimate annual loading to Lake Whatcom. In a Lake Whatcom Water Quality Protection Study (URS 1985), Basin 1 was used to represent developed land while Basin 3 was used to represent undeveloped land. Using these two land use categories, the authors estimated annual total phosphorus loading of 0.83 lbs/acre/year from developed land and 0.58 lbs/acre/year from undeveloped land, respectively. This same study reported that 16 percent of inflow to Basin 1 contributes 86 percent of its phosphorus load. Supporting this finding, Entranco (2002) reported that Silver Beach Creek and Hillsdale Creek are the third and fourth highest phosphorus contributors to the lake even though they only comprise 1 percent and 2 percent, respectively of the lake's total watershed (COB Grant App. 2007). Both of these streams flow into Basin 1, with approximately 97 percent of Silver Beach Creek's subbasin located within City limits. Walker et al. (1992) did not differentiate the lake by basin, but instead identified hill slope failures and residential land uses as the primary sources of pollutants (including phosphorus) in the watershed. Entranco (2002) identified more specific potential sources of pollution (including phosphorus) to the lake, such as forest practices, nutrient loading, recreation, stormwater, transportation, and urbanization. Although beneficial for the intended purpose, these studies do not provide the data or in-depth analysis required to identify specific sources within the City.

Studies detailing specific sources of phosphorus within an urban watershed and their relative contribution to overall phosphorus loading are somewhat limited. Studies have been primarily conducted in three states, Maine, Wisconsin, and Minnesota. Of the studies reviewed, the one conducted for two residential watersheds (Monroe and Harper) in Madison, Wisconsin is most comparable to the City of Bellingham's portion of the Lake Whatcom watershed (Waschbusch et al. 1999). The Monroe basin was 96.8% residential and 3.2% commercial, while the Harper Basin was 100% residential (Waschbusch et al. 1999). As with the City of Bellingham's portion of the watershed, these two basins were almost completely built-out and included open-space parks.

In the study, Waschbusch et al. (1999) reported that lawns and streets were the largest sources of total phosphorus, dissolved phosphorus, and total suspended solids (TSS) in both basins, with a combined contribution of 80 percent of the phosphorus load (Table 3). Lawns had the highest concentrations of both dissolved and total phosphorus as well as the highest load rates, with 56 percent and 70 percent of total phosphorus loading in each basin coming from lawns. Streets were the next largest contributor of phosphorus in both basins, while parking lots and roofs were the lowest contributors. Based on this study, it is not clear what suite of variables affects phosphorus loading from lawns; however, tree canopy was closely correlated with lawn phosphorus output. Of the sediment mass contributed from streets, the >250 µm size fraction contributed nearly 50 percent of the total phosphorus mass, while the leaf fraction contributed an additional 30 percent. In each sediment particle size class, ~25 percent of total phosphorus mass was derived from leaves and other vegetation.

Table 3. Phosphorus Loading from Two Residential Watersheds in Madison, Wisconsin
(Waschbusch et al. 1999.)

Harper Basin	Water Volume	Total Phosphorus
Streets	41%	20%
Parking Lots	4%	1%
Roofs	12%	3%
Driveways	20%	7%
Lawns	23%	70%
Monroe Basin	**Water Volume**	**Total Phosphorus**
Streets	46%	33%
Parking Lots	7%	2%
Roofs	9%	2%
Driveways	14%	7%
Lawns	24%	56%

Although results vary amongst the studies reviewed based on the differences in the makeup of land uses present, they generally point towards lawns/landscaped areas, streets, and driveways/sidewalks, as being the three dominant phosphorus source areas in a low to medium density urban setting such as the City of Bellingham. However, specific sources of phosphorus to these areas are less clear from the literature.

Nation-wide studies have found a general pattern of

- Lawns/landscaped areas
- Streets, and
- Driveways/sidewalks

as the three dominant phosphorus source areas in a low to medium density urban setting such as the City of Bellingham

Whatcom County recently completed a draft comprehensive stormwater management plan for Lake Whatcom (CH2M Hill 2007). The plan thoroughly presents the water quality, water quantity, and fish habitat issues associated with storm and surface water in the watershed. Phosphorus inputs to the lake are identified as being of particular concern, contributing to increased algae growth and overall degradation of water quality. Reducing these inputs is a high priority of the County's plan. As the plan describes, human activities can exacerbate phosphorus inputs from natural sources such as stream bank erosion and soils. This is particularly the case in an urbanized area such as the City of Bellingham where impervious surfaces intensify stream flows and development results in increased soil exposure through construction and land-clearing activities. For example, the plan identified several locations at the periphery of the City where high velocity and volume of runoff in ditches in the Academy subbasin are thought to contribute to lake phosphorus through scouring and transport of entrained sediment. Similarly, several City locations within the Hillsdale subbasin have been identified as potential phosphorus sources because of increased stream velocities and sediment loads in Silver Creek.

As recognized by the County plan, since historical monitoring has not included phosphorus, there is a paucity of data from different land-uses and activities for a thorough analysis of potential phosphorus sources. However, as summarized in Table 4 below, the plan does use best professional judgment to identify which sources are thought to have relatively high, medium, and low, influence on phosphorus inputs to the lake.

Table 4. Relative Influence of Different Sources on Phosphorus Inputs to Lake Whatcom

Source	Relative Influence
Roads Vehicles Yards (and yard care activities) Existing Stormwater Conveyance Construction Activities New Development (land clearing)	High
Septic Systems Recreation in Watershed	Medium to High
Pets	Medium
Existing Stormwater facilities Groundwater interception Building Materials Atmospheric Deposition	Low

In an attempt to identify specific land management practices responsible for phosphorus loading in urbanized portions of the basin, the City of Bellingham proposed the following potential sources of phosphorus from within its portion of the watershed: leaves and grass clippings, stream erosion, pet and wildlife waste, land clearing, wastewater, failing septic systems, sewage spills, leaking sewer pipes, and phosphate based chemicals (detergents, fertilizers, pesticides, etc.) (Fogelsong 2007; City of Bellingham 2007c).

Based on the above discussion, we propose the following list of phosphorus source areas in a general order of importance:

- Lawns/Landscaped Areas
- Residential Streets, Driveways, and Sidewalks
- Stream Erosion
- Land Clearing and Other Disturbed Surfaces
- Animal Waste
- Stormwater Treatment Facilities as a Phosphorus Source
- Household Products
- Septic systems

Within each source area, information regarding specific sources of phosphorus (fertilizer, pet waste, detergents, etc.) is discussed. Relative contributions of each source are difficult to quantify even after significant investigation; consequently, this list is presented in general order of priority to be used only as a starting point for developing a fine-tuned source identification list. Indeed, two of the City's priority tasks for 2007 include using pollutant loading models to identify, rank, and designate priority treatment areas and developing strategies for pollutant source reduction, such as outreach, regulations, and enforcement.

1.4.2.1 Lawns/Landscaped Areas

Matthews (2005) identifies lawn fertilizers as almost always being the single largest source of phosphorus in urban soils, while Barr (2005) identifies fertilizers as contributing 1.4 percent of the total phosphorus load in a Minnesota watershed. Although typically applied in granular form, other forms of soil amendments such as compost and mulch also contribute phosphorus to lawns and other landscaped areas. Other phosphate based chemicals typically applied to landscaped areas also contribute phosphorus, including organophosphorus pesticides such as diazinon, chlorpyrifos, and malathion, which have been detected in a Lake Whatcom storm drain (Entranco 2002). Finally, improperly handling and disposal of grass clippings, leaves, and other yard debris contributes phosphorus to urban waterways.

Cascadia (2005) conducted a telephone survey that helped determine the awareness of local residents regarding proper lawn and garden care practices in the Lake Whatcom watershed. Results from this survey were not available for this report; however, they should be used by the City to determine what lawn care practices are the primary sources of phosphorus to the watershed. The above list, as well as education programs, ordinances, etc. recommended in this report, can be fine-tuned based on the results of this source identification exercise.

1.4.2.2 Residential Streets, Driveways, and Sidewalks

Waschbusch et al. (1999) report streets as the second greatest contributor of phosphorus in an urban setting, while Barr (2005) reports that these sources contribute 41 percent of the phosphorus load in a Minnesota watershed. Less literature exists regarding the sources of phosphorus *to* streets, driveways, and sidewalks; however, due to their close proximity to landscaped areas in a residential setting such as the City of Bellingham, likely sources include:

- Fertilizers, pesticides, mulch, etc. inadvertently applied or swept/blown onto streets;
- Yard debris (leaves, clippings, etc.) raked or blown onto streets;
- Detergents containing phosphorus used to wash cars, etc.;
- Animal waste; and
- Dust and dirt from disturbed land.

Typical streets, roofs, and lawns within City of Bellingham lakeside neighborhoods

1.4.2.3 Stream Erosion

Eroding streambanks contribute sediment that in urban areas often has elevated levels of phosphorus. As alluded to, this is exacerbated in the City by increased runoff to streams and increased stream velocities. Protecting streambanks and ditches from erosion is an important component for many aspects of water quality and stream health, including phosphorus control.

1.4.2.4 Land Clearing and Other Disturbed Surfaces

Bioavailable: That portion of a chemical or contaminant that is readily accessible for uptake or adsorption by aquatic life with the potential for causing a toxic effect. That portion of the chemical that is not bioavailable does not affect or harm the exposed organism.

Within the City's portion of the watershed, land clearing is limited primarily to land being cleared for construction; however, other small scale land disturbances could include landscaping and any other activity that exposes bare soil. Typically, the vast majority of phosphorus found in the natural environment is adsorbed to sediment particles that settle out, essentially losing phosphorus from a lake system shortly after entering (Schlesinger 1991). However, Liang (1994) found that 50 percent of total phosphorus bound to the surface of soil collected from a construction site in the Lake Whatcom watershed was "bioavailable" and could be extracted by algae and microbiota. Therefore, although the vast majority of phosphorus contributed as a result of clearing in previously undisturbed areas will be adsorbed to sediment particles, it should not be ignored as a potentially significant source. This is of particular importance at redevelopment sites where exposed soils likely have elevated levels of phosphorus due to previous applications; consequently, erosion of these soils has the potential to contribute very high levels of phosphorus to the lake.

1.4.2.5 Animal Waste

Both domestic animal and waterfowl waste, which typically are most abundant in parks and lawns, also can be significant sources of phosphorus. Caraco (2003) reports that the average dog produces 1.2 pounds of phosphorus per year. Using this estimate, Barr (2005) identified pet waste as contributing 5.1 percent of the phosphorus load to a Minnesota watershed.

Geese on landscaped shores of Lake Whatcom

When present in large numbers, waterfowl (especially geese) can increase nutrient loading and shoreline erosion and harm native species populations. Reilly (pers. comm. 2007) reports that based on DNA studies, birds were identified as a major source of phosphorus to Bloedel Donovan. Additionally, in a study of phosphorus loading to Green Lake, a productive, urban lake in Seattle, Washington, Scherer and Gibbons (1995) reported that bird droppings constituted 27 percent of total phosphorus loading in 1992, 25 percent in 1993, and 34 percent in 1995.[2] Although 87 percent of phosphorus in the waterbird droppings was estimated to have come from aquatic food sources and therefore represents internal nutrient cycling, this percentage likely is lower in a low to moderately productive lake such as Lake Whatcom where a greater percentage of waterfowl's diet comes from terrestrial sources. Regardless, waterfowl may have a long-term impact on water quality by enriching sediment, stimulating macrophytes productivity, and altering nutrient cycling pathways and rates (Scherer and Gibbons 1995).

The City's portion of the Lake Whatcom watershed also contains properties with small hobby farm operations. Livestock waste from these properties may contribute elevated concentrations of phosphorus in runoff if not managed properly.

1.4.2.6 Stormwater Treatment Facilities as a Phosphorus Source

As stated previously, the City began an aggressive BMP retrofit program in 2000. Although a critical component to any stormwater management program, stormwater treatment, particularly for phosphorus control, is a relatively new field where technology is continuously being developed and refined. Additionally, technologies must be adapted to the unique circumstances of a site.

The City's stormwater treatment program is both a potential source of phosphorus as well as a sink. The City has achieved significant success and with its adaptive management program, performance is expected to improve in the future. However, based on available monitoring data, some BMPs currently appear to act as sources of phosphorus, i.e., some BMPs have negative phosphorus removal rates. The City is aware of this problem and current efforts to improve maintenance, amend treatment media, etc. should help improve performance over

---

[2] Waterbirds accounted for greater than 99% of phosphorus loading by birds at Green Lake; the primary species present were American coots, gadwalls, mallards, and various species of gulls.

time. Consequently, although a temporary concern, contribution of phosphorus from BMPs is not a long-term concern.

1.4.2.7 Household Products

Over the past 30 years, over half of the states have adopted legislation banning phosphorus as an ingredient in most non-industrial cleaning agents, including laundry detergents. As a result, phosphorus loading from household products has declined from earlier years such that it contributes approximately 10 percent of wastewater treatment plant (WWTP) effluent. In spite of this success, all states still allow phosphorus to be up to 8.7 percent of automatic dishwashing detergent products. Canada implemented a 2.2 percent phosphorus limit in 1972, and current research shows that phosphorus is not a necessary component of automatic dishwashing detergents (Illinois Association of Wastewater Industries. 2005). Washington adopted legislation effective in 1994 imposing a statewide limit of 8.7 percent on the phosphorus content of household detergents (although detergents used for commercial and industrial purposes are exempt from this regulation) (RCW 70.95L.005). Starting July 1, 2008, this limit will drop to 0.5 percent phosphorus by weight for selected counties (based on population size, and will become effective for the entire state July 1, 2010.

