Watershed and stormwater drainage assessment of the Washington Park Arboretum

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Dedication

This project is dedicated to my wife Corey;

our daughters Mara and Greta;

and my parents Kim and Amy.

This project would not be possible without your love and support.

1. INTRODUCTION

The Washington Park Arboretum (WPA) is a 234-acre public garden located in Seattle, Washington (Figure 1). The University of Washington and the City of Seattle jointly manage the WPA. Seattle Parks and Recreation manage the park functions and the University of Washington Botanic Gardens (UWBG) manages the plant collection. Due to the unique nature of this partnership, WPA managers must work in cooperation as many issues affect each organizations areas of responsibility.

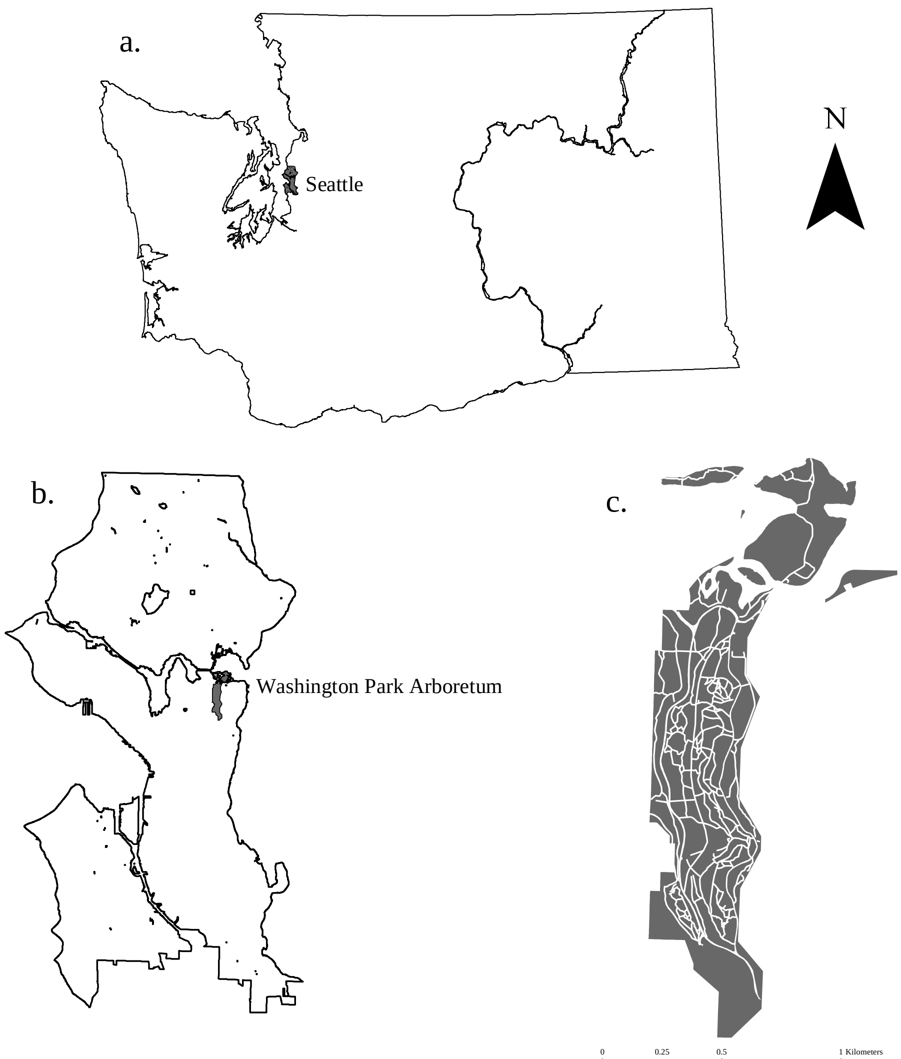

Figure 1. (a) Washington state, (b) city of Seattle, and (c) the Washington Park Arboretum

Stormwater management is an issue that affects all WPA stakeholders. It requires a broad view of potential impacts, including where they originate, where they end up, and how multiple organizations can work together to minimize negative affects. This report will outline an approach to mapping and assessing stormwater drainage in the WPA using remote sensing technology and geographic information systems (GIS).

1.1 Site

The WPA is located adjacent to Lake Washington and surrounded by the Montlake, Stevens and Harrison/Denny Blaine neighborhoods, as well as the Broadmoor Golf Club (Figure 2). The WPA sits within the Lake Washington Basin, which is a part of the much larger Cedar River - Lake Washington watershed (Seattle Public Utilities, 2016).