1.4.2.8 Septic systems

Faulty septic systems and those improperly sited can contribute phosphorus to groundwater and eventually the lake. Winsten (2004) estimates that 0 percent of phosphorus escapes from a properly functioning septic system, while 20 percent escapes from a failing system.

1.4.3 Future Source Identification

The City has proposed several sources of phosphorus in the watershed, and as detailed in subsequent sections of this report, is implementing a stormwater management program to address these sources. However, in order to maximize the effectiveness of their phosphorus control efforts, and the City should develop a prioritized source list and use it to inform various elements of its program. Based on the literature summary provided above and the City’s intimate knowledge of its portion of the watershed, the City has the information to qualitatively prioritize sources within its portion of the watershed. However, a more quantitative approach would likely be beneficial. A quantitative approach could include delineating source areas by land use and/or activity, estimating the total acreage for each source area, and calculating relative contributions based on source area acreage and weighted loading rates. The result of this exercise could provide a watershed wide phosphorus loading estimate for each source area type, which can then be used to support management decisions.

2. CURRENT CITY STORMWATER PHOSPHORUS CONTROL PROGRAM

Due to recent downward trends in the water quality of Lake Whatcom and the highly developed nature of the City's watershed (Figure 4), the City is concerned about its impact on the lake's health. Consequently, over the past decade, the City has implemented a rigorous phosphorus BMP control program which includes the components described below. In 2001, the City passed a monthly stormwater fee structure to ensure a dependable source of revenue for stormwater management, including its Lake Whatcom phosphorus control efforts.

What are Best Management Practices (BMPs)?

BMPs are practices and treatment technologies or methods that can be used to meet water quality criteria. There are many different types of BMPs. Some are treatment technologies such as bioswales and sand filters. Others are maintenance measures that can be implemented as part of a project, such as sweeping streets of debris. Some BMPs are permanent features of a project; other can be temporary measures employed during construction.

2.1 STORMWATER RETROFIT PROGRAM

The City implemented an aggressive stormwater retrofit program in 1992. To date, this program has provided treatment for approximately 246 acres, approximately 40 percent of the City's portion of the Lake Whatcom watershed (City of Bellingham 2007a). Through April 2007, BMPs constructed by the City include 10 media filters, 2 wet ponds, 1 dry pond, 3 infiltration swales, 1 biofiltration facilities (e.g., "rain gardens"), 2 sand filters, and 2 rain garden/media filter/infiltration treatment train facilities.

A **stormwater retrofit program** incorporates new BMPs and upgrades existing BMPs in existing developments.

Four additional retrofits are planned for 2007, bringing the total area covered to 263 acres (City of Bellingham 2007a). The City plans to extend its Stormwater Retrofit Program onto residential parcels. Although it will cover the entire City, preference will be given to retrofits within the Lake Whatcom watershed (City of Bellingham 2007e). BMPs currently being considered for implementation include bioswales, biofilters, rain gardens, pervious pavement, habitat/retention ponds, and roof drainage infiltration systems (City of Bellingham 2007e). In addition, the City plans to use pollutant loading models to identify, rank, and establish priority areas for treatment (ICT 2007). Lastly, the City also plans to evaluate stormwater system cost-effectiveness to identify and prioritize future retrofits within these high priority areas (ICT 2007).

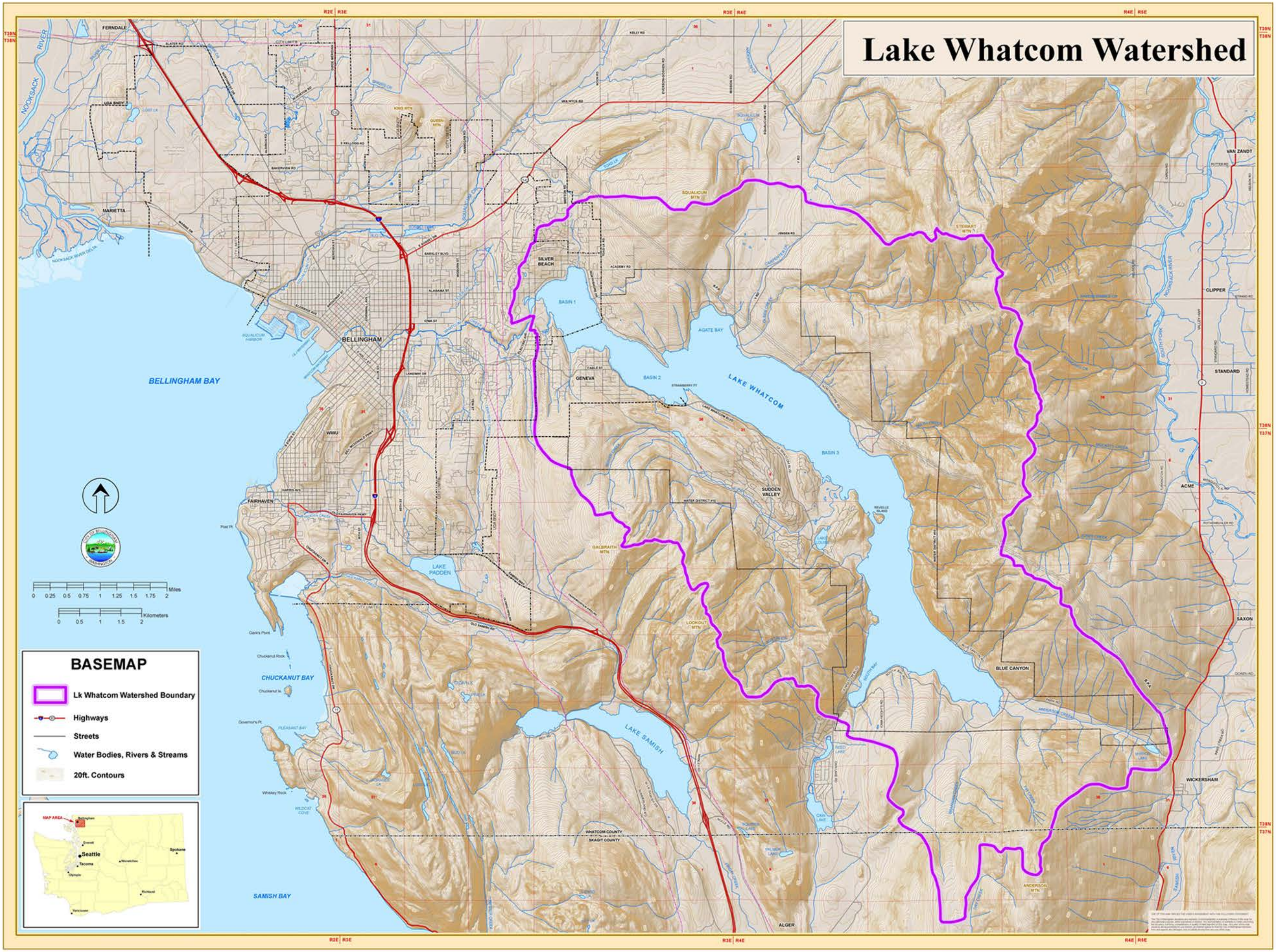


Figure 4
Lake Whatcom Watershed

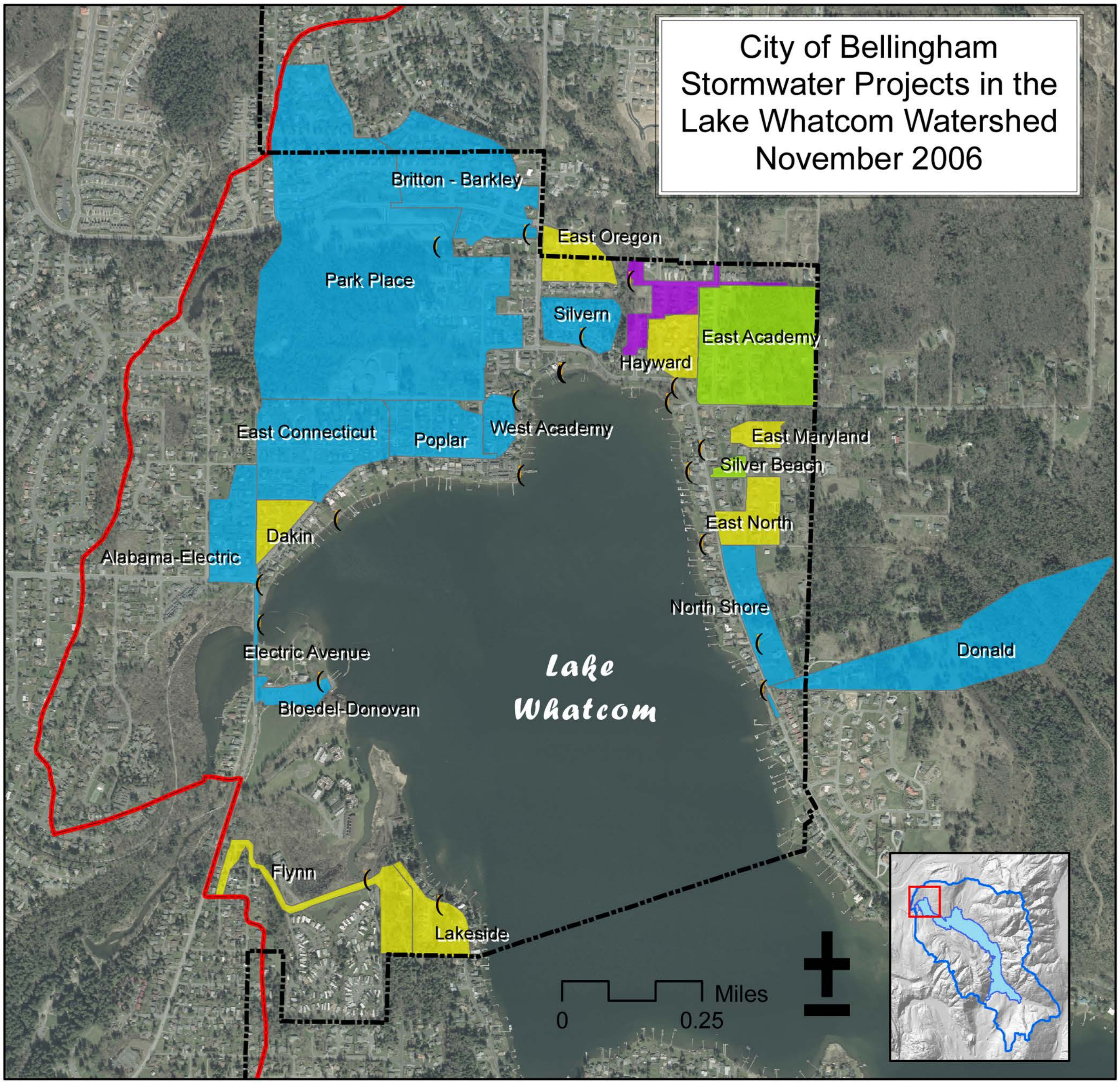
2.2 MAPPING AND BMP COVERAGE

To track the progress of the City's stormwater retrofit program, the City has created an inventory and mapped BMP coverage (Figure 5) as well as protected properties within the watershed (Figure 6). Information provided for the stormwater retrofit program includes the location and extent of four coverage types: existing, recent, future, and private. Location, area treated, completion date, and cost are also provided for each facility. Information regarding conveyance systems, facility design, etc. is not provided but is assumed to be catalogued elsewhere. The inventory of protected properties within the watershed includes three protection categories: City Protected Watershed, Whatcom County Protected, and Whatcom Land Trust. The location and extent of all protected properties, as well as current zoning for the entire watershed, also is provided.

As is evident from Figure 5, the City has made significant progress in providing treatment coverage for its portion of the watershed. Because of the City's level of development and the scarcity of undeveloped land available for preservation within its boundaries, the City has judiciously placed the vast majority of its efforts within City limits in two areas: source control and stormwater treatment.

2.3 MONITORING AND MAINTENANCE PROGRAM

To compliment its stormwater treatment program, the City has initiated an aggressive monitoring and maintenance program. The monitoring program, funded by the City but implemented primarily by WWU, monitors the performance for a representative number of the City's stormwater BMPs. The maintenance program, which includes amendments to filter media, accounts for approximately 40 to 50 percent of the program's budget. It is adaptively managed based on field observations, monitoring data, and the latest research in stormwater treatment in an effort to move the BMPs towards their maximum potential performance (Bill Reilly, pers. comm. 2007). With this level of effort and commitment, the City is on-track to maximize facility performance and should be commended for its program's accomplishments.



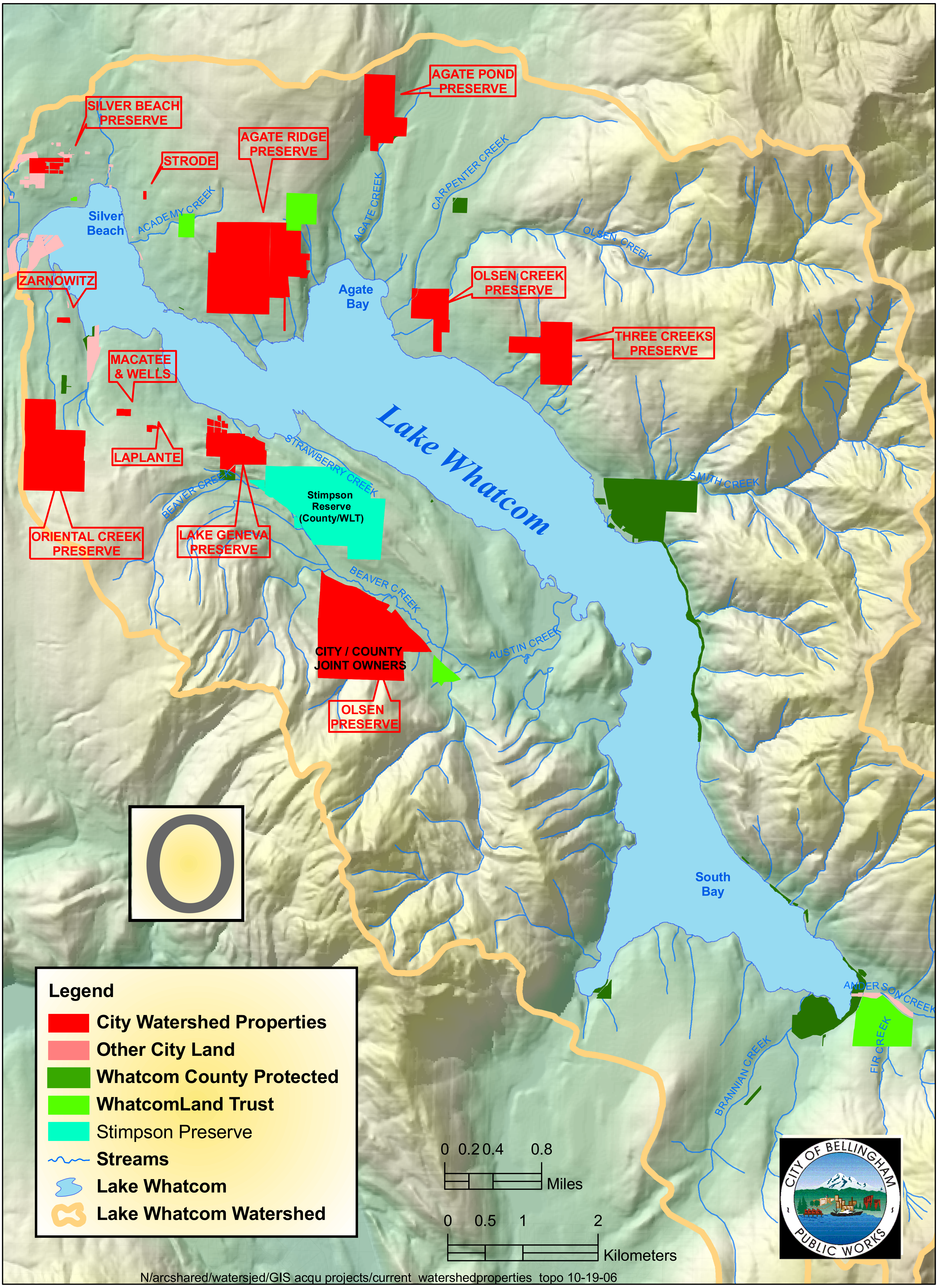
Legend

- City Limits
- Watershed Boundary
- (Stormwater Facilities
- 🟦 Existing Treatment Area
- 🟩 Recent Treatment Area
- 🟨 Future Treatment Area
- 🟪 Private Treatment Area

City of Bellingham Lake Whatcom Watershed Stormwater Projects

	Construction Year	Description	Area (acres)	Cost
Past Projects	1992	Britton & Barkley	N/A	$48,000
	1994	Park Place	117.47	$286,000
	2000	Silvern Lane	6.34	$30,000
	2002	Electric Avenue, Alabama to Bloedel	0.8	$189,640
	2003	Bloedel Donovan/Alabama Street	18.9	$198,082
	2004	E. Connecticut Outfall	25.8	$150,535
	2005	Park Place Water Quality Facility	N/A	$60,000
	2005	Poplar Drive	8.6	$120,000
	2005	W. Academy Street	2.05	$30,000
	2005	Donald Ave	28	$30,000
	2005	North Shore Swales	3.5	$50,000
Current Projects	2006	E. Academy Street	29	$120,000
	2006	Silver Beach Avenue	6	$25,000
Future Projects	2007	E. Oregon Street	6.56	$50,000
	2007	Flynn Street	10	$50,000
	2007	Brentwood Retrofit	TBD	$330,000
	2008	E. Maryland Street	2.62	$100,000
	2008	E. North Street	9	$100,000
	2008	Hayward Avenue	8.2	$100,000
	2008	Lakeside	6.88	TBD
		TOTAL:	289.72	$2,067,257

Figure 5
City of Bellingham Stormwater Projects in the Lake Whatcom Watershed, November 2006



Created 8/7/07
Data Source: City of Bellingham Public Works GIS

Figure 6
City Protected Acquisition Property in the Lake Whatcom Watershed (As of 8/3/2007)

2.4 ORDINANCES

The City is commended for its rigorous Stormwater Retrofit Program and commitment to monitoring facility performance.

Currently, the City has the following regulations in place to address phosphorus loading into the lake:

- **COB Ordinance 2001-01-001 (the Silver Beach Ordinance)** limits the amount of exposed dirt to 500 square feet from October 1st through April 30th and limits the portion of a lot that can be covered by impervious surfaces to 15 percent. This percentage can be increased through impervious area credits, e.g., by implementing a variety of on-site stormwater treatment or LID BMPs or by protecting other parcels from future development.

- **COB Ordinance 2002-03-017** revised residential street standards for the Lake Whatcom watershed.
- **COB Ordinance 2005-06-044** prohibits the use of any fertilizers containing more than 0 percent phosphorus (except when applied to newly established turf during the first growing season) and prohibits the application of any fertilizer onto impervious surfaces or when the ground is frozen.
- **COB Ordinance 2005-06-045** prohibits the operation of all carbureted two-stroke engines on the portion of Lake Whatcom located within city limits.
- **COB Ordinance 2005-11-092** designated and classified environmentally sensitive and hazardous areas as Critical Areas. The City passed this ordinance to protect, maintain, and restore these areas, as well as their functions and values, many of which benefit water quality in Lake Whatcom and its tributaries.
- **COB Ordinance 2006-05-047** formally adopted Ecology's 2005 Stormwater Management Manual for Western Washington (Ecology 2005a). This included adoption of the manual's low-impact development practices.

2.5 ACQUISITION/EASEMENT/TRANSFERABLE DEVELOPMENT RIGHTS PROGRAMS

The City initiated the Lake Whatcom Watershed Property Acquisition Program in 2001 to help protect its drinking water source. As of spring 2007, the program, which is financed by water usage fees, had acquired 773 acres of land zoned for development (City of Bellingham 2007c). In addition, the Lake Whatcom Watershed Easement Program currently holds an easement on 104 acres of privately owned land that was zoned for development (City of Bellingham 2007c). The City also plays an active role in the County's Transferable Develoment Rights (TDR) program. Established in 1999, the program designated the Lake Whatcom watershed as a sending area (LWMP 2007). The City and County have amended the program a number of times to designate additional receiving areas, adjust transfer ratios, enhance public understanding, and help facilitate the program (LWMP 2007). In 2007, the City plans to enhance the program by ensuring coordination between the City, County, and Water District and other planning efforts (ICT 2007). The City also will investigate the possibility of creating a TDR bank and an in-lieu payments option for the TDR program (ICT 2007).

2.6 ENACTMENT AND ENFORCEMENT OF STRICT DEVELOPMENT RESTRICTIONS

Both the City and County have dedicated staff that provide technical assistance to landowners developing in the Lake Whatcom watershed. Assistance provided includes explanations of applicable regulations and options that can be used to address them. These staff also coordinate with Ecology to monitor the installation and maintenance of erosion control and stormwater BMPs and are responsible for enforcing seasonal land clearing restrictions. The City also hires additional labor during the watershed building window and has a goal of inspecting each active construction site at least once per day.

2.7 YARD DEBRIS COLLECTION PROGRAM

The City regularly collects yard debris (including leaves) from private residences. This can be an effective source control, as Bannerman et al. (1996) found that about 80 percent of the total phosphorus mass in Wisconsin stormwater resides in the leaf and >250 micron size fraction.

2.8 STREET SWEEPING PROGRAM

The City implements a street sweeping program that regularly cleans all streets within its jurisdiction using a regenerative sweeper (Bill Reilly pers. comm. 2007). Street sweeping can complement other stormwater treatment practices by capturing pollutants before they are made soluble by rainwater. Street sweepers capable of removing 60 percent of the deposited total suspended solids (TSS) can reduce TP loads by 25 to 35 percent (Schilling 2005).

2.8 INCENTIVES TO DISCOURAGE PERSONAL MOTOR VEHICLE USE

The City provides a variety of incentives to residents to use public transit or another means of transportation other than a personal vehicle.

2.9 ILLICIT DISCHARGE DETECTION AND ELIMINATION

The City implements a program to detect, pursue, and eliminate illegal discharges to Lake Whatcom and its tributaries. Since 2001, the City has established a stormwater hotline to accept calls regarding stormwater issues. The City plans to reemphasize this hotline in its website update in the near future.

2.10 SEPTIC SYSTEM INSPECTION AND CERTIFICATION PROGRAM

Although the septic system inspection and certification program is implemented by the County Health Department, the City has worked with them to ensure that all septic systems within the Lake Whatcom watershed receive priority for compliance inspections.

Additionally, on-site septic systems are no longer allowed for development within City limits (Bill Reilly pers. comm. 2007).

2.11 EDUCATION AND OUTREACH PROGRAMS

The City has taken a proactive role in educating the public, general contractors, landscapers, etc. about the importance of controlling phosphorus in the watershed. Two examples of these programs are the Healthy Hounds initiative, which encourages pet owners to properly dispose of waste, and a "watershed friendly" certification program for landscapers, retailers, and realtors, which the City plans to develop in 2007.

2.12 PLANNED FUTURE EFFORTS

In addition to the programs outlined above, the City intends to implement the following measures in 2007 as part of its stormwater management program:

- Coordinate the stormwater management program with other City programs and groups, particularly the transportation group.
- Develop and implement a system for tracking development in the watershed.
- Enhance the established joint development review process.
- Evaluate options for consistent development regulations in the City and County.
- Complete the City Shoreline Management Plan to make it consistent with new state requirements.

The City of Bellingham has instituted an extensive stormwater treatment facility retrofit program along with a complementary performance monitoring program to control stormwater phosphorus. Furthermore, the City has implemented, and/or plans to implement, other source control and programmatic BMPs in an effort to provide a holistic approach to controlling for phosphorus in stormwater runoff.

3. AVAILABLE PHOSPHORUS TREATMENT BMPS AND CITY BMP PERFORMANCE

Best management practices for phosphorus removal can be sorted into several categories that share similar features (Table 5). Overall, those practices that infiltrate and filter stormwater exhibited the highest median removal efficiencies (Table 5) as well as recorded the greatest potential removal efficiencies (Table 5). This was particularly true for soluble phosphorus (Table 5).

Table 5. Median Phosphorus Removal Efficiencies for Stormwater Treatment Practice Groups (Reproduced without modification from Caraco 2001)

BMP	TP [%]	Soluble P [%]
Infiltration Practices	80	85*
Filtering Practices	59	3
Stormwater Wet Ponds	21	66
Stormwater Wetlands	49	36
Water Quality Swales	34	38
Stormwater Dry Ponds	19	-6*

*Data based on fewer than five performance studies

The following sections review these BMP practices and the removal mechanisms proposed for each type. Specific characteristics associated with total phosphorus removal are presented, followed by a discussion of options available to the City of Bellingham for retrofitting and enhancing current phosphorus removal efforts.

> [Special Note: Most of the literature studies reviewed here only presented information for total phosphorus, and not the soluble form. Consequently, we focus here solely on total phosphorus removal in order to be able to appropriately compare removal efficiencies of the different types of removal practices examined in this overview.]

3.1 INFILTRATION/BIORETENTION

Pervious driveway in Lake Whatcom Watershed

Infiltration practices involve the capture, detention and percolation of stormwater through the underlying structures (e.g., porous pavement, vegetation) into the underlying soil layers. As noted above, infiltration practices have proven to be the most effective at removing total phosphorus of all the practices reviewed (Caraco 2001, Delaware DNR 2007). A specialized form of infiltration BMP practice, bioretention treatment BMPs are composed of layers of soil (often with a high sand content) overlaid with either mulch or compost, and then planted with a variety of plant species (Davis et al. 2001, 2006, Hsieh and Davis 2005a,b, Hsieh et al. 2007). A low impact development (LID) practice, these facilities remove phosphorus by first retaining stormwater via infiltration and then filtering, absorbing, or biotransforming this pollutant as the stormwater infiltrates through the underlying soil and plant roots.[3] Treated stormwater is then either discharged to groundwater or to a stormwater system through perforated pipe underdrains.

While the capability of bioretention facilities to remove total phosphorus has been found to vary over a wide range (-178 to 99 percent, Table 6), bioretention has proven to be an effective treatment approach (Table 5). This treatment practice can often achieve maximum removal efficiencies greater than the 50 percent median total phosphorus removal realized by the typical stormwater practice (Caraco 2001).

Low removal efficiencies were observed in a column study with 91 percent mulch, suggesting that mulch does not play an important role in phosphorus removal (Hsieh and David 2005b). After excluding the results of this mulch column experiment, the minimum removal efficiency measured was 37 percent (Hsieh and David 2005b).[4] In both of the studies found to discharge higher effluent phosphorus levels relative influent levels Davis et al. 2001 and Dietz and Clausen 2005 the flow path appeared to be shortened, limiting contact time with the media and desorbing phosphorus from the upper mulch layers.