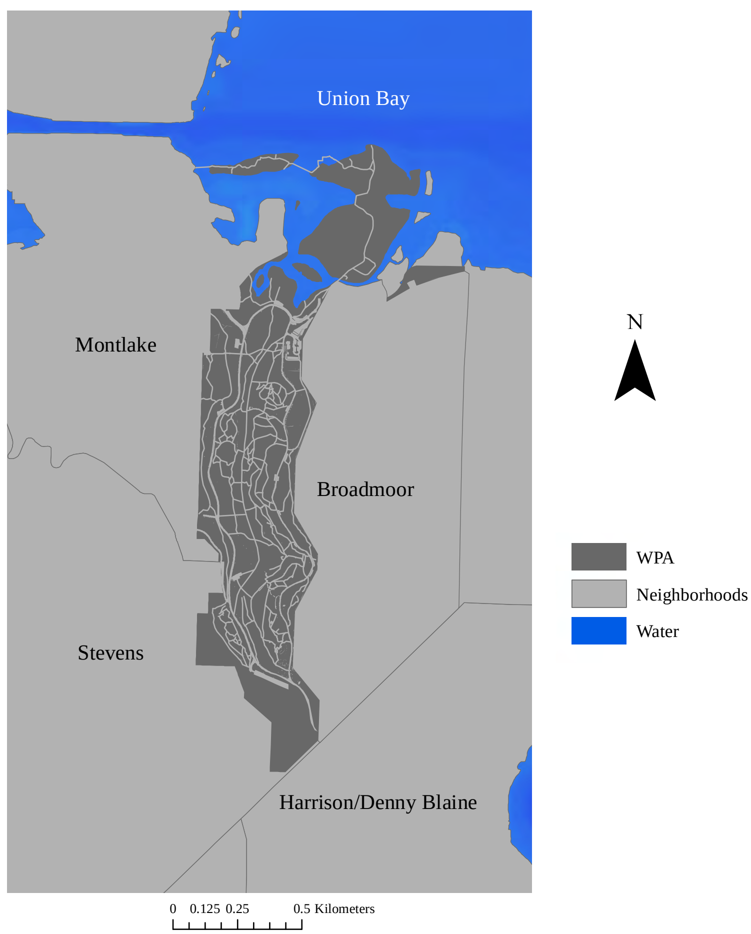

Figure 2. Washington Park Arboretum and surrounding neighborhoods (Office of the City Clerk, 2016)

The main waterway that drains the WPA and surrounding watershed is Arboretum Creek (Figure 3). This drainage begins at the south end of Azalea Way in the Arboretum and meanders north across Lake Washington Boulevard, through the east side of the Pinetum, until it flows into Union Bay and Lake Washington. Medbury (1990) describes the headwaters of Arboretum Creek as a "spring-fed brook" that winds through the west border of the WPA, although surface and possibly subsurface flows add to the flow volume. The Arboretum Creek watershed is relatively small when compared to some of the larger urban watersheds in the city of Seattle. However, its importance lies not in its size, but in the cultural, historical, and ecological significance of the WPA to the city of Seattle, University of Washington and all who access the land and plants for various reasons.

Figure 3. Arboretum Creek viewed from the Wilcox Footbridge

This analysis focuses on Arboretum Creek, its tributaries, and five minor drainages outside of Arboretum Creek. Foster Island and other outlying islands have been omitted from this study due to flat topography and low elevation. These factors combined for a lack of data in this area.

1.1.1 *Vegetation*

The WPA is comprised of several forest types common in native Puget Sound lowland mixed forests. Forest types range from mixed coniferous and broadleaf forested uplands to broadleaf forested wetlands. Dominant species in upland forest types include douglas-fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), big leaf maple (*Acer macrophyllum*), Pacific madrone (*Arbutus menziesii*) and bitter cherry (*Prunus emarginata*). Wetland forests include red alder (*Alnus rubra*), Oregon ash (*Fraxinus latifolia*) and black cottonwood (*Populus trichocarpa*) (Hitchin, 1998). This native forest creates the setting for the UWBG plant collection, horticulture display gardens and system of historic Olmsted designed roads and trails (Medbury, 1990).

1.1.2 *Soils*

WPA soils are surprisingly diverse due to the glacial history of the Puget Sound lowlands. Soil textures range from coarse sands to loams in upland areas and finer silts and clays as elevation decreases. Lower elevation areas near stream beds and shorelines contain soils high in organic matter common in wetland areas. Specific soils found in the WPA are Alderwood Gravelly Sandy Loam, Bellingham Silty Clay, Indianola Fine Sandy Loam, Issaquah Silt Loam, Kitsap Silt Loam, Norma Dine Sandy Loam, and Rifle Peat. Anthropomorphic fill was used in several areas in the north and south ends of the WPA to level out low areas (Gessel, 1966). According to WPA staff, soil amendments have been added throughout the grounds to improve the health of the plant collection or as part of larger development projects.