The variability observed in these experimental treatments is reflective of the dual mechanisms involved in phosphorus retention—fast and slow reactions (Figure 5) (Hsieh et al. 2007). Fast reactions are reversible absorption onto media surfaces (as likely occurs with mulch). Slow reactions involve the deposition of phosphorus with iron and aluminum oxide materials and chemical precipitation of calcium phosphate (McGechan and Lewis 2002). Phosphorus deposition and precipitation are pH-dependent, with higher levels of removal at acidic pH conditions.

Factors found to correlate with higher percent removals (>75 percent) in bioretention experiments were percent organic matter in the soil layer (Hsieh and Davis 2005b) and contact time with the adsorptive media (Davis et al. 2006, Hsieh et al. 2007). Hsieh et al. (2007) found that placing a high conductivity media over a lower conductivity one promoted both infiltration (through the high conductivity media) and 85 percent phosphorus mass removal (by promoting higher contact times through increased retention due to the underlying layer of the lower conductivity media) compared to columns with the reverse arrangement (low conductivity media over high).

Ecology has established an overall set of site suitability criteria for siting infiltration facilities, such as bioretention facilities (Section 3.3.7, Ecology 2005a). Specific characteristics of bioretention water quality treatment facilities associated with phosphorus removal are:

- Soil layer combinations that enhance initial rapid infiltration to retain stormwater (limiting runoff) while increasing contact time with soil and roots prior to discharge.
- High levels of organic matter (minimum of 10 percent by dry weight [Hinman 2005]).
- Effective management of the growth and harvesting of vegetation in bioretention facilities contributes to removing a major portion of captured phosphorus (Davis et al. 2006).

---

[3] The inclusion of a high sand content, at least in the upper layers, can be important in promoting rapid infiltration and preventing pooling.

[4] Mulch has been found to play an important part in metals removal (Davis et al. 2001).

Table 6. Removal efficiencies of water quality treatment Best Management Practices (BMPs)

Category	Treatment BMP	TP Removal Efficiency	Reference
Infiltration	Infiltration Trench	>90%	Caraco 2001
	Infiltration Practices	70%	Delaware DNR 2007
	Porous Pavement	65%	Caraco 2001
Bioretention	Bioretention Media (sandy loam, mulch, creeping juniper) Bioretention Column (Mixtures of mulch, soil, sand) Rain Garden Bioretention Media (Mixtures of mulch, soil, sand) Bioretention Media (1 mixture of mulch, soil, sand) Bioretention Media (sandy loam, mulch, creeping juniper) Bioretention (varied media from several studies) Stormwater Infiltration Basin Rain Gardens	70-85% 63-85% 81% 47-68% 4-99% -179-81% 65% 51% -100%	Davis et al. 2006 Hsieh et al. 2007 Delaware DNR 2007 Hsieh and Davis 2005a Hsieh and Davis 2005b Davis et al. 2001 Caraco 2001 Birch et al. 2005 Dietz and Clausen 2005
Filtration	Multi-chambered treatment train	88%	Greb et al. 2000
	Sand Filter	41%	Delaware DNR 2007
	Steel Enhanced Sand Filtration	34-81%	Erickson et al. 2007
	Steel Enhanced Sand Filtration	25-99%	Anderson-Wenz 2005
	Delaware Sand Filter	72.30%	JSPPO Handbook 2004
	Organic Filter	61%	Caraco 2001
	Surface Sand Filter	59%	Caraco 2001
	Vertical Sand Filter	45%	Caraco 2001
	Perimeter Sand Filter	41%	Caraco 2001
	Austin Sand Filter	33%	JSPPO Handbook 2004
Wet/Dry Ponds	Wet ponds	20-50%	Comings et al. 2000
	Multiple Pond System	76%	Caraco 2001
	Pond/Wetland System	56%	Caraco 2001
	Wet Extended Detention Pond	55%	Caraco 2001
	Stormwater Wet Ponds	50%	Delaware DNR 2007
	Wet Pond	49%	Caraco 2001
	Stormwater Dry Ponds	25%	Delaware DNR 2007
	Dry Extended Detention Pond	20%	Caraco 2001
Swales	Grassed swales	28.8-98.6%	Yu et al. 2001
	Dry Swale	83%	Caraco 2001
	Grass filter	46%	Deletic and Fletcher 2006
	Water Quality Swales	34%	Delaware DNR 2007
	Grass Channel	29%	Caraco 2001
	Wet Swale	28%	Caraco 2001
Wetlands	Submerged Gravel Wetland	64%	Caraco 2001
	Stormwater Wetlands	49%	Delaware DNR 2007
	Shallow Marsh	43%	Caraco 2001
	Extended Detention Wetland	39%	Caraco 2001

3.2 FILTRATION

A common wastewater and drinking water quality treatment practice, sand filters have been used to treat storm water quality since their application by the City of Austin in the late 1980s (USEPA 1994). The basic configuration of a sand filter consists of a sedimentation chamber to remove floatables and heavy sediments and a filtration chamber which removes additional pollutant by filtering flow through a sand layer (USEPA 1994). The treated filtrate is typically discharged to a storm drain conveyance system through a perforated pipe underdrain. Advances on this basic design have involved adding a re-settling grit chamber and amending the sand bed with peat and activated carbon in a multi chambered treatment train (Greb et al. 2000).

The utility of sand filters is their adaptability to limited space, particularly in site retrofits and the wide range of pollutants that can be removed. Pre-caste concrete sand filters can be placed at the surface and in underground vaults at small sites where ponds and other treatment facilities are not feasible due to space constraints. Long-term performance of sand filters may be maintained by frequent inspections and replacement of at least the top of the media every three to five years, depending on the pollutant load being treated. Depending on the sediment load, accumulated debris may need to be removed approximately every six months.

The overall performance of this class of BMP ranges from 25 to 99 percent removal of total phosphorus (Table 6). Phosphorus removal in the 25 to 50 percent range is typically expected of systems using only silica sand in the filtration chamber (Anderson-Wenz 2005, Caraco 2001, Delaware DNR. 2007, Erickson et al. 2007, JSPPO Handbook 2004). Higher rates of total phosphorus removal have been achieved by amending the sand with a variety of metal particles, particularly steel and alumina (Anderson-Wenz 2005, Erickson et al. 2007). Amendment materials have consisted of chopped steel wool, slag from blast-oxygen furnaces, and aluminum oxide (Erickson et al. 2007). These findings parallel the discussion presented above concerning role of metals in slow removal reactions (McGechan and Lewis 2002). It is likely that design features promoting longer contact times with these metal amended sands would be equally associated with higher percent removal efficiencies.

Glen Meadows wet pond

Specific characteristics of sand filter water quality treatment facilities associated with phosphorus removal are:

- Removal of heavy sediments by pre-settling, and
- Deposition of phosphorus with iron and alumina particles amended into the sand bed

3.3 WET/DRY PONDS

While the basic pollutant removal mechanism in stormwater treatment ponds is particle settling, phosphorus removal is better associated contact with sediments (Comings et al. 2000). The basic pond design consists of a series of ponds or cells separated by weirs, where the initial ponds remove the heavier, more readily settled particles, with finer particles passing through to next ponds in the treatment train. Design features that allow for "short-circuiting" of the flow path and reduce the amount of time stormwater is detained in the treatment facility can limit phosphorus removal efficiency (Comings et al. 2000)

Thus the general pattern for pollutant removal, and specifically phosphorus, is that removal efficiencies increase the longer the period that stormwater is retained in the pond treatment facility (Delaware DNR 2007, Caraco 2001). Phosphorus removal efficiencies for wet ponds can range from 20-76 percent, but the bulk of the studies reviewed found removal efficiencies in the 50 to 60 percent range (Table 6). Ponds without dead storage (ponds that completely infiltrate, evaporate, or discharge treated stormwater between wet weather events) record much lower phosphorus removal efficiencies (20 to 25 percent) (Table 6).

Specific characteristic of wet pond water quality treatment facilities associated with phosphorus removal are:

- Extended flow paths that result in increased exposure to sediments

3.4 SWALES

Constructed swales for water quality treatment are vegetated (usually grass) open drains set perpendicular to the general overland flow of stormwater that remove pollutants by the physical processes of filtration, deposition, and infiltration (Deletic and Fletcher 2006). As with the above BMPs, features that increase contact time (length, longitudinal slope and the inclusion of check dams that cause pooling) have been associated with increased phosphorus removal (Yu et al. 2001, Delectic and Fletcher 2006). Of these three, length and check dams account for bulk of phosphorus removal achieved, with slope having only a minor effect (Yu et al. 2001, Delectic and Fletcher 2006). Swale performance has been found to highly variable (0 to 97 percent, Table 6), with these treatment BMPs being susceptible to clogging via sedimentation which can increase flows and decrease retention times.

Maynard infiltration swale

Specific characteristic of swale water quality treatment facilities associated with phosphorus removal are:

- Swale length (Deletic and Fletcher [2006] recommend a minimum length of 75 meters for pollutant removal),
- Presence of check dams that slow flows and detain and pool stormwater, and
- Longitudinal slope

3.5 WETLANDS

Phosphorus removal by wetlands varies between 40 and 60 percent, and depends on the processes described above for wet ponds and grass swales (Caraco 2001, Delaware DNR 2007). The observed variability relates in part to internal phosphorus cycling within the wetland, phosphorus release from sediments, and vegetative dieback during the non-growing season (Caraco 2001). The higher removal levels were typically associated with wetlands with larger proportions of their storage in deep pools. Treatment wetlands have been found to have elevated phosphorus levels in their upper sediment layers (Chimney and Moustafa 1999), and are potential exporters of phosphorus during high flows that remobilize these sediments.

Specific characteristic of wetland water quality treatment facilities associated with phosphorus removal are:

- Deep pools and significant portions of open water, and
- Longer flow paths through the wetland that decrease flow and increase retention times

3.6 REVIEW OF CITY BMP MONITORING DATA

First, it is important to note that the City has employed an example of at least one BMP from each of the Stormwater Treatment Practice Groups reviewed above and has, along with WWU, been monitoring their performance for several years.

The City has employed an example of at least one BMP from each of the Stormwater Treatment Practice Groups identified for phosphorus control

For this evaluation, we reviewed data from WWU's most recent report (Lake Whatcom Monitoring Project – 2005/2006 Final Report by Matthews et al) and from stormwater monitoring conducted by the City in 2005, 2006, and 2007. Our review was limited to these two data sources and time frames primarily because they offer the most expansive and up to date sampling of the City's suite of stormwater BMPs. Additionally, although sampling dates vary, by analyzing within a limited timeframe, variability in weather conditions, storm events, etc. is reduced.

Media filter stormwater treatment facility

Monitoring reports reviewed as part of this analysis include data from the following BMPs located within the City of Bellingham. All of these BMPs are in the Lake Whatcom watershed, except the South Campus BMP, which is located on the WWU campus.

- Alabama Street and Electric Avenue Stormwater Vault
- Park Place Sand Filter
- Brentwood Wet Pond
- Bloedel Donovan Filter Vault
- Bloedel Donovan Rain Garden
- South Campus Facility (a combination of grass swales and rock/plant filters)

Of these monitoring locations, only the South Campus facility had statistically significant reductions of total phosphorus (Matthews et. al. 2007) (Table 7). All other sites either (1) exported phosphorus, (2) had minimal reductions that are not statistically significant from zero, or (3) the number of sampling events is too small to make a determination regarding performance (Matthews et al. 2007; City of Bellingham 2007d). In the latter of these three categories is the Park Place facility, which was retrofitted in 2006. Prior to the retrofit, the facility consisted of a series of three wet ponds that were undersized for their treatment area. Consequently, inadequate detention times and performance were realized. In 2006, the City replaced the second two ponds with sand filters (Bill Reilly pers. comm. 2007). Monitoring conducted in July and November of 2006 (presumably after the facility was allowed to establish/“season”) showed promising removal rates; however, additional data are required to confirm the performance and reliability of this facility.

Based on these results, sand filters and complex swale/filter systems such as the South Campus facility show the greatest promise for removal of TP from stormwater runoff in the urban portions of the Lake Whatcom watershed. Treatment trains consisting of wet ponds and sand filters also may perform well.

Table 7. Reduction of TSS and TP of Selected Stormwater Treatment BMPs.

Facility	Sampling Period	Mean % Reduction TSS (statistical significance)	Mean % Reduction TP (statistically significant)	Mean Effluent [TP] µg/L
Alabama Hill[1]	2005/2006	31.6 (0.05)	-7.2 (NS[3])	195
Brentwood Wet Pond[1]	2005/2006	-51.0 (0.05)	-11.1 (NS)	NA
South Campus[1]	2005/2006	80.0 (<0.0001)	50.3 (<0.0001)	24
Park Place Wet Pond[1]	2005/2006[4]	14.5 (NS)	-5.1 (NS)	80
Park Place WP/Sand Filter[2]	2006[5]	95 (NA)	65 (NA)	76
Bloedel Donovan Sand Filter[2]	2006/2007	NA	-10.5 (NA)	227
Bloedel Donovan Rain Garden[2]	2005 - 2007	25[6] (NA)	-164 (NA)	234

Notes: 1 Source: Matthews et al. 2007

2 Source: City of Bellingham 2007d

3 NA = not available; NS = not significant

4 The final sample date for the 2005/2006 Monitoring Report was 5/23/06.

5 Sample dates were 7/12/06 and 11/2/06, after the WWU 2005/2006 Monitoring Report had been drafted and the retrofitted facility had time to establish.

6 Results are for turbidity (not TSS) and are reported in NTUs.

3.7 PERFORMANCE OF THE CITY'S BMPS

The performance of currently functioning City phosphorus removal BMPs was calculated by comparing the concentrations of phosphorus going into a BMP (termed the influent) with the concentration of phosphorus in the stormwater leaving a BMP (termed the effluent). Percent removal is calculated using the following equation:

$$\text{Percent Reduction} = \left[\frac{\text{Influent Concentration } (\mu\text{g/L}) - \text{Effluent Concentrations } (\mu\text{g/L})}{\text{Influent Concentration } (\mu\text{g/L})}\right] * 100$$

When there is more phosphorus in the effluent (outgo) than in the influent (incoming), then the percent removal is calculated to be a negative value. Review of Table 7 shows that the mean percent reduction of total phosphorus for the Alabama Hill, Brentwood Wet Pond, Park Place Wet Pond, Bloedel Donovan Sand Filter, and Bloedel Donovan Rain Garden are all negative. It is important to note that these measurements were either not significant or calculated from too few measurements to make meaningful comparisons. Given this caution, it is still possible to state that there is not evidence that these facilities are reducing total phosphorus concentrations in the stormwater treated by each.

In contrast, two facilities–South Campus and Park Place WP/Sand Filter–have positive percent reductions of total phosphorus, meaning that for these facilities the measured effluent phosphorus concentrations were less than the measured influent concentrations. This result was significant (meaning less than a 5% probability of error) for South Campus treatment facility. The measured 50% reduction is well within the range of removal values presented in Table 6, with swales, wet ponds, and un-amended sand filters generally showing lower removal efficiencies and most bioretention and amended sand filters generally removing greater percentages of phosphorus.

- ☐ **Several of the City's treatment facilities do not appear to be reducing phosphorus levels.**
- ☐ **The South Campus and Park Place treatment facilities do appear to reduce phosphorus.**
- ☐ **Continued monitoring will be important to establish a statistically significant pattern of removal or addition of phosphorus.**

4. PHOSPHORUS LOADING TO LAKE WHATCOM: PRELIMINARY APPROACH

This section describes a preliminary approach to evaluating future phosphorus loadings into Lake Whatcom based on simple desktop calculations. The purpose of this exercise is to explore the use of loading estimates and City BMP performance data to support future phosphorus control strategies. It should be noted that these analyses are based on limited data and many assumptions regarding associated land use, subbasin contribution, and BMP performance.

As stated in Section 1, approximately 13 percent of the Lake Whatcom watershed (4,007 acres) is currently developed. Under current zoning, an additional 3,208 homes could be constructed on 5,552 acres (City of Bellingham 2007c). Full build out of the watershed (which, based on current building rates, would occur in 12 years) could add approximately 16,000 more residents than lived in the watershed in 2000 (Entranco 2002; City of Bellingham 2007c).

With the prospect that future development will lead to increased phosphorus loading to Lake Whatcom, the following steps are proposed as an approach to addressing the problem at the watershed level. First, there will be a need to establish a target phosphorus loading. Then, loading estimates under current conditions can be calculated (undeveloped plus developed land with some level of assumed BMP treatment), as well as under possible future conditions. The latter could also include an evaluation of future loadings assuming that one of the better performing BMPs cited by Matthews et al. (2007) could be used. These loadings can then be compared to the target loadings to determine how much more might need to be undertaken to achieve the watershed’s goals and provide input to overall approach. These steps are described below.

4.1 ESTABLISHING TARGET PHOSPHORUS LOADING

Three possible options exist for establishing a target phosphorus loading rate to Lake Whatcom:

1. **No net increase** – Under the no net increase option, the watershed’s current loading rate would be estimated and established as the maximum allowed for the watershed. This has two primary implications: (a) all existing sources must maintain current load rates or reduce current load rates to accommodate for future development, and (b) any future activities that have the potential to increase phosphorus loading must be off-set by reducing loading at another location by an equal or greater amount.
2. **Percent reduction over current loading estimate** – Similar to the “no net increase” option, a percent reduction approach begins with an estimate of current loading. It differs in that it reduces the current loading estimate by a specified amount or percentage to establish the maximum load rate for the watershed. This reduction typically is a policy decision that is partially established based on water quality goals, and/or performance of best available treatment technology.
3. **TMDL** – Under this option, the loading rate designated in a TMDL is established as the maximum allowed for the watershed. In addition to establishing the maximum acceptable loading rate, the TMDL also will allocate maximum load rates to individual land uses and point sources. Ecology plans to publish the Lake Whatcom phosphorus TMDL in the near future (sometime in 2007).

4.2 ESTIMATING PHOSPHORUS LOADING RATES BY LAND USE

For the purpose of this exercise, sampling data collected by Matthews et al. (2004) for the Lake Whatcom monitoring project were used. Data from two Lake Whatcom subbasins were selected: Smith Creek representing a relatively undeveloped subbasin, and Silver Beach Creek representing a developed urban subbasin. Smith Creek is a forested subbasin that flows into Basin 3 of Lake Whatcom. It has the lowest percentage of impervious surface of all Lake Whatcom subbasins (0.11 percent) and can be used to represent phosphorus loadings from relatively undeveloped land (Entranco 2002). In contrast, the Silver Beach Creek subbasin is the most developed subbasin in the Lake Whatcom watershed. It is dominated by low-intensity development, with small patches of high-intensity development, and has 22.6 percent impervious cover (Entranco 2002). These data can be used to estimate annual phosphorus loading rates for undeveloped and developed land uses, and then to estimate loading rates to the lake under current and possible future conditions.

4.2.1 Undeveloped Land Loading Rates (Smith Creek)

For Smith Creek, the 2004/2005 Lake Whatcom Monitoring Report reports a mean TP concentration of 17.4 µg/L and a mean discharge of 10.17 cfs (Matthews et al. 2006). Using these data, annual phosphorus loading rates from this subbasin can be estimated:

10.17 cfs X 1 MGD/1.55cfs = 6.57 MGD

17.4ug/L X 3.79L/gal = 65.9ug/gal X 1lb/453,592,370ug = 1.453xe-7lb/gal

Annual TP load rate = 1.453xe-7lb/gal X 6.57 MGD X 365days/year = 349 lbs/year

The Smith Creek subbasin is 3,305 acres (Entranco 2002). Using this area allows the annual per acre load rate to be calculated. Because the Smith Creek watershed is almost completely undeveloped, this per acre load rate can be used to estimate phosphorus loading from any undeveloped portion of the Lake Whatcom watershed.

Undeveloped Land TP Load Rate = 349lbs/year ÷ 3,305 acres = 0.11 lbs/acre/year

4.2.2 Developed Land Loading Rate (Silver Beach Creek)

The same series of calculations can be used to estimate the per acre loading rate from the Silver Beach Creek subbasin, with reported mean TP concentration of 45.7 ug/L, a mean discharge of 1.36 cfs, and an area of 435 acres (Entranco 2002).

1.36 cfs X 1 MGD/1.55cfs = 0.88 MGD

45.7ug/L X 3.79L/gal = 173.20ug/gal X 1lb/453,592,370ug = 3.818xe-7lb/gal

Annual TP load rate = 3.818xe-7lb/gal X 0.88 MGD X 365days/year = 123 lbs/year

Developed Land TP Load Rate = 123lbs/year ÷ 435 acres = 0.28 lbs/acre/year

Since Silver Beach Creek Subbasin is nearly 100 percent developed, it is assumed that loading rates from any developed areas are at least 0.28 lbs/acre/year.[5] It should be noted that this loading rate does reflects some level treatment within the subbasin although this cannot be quantified at this time without more accurate information on BMP coverage, or the type of BMP. Furthermore, the topography and development within the Silver Beach Creek subbasin

---

[5] This method includes loading from nonpoint sources only. Any loading from precipitation, the MF Nooksack River diversion, point sources, etc. are not considered. Consequently, this estimate should be used only to inform land use decisions and not as an estimate of total loading to the lake.

is likely introduce a certain amount of error into this calculation. For example, from available maps, it appears that several small drainages included in this subbasin drain directly to the lake and therefore are not tributaries to Silver Beach Creek. Constructed ditches, drainage swales, etc. may exacerbate this error. These factors likely make the designated subbasin area larger than the actual area that drains to Silver Beach Creek. Consequently, the acreage by which the total annual load is divided is too high, thereby making the per acre load rate artificially low. To minimize errors such as this, a more accurate delineation of the subbasins would be needed.

4.3 ESTIMATING CURRENT AND FUTURE PHOSPHORUS LOADING RATES

The per acre loading rates calculated above allow the current and future watershed wide phosphorus loading rates to be estimated based on the primary land uses in the watershed (forestry and urban development).

4.3.1 Current Loading Estimate

The Lake Whatcom water shed is estimated to be 31,127 acres with 4,007 acres of developed land (City of Bellingham 2007c). Assuming the remainder is in a relatively undisturbed condition, the following calculations can be used to estimate current loading:

Watershed size = 31,127 acres (4,007 acres developed; 27,120 acres undeveloped)

Estimated loading from developed land = 4,007 acres X 0.28 lbs/acre/year = 1,122 lbs/year

Estimated loading from undeveloped land = 27,120 acres X 0.11 lbs/acre/year = 2,983 lbs/year

Estimated Current TP Loading = 1,122 + 2,983 = 4,105 lbs/year

4.3.2 Future Loading Estimate

Current zoning allows an additional 5,552 acres of future development (City of Bellingham 2007c). Assuming 100 percent of this land is developed, the following calculation provides an estimate of possible future loading:

Watershed size = 31,127 acres (9,559 acres developed; 21,568 acres undeveloped)

Estimated loading from developed land = 9,559 acres X 0.28 lbs/acre/year = 2,677 lbs/year

Estimated loading from undeveloped land = 21,568 acres X 0.11 lbs/acre/year = 2,372 lbs/year

Estimated Future TP Loading = 2,677 + 2,372 = 5,049 lbs/year

Based on these estimates, future development (with assumed same level and type of BMP treatment) could increase phosphorus loading by 944 pounds per year above current levels.

4.4 ESTIMATING FUTURE PHOSPHORUS LOADING RATES USING TREATMENT BMPS

For comparison purposes, the following calculations were performed assuming (a) that future development could be treated using the South Campus BMP and that existing development could be retrofitted with the South Campus BMP, and (b) that only future development could be treated using the South Campus BMP and that existing development maintained current levels of treatment.

The South Campus BMP was selected for this exercise since it appears to be the most effective BMP in the City of Bellingham's stormwater treatment program (Matthews et al. 2007). Its mean percent removal for total phosphorus during the 2005/2006 sampling period was 50.3 percent with a mean effluent concentration of 24 µg/L.

Using this concentration for the Silver Beach Creek subbasin results in the following:

4.4.1 Future Development and Existing Development with South Campus BMP

Developed Land TP Load Rate with South Campus BMP = 0.15 lbs/acre/year

Estimated loading from developed land with South Campus BMP = 9,559 acres X 0.15 lbs/acre/year = 1,434 lbs/year

Estimated loading from undeveloped land = 21,568 acres X 0.11 lbs/acre/year = 2,372 lbs/year

Estimated Future TP Loading with South Campus BMP = 1,434 + 2,372 = 3,806 lbs/year

Based on these estimates, if future development was able to use the South Campus BMP and if existing development could be retrofitted with the South Campus BMP, phosphorus loadings could be around 3,806 lbs/year; below the 4,105 lbs/year under current conditions. This assumes that a treatment BMP such as the South Campus could indeed be utilized and that it would continue to function as efficiently as it has to date. Since the South Campus BMP is a complex facility that is expensive to construct and has a large footprint, using such a facility for future development and even retrofitting existing development may not be a viable solution.

4.4.2 Future Development with South Campus BMP, Existing Development with Current BMPs

Developed Land TP Load Rate with South Campus BMP = 0.15 lbs/acre/year

Estimated loading from future developed land with South Campus BMP = 5,552 acres X 0.15 lbs/acre/year = 833 lbs/year

Existing Developed Land TP Load Rate with current BMPs = 0.28 lbs/acre/year

Estimated loading from existing developed land with current BMPs = 4,007 acres X 0.28 lbs/acre/year = 1,122 lbs/year

Estimated loading from undeveloped land = 21,568 acres X 0.11 lbs/acre/year = 2,372 lbs/year

Estimated Future TP Loading = 833 + 1,122+ 2,372 = 4,327 lbs/year

Based on these estimates, if future development was able to use the South Campus BMP and if existing development maintained its current level of BMP treatment, phosphorus loadings could be around 4,327 lbs/year; slightly above the 4,105 lbs/year under current conditions. Under such circumstances, the watershed will have to find opportunities, in addition to treatment BMPs, to control for phosphorus in stormwater runoff to Lake Whatcom.

4.5 METHOD ASSUMPTIONS

In addition to some of the assumptions mentioned above in the calculations, additional assumptions include the following:

1. Urban development patterns and densities within the Silver Beach watershed are representative of both current and future development.
2. The Silver Beach Creek subbasin is at 100 percent build-out.
3. Smith Creek subbasin is completely undeveloped and does not have any other activities that contribute anthropogenic sources of phosphorus, e.g., application of phosphate based herbicides or fertilizers.
4. The 2004/2005 sampling period is representative of precipitation, runoff, source contribution, and other factors that would affect phosphorus loading in the watershed.
5. This method includes loading from nonpoint sources only. Any loading from precipitation, the MF Nooksack River diversion, point sources, etc. are not considered. Consequently, this estimate should be used only to inform land use decisions and not as an estimate of total loading to the lake.