1.2 Problem Statement

Land use in the areas surrounding the WPA is highly varied and has the potential to impact landscape features, plant collections, wetlands and drainages within the WPA. The Woodland Garden Pond, Rhododendron Glen Pond and Arboretum Creek, which flows directly into Lake

Washington, are of particular concern due to their aesthetic and ecological importance. These drainages and their corresponding watersheds have significant value as the site of several historic and important UWBG plant collections. Other areas of importance include future development sites such as the UWBG Education building, the Pacific Connections gardens and Maintenance facilities. Potential impacts include sedimentation of wetlands, erosion and channelization of WPA drainages, and pollution caused by excess nutrients and pesticides (Figure 4). Addressing these impacts is essential to the stewardship and management of the WPA and surrounding communities.

a. b. c. d.

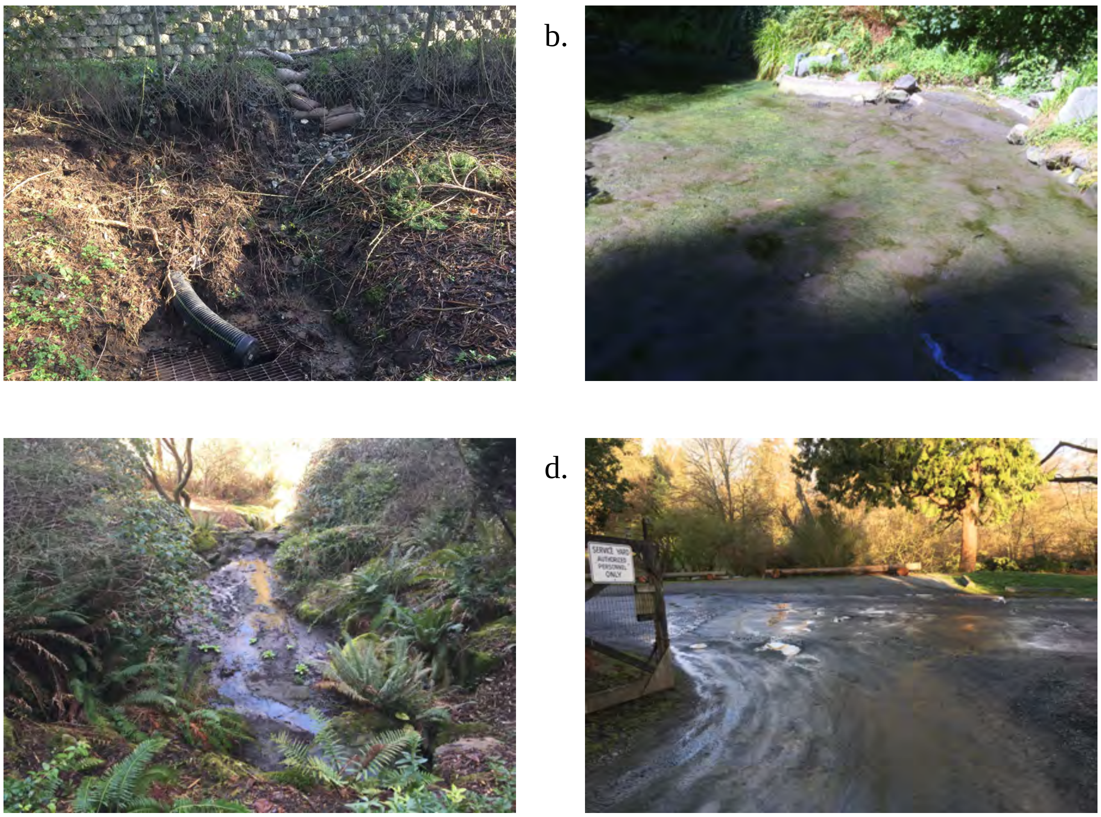

Figure 4. Surface water impacts: (a) erosion at catch basin at WPA and Broadmoor Golf Club boundary, sedimentation of (b) Woodland Garden upper pond and (c) Rhododendron Glen upper pond, and erosion and potholing at WPA Maintenance Facility and Foster Island Road

1.3 Goals of Project

The overarching goal of this project is to demonstrate that remote sensing technology and GIS tools can be utilized to assess stormwater drainage and watershed on the scale of municipal greenspaces and large park areas. Specifically, this analysis will (1) determine areas of high storm water runoff accumulation within a 1 kilometer buffer around the WPA (excluding Foster Island and outlying islands, (2) where these high accumulation areas enter the WPA property, where the storm water originates and where it eventually drains, (3) delineate main watersheds, major sub-watersheds, and minor sub-watersheds within the study area and (4) develop management recommendations based on observed stormwater impacts and land use and land cover analysis to minimize potential impacts of storm water runoff.