5. OPPORTUNITIES AND RECOMMENDATIONS FOR ENHANCING THE CITY'S PHOSPHORUS STORMWATER MANAGEMENT PROGRAM

This section discusses potential opportunities for the City to improve its phosphorus stormwater management program. While it includes a discussion on how the City can enhance the performance of its current phosphorus treatment BMPs, it is noted that treatment BMPs can only be part of a stormwater phosphorus control program. It is unlikely that stormwater treatment alone will meet the phosphorus control requirements for the Lake Whatcom TMDL and associated water quality regulations. Thus, this section also provides the City with ideas on updating existing ordinances, implementing source controls, instituting product bans, and applying land use modifications in conjunction with its stormwater treatment program. Thus, this section concludes with a summary of recommended programmatic management options for the City to consider.

5.1 ENHANCING PHOSPHORUS TREATMENT BMPS

As the above review demonstrates, the City of Bellingham has employed an example of at least one BMP from each of the Stormwater Treatment Practice Groups presented in Tables 5 and 6. Clearly the watershed will benefit from reaching the goal of a complete retrofit of city neighborhoods within the Lake Whatcom Watershed (as well as the remainder of the City). Additionally, this review emphasizes the potential for enhancing BMP performance by focusing on the main phosphorus removal mechanism, namely the slow reaction (as shown in Figure 2). As noted above, the specific characteristics associated with greater levels of phosphorus removal are longer detention of stormwater within the treatment facility and increased exposure to sediments and soil amendments, particularly iron particles. Strategies for longer contact times include reduced permeability in lower sand layers (bioretention and filtration), reduced flows (swales), and increased flow paths (wet ponds and wetlands).

Several soil factors have been found to influence the adsorption and precipitation of phosphorus to iron-rich soils and, conversely, the solubility of phosphorus in water with accompanying mobility (i.e., movement through soil to the groundwater [Figure 3]) (Chardon and Schoumans 1999; McGechan and Lewis 2002). The water solubility/mobility of phosphorus in soils is increased when soils become more basic (higher pH), as temperatures increase, and soil organic acids increase (Table 8). Phosphorus water solubility/mobility decreases with higher levels of soil oxygen (termed redox potential) (Table 8). Of these soil factors, it is possible to design and maintain stormwater facilities to maintain well oxygenated, acidic soil conditions. Soils can be acidified by adding sawdust, composted leaves, wood chips, cottonseed meal, leaf mold and peat moss. Soil oxygen levels can be maintained by keeping them well-drained.

Table 8. Influence of soil factors on phosphorus water solubility

Soil Factor	Low	High
pH	P solubility decreases	P solubility increases
Soil oxygen	P solubility increases	P solubility decreases
Temperature	P solubility decreases	P solubility increases
Organic Acids	P solubility decreases	P solubility increases

The City retrofit program has already employed some of these approaches (e.g., check dams in swales to reduce flows and increase ponding) and has been experimenting with adding alum to filters. We endorse these efforts and recommend building on them, such as evaluating existing and future stormwater treatment facilities for increased detention possibilities and testing a range of soil/sand filter amendments for increased phosphorus removal. An additional approach that could address both of these issues is the development of treatment trains, systems consisting of a series of BMPs and natural features, each designated to treat different aspects of runoff such as TSS removal and phosphorus binding and precipitation. We also recommend prioritizing bioretention and filtration practices over wetlands and ponds (particularly dry ponds), when applicable to site conditions.

The City of Bellingham can profit from continuing to enhance the performance of existing phosphorus treatment BMPs. Specific opportunities include:

1. **Enhance detention and soil/sediment contact times to promote slow reaction**
2. **Amend filters and swales with iron particles and mulch or compost**
3. **Retrofit facilities with treatment trains**
4. **Prioritize bioretention and filtration where possible**
5. **Revise and adopt State of Michigan BMP recommendation table**

5.2 APPLYING BMPS TO SINGLE LOTS

Applying many of the City’s structural BMPs to single lots is dependent on the size of the property, the amount of land disturbed during construction, the square footage of impervious surface, and the conversion of natural vegetation to lands or pastures (Ecology 2005a). Many individual lots may not qualify for mandated stormwater treatment facilities or may only require minimal elements of stormwater management such as roof downspouts. Equally these smaller lots (an example being 1/4 acre lots with 1,000 square-foot home footprint [USEPA 2006]) may be inadequate for the installation of large ponds or underground vaults. In these cases, applicable BMPs include:

- Infiltration Practices
- Filtration/Biofiltration
- Public Education
- Pollution Prevention/Good Housekeeping

Constructed sand filters and rain gardens are likely candidates for single lots, particularly when amended with iron particles or iron enriched soils. However, installing and operating these facilities could add a substantial cost to individual lot projects (JSPPO 2004).

5.3 UPDATING AND/OR ADDING PHOSPHORUS CONTROL POLICIES

The City has passed several ordinances designed to improve water quality in Lake Whatcom. These include restrictions on land clearing, a ban on all fertilizers containing more than 0 percent phosphorus, and a ban of all carbureted two-stroke engines on the lake (City of Bellingham 2007c).

Possibilities for the future include:

- Extend the Silver Beach Ordinance to all portions of the City located within the Lake Whatcom watershed. This would cover an additional 156 acres within the Academy and Hillsdale watersheds.
- Adding manure-based fertilizer to Ordinance 2005-06-044, the ban on "commercial fertilizers." Additionally, amend the ordinance to mandate testing of soils for phosphorus content prior to applying phosphorus based fertilizers during the first growing season (as the ordinance currently allows). Permit application only if soil phosphorus content does not exceed a threshold level. If permitted to use phosphorus based fertilizers, enact regulations regarding when it can be applied (after the rainy season), mulching immediately after application, etc. Also, require application to be done by a licensed and certified professional who has undergone a City training/certification program.[6]
- Ban all garden and lawn care products containing more than 0 percent phosphorus. Allow application by a professional if soil tests indicate that phosphorus amendments are required (Fogelsong 2007).
- Amend local regulations to reduce the maximum phosphorus content of household cleaning agents that are sold or distributed to 0.5 percent by weight (Winsten 2004) prior to the state mandated deadline of July 1, 2010. This is of critical importance for all products used outside the home (e.g., car washing products) and for all products in households served by a septic system.[7] Fogelsong (2007) recommends that soaps containing phosphorus that are used for car washing and other external purposes be regulated the same as fertilizers and pesticides containing phosphorus, i.e., a phosphorus content of 0 percent could be considered.
- Ban car washing except in designated areas (located outside of the Lake Whatcom watershed and/or where runoff drains to the sanitary sewer system) or at commercial car washes. At a minimum, encourage (through education) residents that wash their cars at home to do so on lawns (or other pervious areas) and to use detergents or soaps that do not contain phosphorus.
- Require septic maintenance programs for each septic system and a maintenance report to be submitted during annual inspections (Fogelsong 2007).
- Require maximum infiltration on all development sites by requiring all sidewalks, driveways, patios, and residential streets be constructed of pervious pavement (where

---

[6] The City plans to develop a "watershed friendly" certification program for landscapers, retailers, and realtors using the County's 2005 Centennial Grant money. This program could be used/modified to address this regulation.

[7] Winsten (2004) presents this option and reports that it was the most cost-effective option considered in its analysis.

site soil conditions allow). Design and landscape lawns with the primary goal of absorbing runoff from on-site impervious surfaces. Require "zero runoff" through these and other infiltration practices.

- Levy "green taxes" on household and yard products that contain phosphorus to make them more expensive (or at least comparable in price) to those that contain less than 0.5 percent phosphorus by weight (Winsten 2004). Currently, price structures do not favor phosphorus control, i.e., environmentally friendly products typically carry a price premium. Therefore, a general policy development option is to enact policies that produce price structures that benefit the public good where markets fail to do so (Winsten 2004).
- In order to be effective, any such tax likely would have to be levied in concert with the County or on a regional or state-wide scale. Tax revenue generated could be returned to citizens as subsidies for phosphorus reduction programs, or some other tangible phosphorus control BMP that is visible in the public spaces.

5.4 HOMEOWNER POLICIES

Possible new policies/programs designed to control phosphorus loading that are directed at homeowners could include:

- Evaluating the current leaf management program to determine if there are opportunities for improvement. Potential program enhancements include requiring residents to rake leaves to the edge of their lawn (as opposed to into the street) or bag leaves in biodegradable bags (Urban Engineers et al. 2004). Also consider collecting leaves on more frequent basis.
- Encouraging home and business owners as part of the Residential Stormwater Retrofit Program to direct runoff from roofs, driveways, patios, etc. to dry pits, infiltration facilities, or rain barrels to reduce the volume of runoff that enters the storm sewer system. If collected in a rain barrel or cistern, water can be stored for use during dry periods. EPA-approved, biological mosquito control devices are readily available in hardware and gardening stores to ensure these collection facilities do not breed mosquitoes (Urban Engineers et al. 2004).
- During a visit to two lawn and garden supply stores in the city on June 25, 2007, the phosphate-free fertilizer blend manufactured specifically for Lake Whatcom could not be found. One phosphorus-free product was available at each store; however, it was neither promoted nor obvious. Therefore, the City should consider making "lake friendly" products more available to consumers. Efforts could include distributing phosphorus-free fertilizers and car soaps to all citizens as well as phosphorus-free household cleaning products to citizens on septic systems.

5.5 WATERFOWL CONTROL OPTIONS

Expanding waterfowl control options, such as:

- Employing dogs to chase away waterfowl. Some dogs can be very effective at chasing waterfowl away, and if done routinely, waterfowl often will relocate (Urban Engineers et al. 2004). The City should consider obtaining dogs for this purpose, or at a minimum, providing financial incentives to lakefront residents with dogs that are effective at chasing geese to do so on a routine basis.
- Maintaining a band of un-mowed vegetation around a lake is one of the most effective (and least expensive) methods of discouraging geese and other waterfowl from residing in a particular area as geese and other waterfowl prefer not to walk through tall grasses or sedges (Urban Engineers et al. 2004). The City could encourage and/or provide financial incentives for lakefront residents to allow the vegetation within a specified distance of the lake to remain un-mowed. Un-mowed, vegetated buffers have the additional benefit of filtering runoff prior to entering the water and do not require fertilizer for maintenance. This management option also could be considered through legislation.
- Employing loud noises, visual deterrents, and other disturbance regimes (including shining lasers in their eyes at night). While these are effective at discouraging waterfowl; they may be less palatable to City residents (Urban Engineers et al. 2004).
- Excluding geese from congregating by fencing or other barriers erected around areas to be protected. Additionally, breeding can be minimized via egg addling, and geese can be gathered and moved during the molting period (Urban Engineers et al. 2004).

5.6 PHOSPHORUS CONTROL INCENTIVE PROGRAMS

Currently, the City has the following incentives in place to address phosphorus loading into the lake:

- The Silver Beach Ordinance stipulates a maximum percentage of impervious surfaces in new developments. Effectively, it encourages LID and acquisition of undeveloped property as means of increasing imperviousness beyond the 15 percent maximum per lot (Bill Reilly, pers. comm. 2007).
- The City provides a variety of incentives to decrease motor vehicle use (City of Bellingham 2007c).

Possible new incentive programs include the following:

- Establish an incentive program for developers rewarding them for stormwater friendly development practices. These practices could include minimizing clearing of native vegetation, zero runoff development, landscaping with native species, donating land to the City's Land Acquisition Program, and "cluster" development. Potential rewards include, fast-track review processes and fee reduction.
- Control waterfowl by allowing a border of vegetation along the lakefront to remain un-mowed and chasing geese with dogs (Urban Engineers et al. 2004). Many of these control activities could be implemented by lakefront residents, and since many of these residents are on septic systems, incentives could include providing them with free fertilizers and household cleaning products that contain 0 percent phosphorus,

free septic system servicing, etc. Such incentives would have dual phosphorus control benefits.

- Create a low interest or no interest “P reduction” revolving loan fund from which home and business owners can borrow funds to construct on-site infiltration facilities, redesign site drainage, or finance other activities designed to reduce phosphorus loading (Winsten 2004).
- Develop a rewards program for citizens that report illegal activities or sites that are not in compliance.

5.7 EDUCATION PROGRAMS

Currently, the City has the following education programs in place to address phosphorus loading into the lake:

- Healthy Hounds: The City encourages pet owners to pick up waste and have their dogs chase geese from the Lake Whatcom shoreline, especially Bloedel Donovan Park (City of Bellingham 2007c).
- The City has placed several signs throughout the watershed encouraging residents to protect the lake and providing specific recommendations for actions they can take.
- In 2007, the City plans to implement a “watershed friendly” education and certification program for landscapers, retailers, and realtors. The purpose of the program is to let private developers and the public know that they are subject to permit requirements for any project greater than 500 square feet and that erosion practices should be part of all land disturbance activities.

Possible new education programs include:

- **Media Campaigns.** Swann (2000, as reported in Dietz et al. 2004) reports that media campaigns and intensive training sessions are the education methods most effective at producing changes in resident behavior, with up to a 50 percent increase in BMP implementation. Media campaigns included a combination of TV, radio, mailings, and signs; intensive trainings included consultations, guidebooks, and media workshops. Community newsletters, demonstration projects, and the internet are commonly used education techniques that were less effective (Swann 2000, as reported in Dietz et al. 2004).
- **Educational Efforts.** Dietz et al. (2004) provided education to residents of a small Connecticut town to determine if informing residents about residential BMPs could improve stormwater quality. Results indicate a significant increase in BMP adoption following education, with BMP implementation occurring on 35 percent of lots (Dietz et al. 2004). Additionally, concentrations of NO3-N decreased by 75 percent in the treatment watershed during the 22 months following education (Dietz et al. 2004). However, TP concentrations did not change significantly, and no change in fertilizing (including frequency and amount applied), watering, and management of clippings and pet waste was observed (Dietz et al. 2004).
- **Informational Efforts.** Based on these studies, education has limited effectiveness at changing residents’ behavior and improving water quality. Therefore education should focus on informing residents of ordinances, incentive programs, etc. that either mandate changes in management or provide incentives for them. Additional new education topics also could include the following:

  - Specific actions individuals can take that will not take a significant amount of time and/or will save them money.
  - Specific programs available for technical and funding assistance.
  - Spending now to prevent problems can save tax money in the future on lake management, water treatment, and reducing future phosphorus loads (e.g., expensive BMP retrofits as currently are occurring).

Based on results reported by Swann (2000), these education efforts should occur as media campaigns and intensive training sessions in order to maximize their effectiveness.

5.8 COMPLIANCE/ENFORCEMENT PROGRAM

Currently, the City has the following existing compliance/enforcement programs in place:

- Illicit discharge detection and elimination.
- Septic system inspection and certification (due to phosphorus concerns, the Lake Whatcom watershed is the Department of Health's highest priority for inspecting septic systems).
- Enactment and enforcement of strict development restrictions.

Potential new compliance/enforcement programs include the following:

- Consider implementing a program where all retailers must ask for identification and proof of address when customers purchase fertilizers and other products that contain phosphorus above regulated concentrations. If the customer's residence is located in Lake Whatcom watershed, then the purchase is automatically invalidated. This system could be automated similar to the mandatory birthdate entry required when purchasing alcohol.

5.9 STORMWATER RETROFIT PROGRAM

- Incorporate specifics regarding the design, operation, and maintenance requirements for each stormwater facility. For example, each facility could be linked to as-built drawings, an operation summary, and an interactive maintenance schedule that allows for maintenance tracking.
- As the City adaptively manages their stormwater retrofit program, enhance the use of existing GIS data by linking each facility to data on its retrofit, maintenance, or inspection for example.
- Incorporate an annual monitoring/performance summary in the data for each treatment facility. This data could be used to track annual performance in an effort to identify trends in facility performance and (if tied to maintenance and amendment data) the effects of various management practices on system performance. If data for that specific facility is not available, include (and label as representative) data from the most similar facility for reference. Available monitoring data for all streams, ditches, and tributaries also should be included.

5.10 DISCONTINUE DEFICIT FINANCING OF INFRASTRUCTURE

No longer allow deficit financing of services, facilities, and infrastructure based on a "pay as you grow" system, i.e., development can only be approved if the services, facilities, and infrastructure required are in place and functioning (Winsten 2004). Related to the phosphorus control, this applies primarily to stormwater management and wastewater treatment.

5.11 DEVELOP A STORMWATER INDEX

Develop a stormwater index, i.e., a site assessment protocol that ranks sites zoned for development, proposed developments, and/or existing developments based on their potential to export phosphorus. Potential factors include slope, soils, vegetation, phosphorus content of the soil, and source area load rates. The City could use this ranking to prioritize the regulations proposed above, inform the TDR and land acquisition programs, assess stormwater taxes/fees, encourage developments to use existing grant programs to retrofit their property, give credits/reductions in property taxes, provide other financial incentives, and provide public recognition to new developments or retrofitted sites scoring above a threshold level.

5.12 INVENTORY/MAPPING OF TDR, ACQUISITION, AND EASEMENT PROGRAMS

The acreage, purchase price (if applicable), current market value, and stormwater index value of all lands in the TDR, Acquisition, and Easement Programs could be included in the existing mapping/inventory system. This could also include the location, extent, ownership, market value, and stormwater index value of all undeveloped land zoned for development. Additionally, available data regarding sensitive habitats, wetlands, riparian areas, etc. could be incorporated into the inventory. Based on the data inventoried, the City would have a visual and analytical tool to evaluate potential transactions.

5.13 EXPANDING THE TDR, LAND ACQUISITION, AND EASEMENT PROGRAMS TO INCLUDE AN ECOSYSTEM MARKETPLACE

Ecosystem marketplaces can function as a network of mitigation solutions, directing mitigation to areas and projects that best address watershed and community priorities.

Ecosystem services are the societal benefits that result from the functioning of intact natural systems. Ecosystem marketplaces provide a mechanism by which ecosystem services can be traded or exchanged for money, and/or for fulfilling mitigation required by federal, state, and local environmental regulations. Ecosystem marketplaces can function as a network of mitigation solutions, directing mitigation to areas and projects that best address watershed and community priorities. For example, landowners who restore wetland and riparian habitats at critical locations within the watershed can provide significant reductions in phosphorus inputs to surface waters. This potentially provides a source of phosphorus 'credits' that can be traded or sold in the context of a TMDL. Private landowners or developers who undertake retrofitting to reduce existing sources of phosphorus can potentially sell the 'credits' generated to those who have more limited options for retrofitting or who are seeking new development permits. Once regulatory structures are in place, a marketplace functions as a trading forum for those who have natural resources and those who need to provide environmental benefits. Several strategies are available for augmenting and expanding the City's current efforts at TDR, Land acquisition, and easements:

- The City currently owns, holds an easement on, or has acquired the development rights for approximately 1,541 acres (City of Bellingham 2007c). Much of this acreage is in its natural/undisturbed state and is therefore providing "ecosystem services" that benefit the public, e.g., wetlands filter water to improve water quality and attenuate flood waters. Due to these benefits, ecosystem services have value that often can provide revenue through wetland banking, carbon sequestration credits, and other market based approaches to ecosystem management. The City should investigate the potential of these properties to generate revenue, which then could be used to acquire additional properties. Additionally, as the City engages in future property acquisition and open space planning, the City can modify its property acquisition and TDR programs with the concept of "natural resource portfolios" in mind. Properties with credit-generating resources can create additional revenue streams, which can be used to fund phosphorus control programs, including the acquisition of new properties. Prioritization of current management objectives and acquisition targets based partially on the ability of a site to perform services that can be sold as credits will provide added value and depth to these programs.

- An added consideration as the City moves forward with its acquisition program is that as the City purchases land, it could use indexes proposed above (or other methodologies) to evaluate the potential of a parcel to export phosphorus both in its natural and developed conditions. Using this data, along with the market value of the property, the City could develop a ratio showing the estimated phosphorus load reduction compared to its appraised value, i.e., cost per pound of phosphorus loading prevented. The City could use this ratio for a variety of applications including (1) comparing the value of various properties available for acquisition, or (2) analyzing the benefit of selling a property currently held by the City in order to fund acquisition of another property(ies) that may provide a greater return on investment, i.e., greater load reduction per dollar. Essentially, the City could maintain a portfolio of properties that it is continuously analyzing for potential trades to increase the program's load reduction without spending added revenue. Many of these trades likely would shift holdings from urban areas, where per acre market values are higher and phosphorus loading per acre is lower, to rural areas where land is less expensive but phosphorus export per developed acre likely is higher.
- As specified previously, research indicates that preventing development is the most effective means of preserving water quality in Lake Whatcom (City of Bellingham 2007c). Consequently, the Land Acquisition, Easement, and TDR programs represent the most effective means of preserving the lake. Because, development is proceeding at a rapid pace within the Lake Whatcom watershed, time is of the essence. Therefore these programs must increase their holdings quickly and effectively. In order to meet this demand, the City should consider commissioning an analysis of the current status of these programs. This study should include the following components: (1) an analysis of current operations and recommendations on maximizing program effectiveness, (2) options to increase funding, and (3) recommendations on how to increase cooperation, coordination, and involvement with the County, DNR, developers, and other groups.

5.14 RECOMMENDED MANAGEMENT OPTIONS

As illustrated by the discussions throughout this document, efforts to control and/or reduce phosphorus in stormwater runoff is extremely challenging for many reasons. The widespread use of phosphorus in agriculture and urban landscaping has probably resulted in an overall elevated level of phosphorus in the soils of the Lake Whatcom watershed. Any land disturbing activities (forest clearing, land development, or yard care) will expose those soils to stormwater runoff. Increased impervious surfaces associated with development in the City contribute to increased surface runoff, stream velocities, and stream bank erosion. In addition, the public is generally unaware of how their every day actions are a source of phosphorus to the lake or that phosphorus is even of concern. Lastly, existing technology is somewhat limited in its ability to remove phosphorus from stormwater, and under performance is often exacerbated by inadequate operation and maintenance programs.

Despite these challenges, the City has made great strides in understanding potential phosphorus sources and developing a stormwater management program accordingly. As concluded in the County plan, the City has implemented both programmatic BMPs (e.g, public education, policy development (ordinances), facility mapping and monitoring, acquisition and transferable developments right program), as well as structural BMPs (e.g., installation of media filters, wet ponds, and biofiltration facilities such as rain gardens). This approach is consistent with the County plan which recommends that future options for managing phosphorus in stormwater will have to include both programmatic and structural BMPs.

In contemplating future options, the City will need to reflect upon the discussions presented in Sections 3 and 4 of this report and the effectiveness of structural BMPs in removing phosphorus from stormwater. In addition, the costs and sometimes infeasibility of retrofitting necessitate that future recommendations emphasize programmatic management options and attempt to control phosphorus at its source. This approach compliments that being proposed by the Department of Ecology with issuance of the NPDES Phase II stormwater permit, and with which the City has to comply. Thus, the management options recommended here focus on additional programmatic BMPs and are summarized in Table 9. As with any recommendations, they are based on information and data gathered to date. Future data collection, monitoring, source identification or loading analyses, may require an adjustment or change in emphasis to the recommended management options.

Table 9. Recommended Management Options and Action Items for City of Bellingham Phosphorus Control Program

Priority	Management Option	Audience	Purpose	Actions Items
High	Public Education	Residents/Homeowners	Responsible every-day practices (yard care, pet waste, car-washing, landscaping, fertilizer use).	Implement Public Education Program as defined in Phase II NPDES Permit. Advertise availability of low-phosphorus fertilizers in hardware stores. Participate in King County Public Outreach Forum. Make public aware of policies and ordinances.
High	Public Education	Residents/Lake visitors	Responsible care of pets; discourage feeding of ducks and geese	Beach and Park signage; Focused education during City/lakeside events.
High	Public Education	Developers/Contractors	Use construction site BMPs correctly.	Implement Phase II NPDES permit requirements; conduct training, inspections, enforcement. Make developers aware of policies and ordinances
High	Phosphorus Control Ordinances	Homeowners	Need policies to bolster public education	Review adequacy of existing ordinances to meet Phase II NPDES requirements (e.g., car washing), and phosphorus specific controls (e.g., include soil testing).
High	Phosphorus Control Ordinances	Developers/Contractors	Need policies to bolster public education	Consider extending Silver Beach Ordinance Require infiltration be the BMP of first choice.
High	Source Identification	City, County, DNR	Thorough source identification key to developing phosphorus control strategy (watershed-wide, site-specific, or both)	Thorough compilation of existing data; develop monitoring approach to fill data gaps; evaluate "added value" (i.e., how much more data do we need to improve upon best professional judgment).
High - Medium	Loading Analysis	City, County, DNR	Loading analysis will support development of future phosphorus control strategies	Review approaches, determine data needs (particularly for runoff coefficients), develop analysis plan.
Medium	Incentives	Developers	City will support responsible practices	Incentive to use LID practices and/or infiltration.
Medium	Incentives	Business Owners	City will support responsible behavior	Low interest loans to finance activities that reduce phosphorus loadings
Medium	Enhance existing BMPs performance	Public Works/ Homeowners	Enhance existing BMPs for treating phosphorus	Explore potential BMP modifications (medium amendments, increase reaction times).
Medium	BMP Operation and	Public Works/Homeowners	Enhance the performance of existing BMPs	Identify deficiencies in current O&M program.

Table 9. Recommended Programmatic Items and Actions for City of Bellingham Phosphorus Control Program (Continued)

Priority	Management Option	Audience	Purpose	Actions Items
	Maintenance			
Medium	Inspections	City/Developers/Contractors/Private Homeowners	Track adherence to regulations; target enforcement	Review adequacy of existing inspection program to meet new Phase II permit requirements and planned development,
Low	Retrofit Program	City	Support existing retrofit program	Identify “gaps” in BMP coverage
Low	Public Involvement	Residents	Get involved by using the City hot-line.	City is updating hotline information on website.
Low	Septic Systems	City/Property Owners	Maintain and repair	Coordinate with Health Department
Low	Ecosystem Market Place	City, County, DNR	Alternative long-term approach	Brown bag presentations; track development of water quality trading.

6. CONCLUDING REMARKS

The City has developed a comprehensive phosphorus control program that is achieving significant success in a difficult aspect of watershed management. In order to maximize program effectiveness, the City should work with the County to develop a focused yet holistic approach to controlling phosphorus in stormwater runoff to Lake Whatcom from both existing and future development across the entire watershed.

It is recognized that although this report suggests opportunities specific to the City for improving its stormwater phosphorus control program (i.e., its portion of the Lake Whatcom watershed), phosphorus control efforts in other portions of the watershed are equally, if not more, important. As noted, 98 percent of developable land in the watershed is located in the County. Therefore all recommendations, as well as all components of the City's current program, should be reviewed for opportunities to involve the County, DNR, and other entities and/or encourage them to incorporate similar management approaches when applicable.

Overall, findings of this review and evaluation are as follows:

- Phosphorus is difficult to control as evidenced by the City of Bellingham's experience as well as similar experiences documented by other municipalities nationwide.
- Review of the literature and other stormwater programs indicates that the City of Bellingham has, and is, employing the range of available technologies and BMPs for phosphorus control.
- Review of the literature also shows that the City of Bellingham could enhance its current program with additional emphasis on programmatic policies as well as improve existing treatment BMP performance.
- Future source identification and loading analyses may necessitate a re-evaluation and re-prioritization of the City's phosphorus stormwater management program.

7. REFERENCES

Anderson-Wenz, Erin. 2005. Topic: Enhanced sand filtration for storm water phosphorus. New Stormwater Treatment Technology Information, July 2005. http://www.rwmwd.org/vertical/sites/%7bab493de7-f6cb-4a58-afe0-56d80d38cd24%7d/uploads/%7b2abcc9e4-5421-4ef1-b6b0-5fc5fc144e64%7d.pdf, Accessed June11, 2005.

Bannerman, R., Legg, A, and Greb, S.R.. (1996). Quality of Wisconsin Stormwater. U.S. Geological Survey. Report 96-458.

Barr Engineering Company. 2005. Detailed Assessment of Phosphorus Sources to the Ramsey-Washington Metro Watershed District. Prepared for the Ramsey-Washington Metro Watershed District.

Birch, G.F., M.S. Fazell and C. Matthai. 2005. Efficiency of an infiltration basin in removing contaminants from urban stormwater. Environmental Monitoring and Assessment, 101: 23-38

Caraco, D. 2001. "Managing Phosphorus Inputs Into Lakes III: Evaluating the Impact of Watershed Treatment." Watershed Protection Techniques. 3 (4): 791-796. Center for Watershed Protection. Ellicott City, MD.

Caraco, D. 2003. The Watershed Treatment Model. Version 3.1. Center for Watershed Protection. Ellicott City, Maryland.

CH2M-Hill. 2007. Draft Lake Whatcom Comprehensive Stormwater Management Plan. Prepared for Whatcom County, WA. Prepared by CH2M HILL. May 2007

Chardon, W. and O. Schoumans. 1999. Solubilization of phosphorus: concepts and process description of chemical mechanisms. Paper presented at meeting of COST 832; Cordoba 13-15 May 1999. Downloaded from http://www.alterra-research.nl/pls/portal30/docs/folder/cost832/cost832/Chardon.doc on June 27, 2007.

Chimney, M.J., Moustafa, M.Z., 1999. Effectiveness and optimization of stormwater treatment areas for phosphorus removal. In: Redfield, G. (Ed.), Everglades Interim Report. South Florida Water Management District, West Palm Beach, FL, Chapter 6, pp. 6-1 to 6-45.

City of Bellingham. 2007a. Unpublished GIS data. Bellingham, Washington.

City of Bellingham. 2007b. Interjurisdictional Coordinating Team Recommendations – 2005-2009 Lake Whatcom Work Plan Tasks - Priority Tasks for 2007. Bellingham, Washington.

City of Bellingham. 2007c. Stewards of the Lake: A City of Bellingham Guide to the Lake Whatcom Watershed. Bellingham, Washington.

City of Bellingham. 2007d. Unpublished Monitoring Data from the Park Place Sand Filter, Bloedel Donovan Filter Vault, and Bloedel Donovan Rain Garden. Department of Public Works - Post Point Laboratory. Bellingham, Washington.

City of Bellingham. 2007e. Residential Stormwater Retrofit Program Presentation. Department of Public Works. Bellingham, Washington.

Comings, K.J., D.B. Booth, and R.R. Horner. 2000. Storm water pollutant removal by two wet ponds in Bellevue, Washington. Journal of Environmental Engineering, 126: 321-330.

Davis, Allen P., Mahmmad Shokouhian, Himanshu Sharma, and Christies Minami. 2001. Laboratory study of biological retention for urban stormwater management. Water Environment Research, 73: 5-14.

Davis, Allen P., Mahmmad Shokouhian, Himanshu Sharma, and Christies Minami. 2006. Water quality improvement through bioretention media: Nitrogen and phosphorus removal. Water Environment Research, 78: 284-293.

Delaware Department of Natural Resources (Delaware DNR). 2007. Broadfill Watershed Urban Stormwater Runoff BMPs. Fact Sheet. http://broadkill.ocean.udel.edu/FactSheets/BKStormwaterRunoffBMPs.pdf. Accessed June 11, 2007

Deletic, A. and T.D. Fletcher. 2006. Performance of grass filters used for stormwater treatment – a field and modeling study. Journal of Hydrology, 317: 261-275.

Dietz, M.E., J.C. Clausen, and K.K. Filchak. 2004. Education and Changes in Residential Nonpoint Source Pollution. Environmental Management Vol. 34, No. 5, pp. 684-690.

Ecology (Washington State Department of Ecology). 2004. Nutrient Criteria Development in Washington State. Phosphorus. April 2004, Publication Number 04-10-033.

Ecology (Washington State Department of Ecology). 2005a. Stormwater Management Manual for Western Washington. Prepared by Washington State Department of Ecology Water Quality Program. Publication Nos. 05-10-29 through 05-10-33 (Replaces Publication 99-11 through 99-15). February 2005.

Ecology (Washington State Department of Ecology). 2005b. Lake Whatcom Total Maximum Daily Load Groundwater Study. Prepared by Charles F. Pitz, Hydrogeologist, Washington State Department of Ecology, PO Box 47600, Olympia WA 98504-7600. January 2005. Publication No. 05-03-001.

Entranco. 2002. Technical Report: Water Quality Assessment/Conditions – Lake Whatcom Stormwater Program. Prepared for Economic and Engineering Services, Inc. and the Lake Whatcom Management Team. Bellevue, Washington.

Erickson, A.J., J.S. Gulliver, and P.T. Weiss. 2007. Enhanced sand filtration for storm water phosphorus removal. Journal of Environmental Engineering, 133: 485-497.

Fogelsong, C. 2007. Phosphorus Issues Paper.

Greb, D.R., R.T. Bannerman, S.R. Corsi, and R.E. Pitt. 2000. Evaluation of a multichambered treatment train, a retrofit water-quality management practice. Water Environment Research, 72: 207-216.

Hardy, F. Joan, Mike Crayton, and Jean Jacoby. 2000. Toxic blue-green algae blooms. Washington State Department of Health, DOH Pub 333-006 6/2000. http://www.doh.wa.gov/ehp/oehas/publications_pdf/algae.pdf, Accessed June 25, 2007.

HDR. 1995. Hinman, C. 2005. LID Technical Guidance Manual for Puget Sound. Puget Sound Action Team and Washington State University Pierce County Extension. January 2005, Revised May 2005.

Horner, Richard R., Joseph J. Skupien, Eric H. Livingston, and H. Earl Shaver, 1994. "Water Quality Impacts of Urban Land Use." In Fundamentals of Urban Runoff Management: Technical and Institutional Issues. Terrene Institute. Washington, DC.

Hsieh, C.-H. and A.P. Davis. 2005a. Evaluation and optimization of bioretention media for treatment of urban storm water runoff Journal of Environmental Engineering, 131: 1521-1531.

Hsieh, C.-H. and A.P. Davis. 2005b. Multiple-event study of bioretention for treatment of urban storm water runoff. Water Science and Technology, 51: 177-181.

Hsieh, C.H., A.P. Allen, and B.A. Needelman. 2007. Bioretention column studies of phosphorus removal from urban stormwater runoff. Water Environment Research, 79: 177-184.

Howland, W.G., B. Gruessner, M. Lescaze, and M. Stickney. 2006. Lake Champlain: Experience and Lessons Learned Brief. Lake Champlain Basin Program. Grand Isle, Vermont, USA. Accessed on June 7, 2007 at http://www.ilec.or.jp/eg/lbmi/reports/07_Lake_Champlain_27February2006.pdf.

ICT (Interjurisdictional Coordinating Team Recommendations). 2007. 2005-2009 Lake Whatcom Work Plan Tasks – Priority Tasks for 2007.

Joint Service Pollution Prevention Opportunity Handbook (JSPPO Handbook). 2004. Sand filter for treating storm water runoff. http://p2library.nfesc.navy.mil/P2_Opportunity_Handbook/10-1.html. Accessed May 16, 2007.

Illinois Association of Wastewater Industries. 2005. Control of Phosphorus – Do Your Part. Accessed at http://www.mwrdgc.dst.il.us/Phosphorus_do_you_part.pdf on June 10, 2007.

LWMP (Lake Whatcom Management Program). 2007. Lake Whatcom Management Program Website. Accessed at http://www.lakewhatcom.wsu.edu/ on June 19, 2007.

Liang, C.W. 1994. Master's Thesis: Impact of Soil and Phosphorus Enrichment on Lake Whatcom Periphytic Algae. Western Washington University.

Matthews, R.A. 2005. Email to Don J. Easterbrook dated April 1, 2005.

Matthews, R.A., M. Hilles and G. Pelletier. 2002. Determining trophic state in Lake Whatcom, Washington (USA), a soft water lake exhibiting seasonal nitrogen limitation Hydrobiologia, 468: 107-121.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews. 2006. Lake Whatcom Monitoring Project 2004/2005 Final Report. Western Washington University, Bellingham, Washington.

Matthews, R.A., M. Hilles, J. Vandersypen, R.J. Mitchell, and G.B. Matthews. 2007. Lake Whatcom Monitoring Project 2005/2006 Draft Final Report. Western Washington University, Bellingham, Washington.

McGechan, M.B. and D.R. Lewis. 2002. Sorption of Phosphorus by soil. Part 1: Principals, equations, and models. Biosystems Eng., 82(1):1-24.

Moore, Allen and Mark Hicks. 2004. Nutrient Criteria Development in Washington State– Phosphorus. Washington State Department of Ecology Water Quality Program, Watershed Management Section. April 2004. Publication Number 04-10-033.

Moustafa, M.Z. 1999. Analysis of phosphorus retention in free-water surface treatment wetlands. Hydrobiologia, 392: 41-53.

Pitt, R., R. Bannerman, S. Clark, and D. Williamson. 2005. Sources of pollutants in urban area (Part 2) – Recent sheetflow monitoring. Chapter 24 IN: Effective Modeling of Urban Water Systems, Monograph 13. William James, Kim Irvine, Edward McBean, and Robert Pitt, eds. Published by CHI, Guelph, Ontario.

Reilly, William. 2007. Personal communication during a site visit on April 24, 2007.

Scherer, N.M., H.L. Gibbons, K.B. Stoops, and M. Muller. 1995. Phosphorus loading of an urban lake by bird droppings. Lake and Reservoir Management 11(4):317-327.

Schueler, T.R. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Publ. No. 87703. Metropolitan Washington Council of Governments, Washington, DC

Schlesinger, W.H. 1991. Biogeochemistry – An Analysis of Global Change. Academic Press. San Diego, California.

Schilling, J.G. 2005. Street Sweeping – Report No. 1, State of the Practice. Prepared for Ramsey-Washington Metro Watershed District (http://www.rwmwd.org). North St. Paul, Minnesota.June 2005.

Swann, C.P. 2000. A survey of nutrient behavior among residents in the Chesapeake Bay watershed. Proceedings of the National Conference on Tools for Urban Water Resource Management and Protection. February 2000. Chicago, Illinois.

USEPA (U.S. Environmental Protection Agency). 1994. Developing successful runoff control programs for urbanized area. Prepared by Northern Virginia Soil and Water Conservation District for the Nonpoint Source Control Branch, Office of Water, U.S. Environmental Project Agency. Final Report July 1, 1994. EPA 841-K-94-003, August 1994.

USEPA (U.S. Environmental Protection Agency). 2002. National Water Quality Inventory 2000 Report to Congress. EPA-841-R-02-001. Office of Water, Washington, DC. Accessed at http://www.epa.gov/305b/2000report/ on June 19, 2007.

USEPA (U.S. Environmental Protection Agency). 200. Effect determination for atrazine. Appendix C-2. Description of two assumptions in Residential Exposure Modeling. Accessed at http://www.epa.gov/espp/effects/atrazine/appendix-c2-chesap.pdf on June 28, 2009.

Urban Engineers, Inc. and F.X. Browne, Inc. 2004. Watershed Management Plan for New Brooklyn Lake. Prepared for Camden County, New Jersey. Accessed at http://www.nj.gov/dep/watershedmgt/DOCS/lakes/New%20Brooklyn%20Lake%20Final%20Report-April%202004-F.X.%20Browne,%20Inc.pdf.

URS Corporation. 1985. Lake Whatcom Water Quality Protection Study. Volumes One and Two.

Walker, S.J., R.A. Matthews, and G.B. Matthews. 1992. Lake Whatcom Watershed Storm Runoff Monitoring Project. Prepared for the City of Bellingham Department of Public Works and the Washington State Department of Ecology.

Waschbusch, R.J., W.R. Selbig, and R.T. Bannerman. 1999. Sources of Phosphorus in Stormwater and Street Dirt from Two Urban Residential Basins in Madison, Wisconsin. U.S. Geological Survey. Middleton, Wisconsin.

Winsten, J.R. 2004. Developing and Assessing Policy Options for Reducing Phosphorus Loading in Lake Champlain. Prepared for the Lake Champlain Basin Program by the Henry A. Wallace Center for Agricultural & Environmental Policy at Winrock International.

Wisconsin Department of Natural Resources. 2004. Phosphorus Total Maximum Daily Load for Half Moon Lake, Eau Claire, Wisconsin. Accessed on June 7, 2007 at http://client-ross.com/spokane-river/docs/Half_Moon_Lake_Final_TMDL_604.pdf.

WSDOT (Washington State Department of Transportation). 2005. Reader-Friendly Document Tool Kit. June 2005. Accessed June 25, 2007. http://www.wsdot.wa.gov/NR/rdonlyres/272DB1DE-36F7-432F-9F60-D1199533AE97/0/ReaderFriendlyToolKit.pdf.

Yu, Shaw L., J-T Kuo, E.A. Fassman and H. Pan. 2001. Field test of grassed-swale performance in removing runoff pollution. Journal of Water Resources Planning and Management, 127: 168-171.