2. METHODS

The remote sensing technology used in this analysis involves a digital elevation model (DEM) generated from aerial light detection and ranging (LiDAR). GIS tools are then used to convert the DEM into a series of layers, including flow direction, flow accumulation and watershed delineation. This approach was chosen due to the availability of the necessary dataset and to demonstrate the viability of this methodology for smaller scale situations. Older methods of DEM generation and watershed delineation (manual delineation) were completed with a visual assessment of topographic maps, now considered slow and inefficient (Bera, 2014). Although these methods can be accurate, an automated or semi-automated GIS approach is faster and more accessible to small and large-scale land managers as the data and tools needed are now widely available to most land management agencies.

2.1 LiDAR

LiDAR technology has many diverse uses, one of which is to determine the distance to a specific point using laser light technology. A pulse of laser light is directed toward a target and reflected back to a receiver. This pulse and the ensuing return are used to determine the distance between the target and the receiver. When LiDAR is used aerially, or flown overhead in an aircraft, a series of light pulses and returns can model surface features such as terrain, vegetation, and buildings. These points can be uploaded and analyzed to derive a detailed model of the surface, sometimes referred to as bare earth model or a DEM, which is the basis for the ArcGIS watershed analysis (Ma, 2005). A DEM is a raster, or grid network, in which each cell has an elevation value. The DEM used in this project (Figure 5) was generated and provided by the University of Washington Remote Sensing & Geospatial Analysis Laboratory (UW RSGAL).

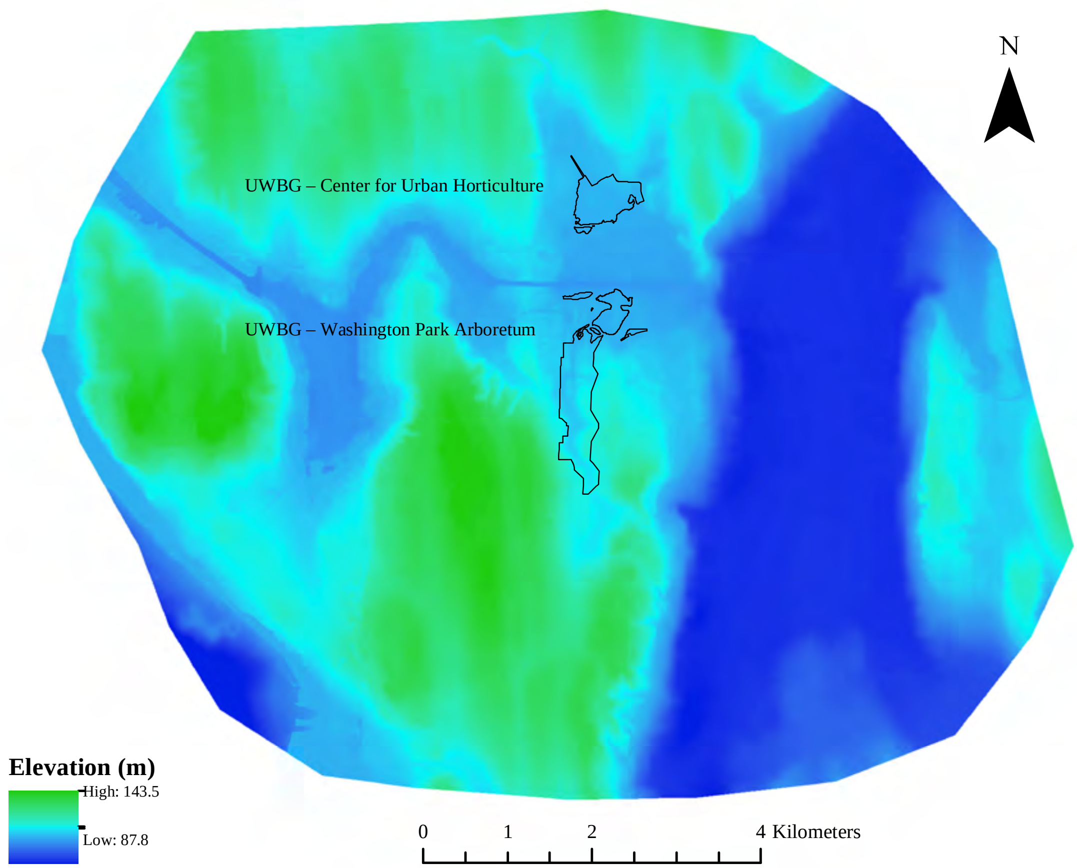

Figure 5. Clipped DEM of study area provided by UW RSGAL

2.2 ArcGIS

This project was completed using ArcMAP 10.3. Using the LiDAR derived DEM as the starting point for the analysis, several steps were needed to convert the elevation data into flow direction and accumulation data, and finally into streams and watersheds. The specific tools needed for the surface runoff analysis are found in the Hydrology tools within the Spatial Analyst toolbox extension.

2.2.1 *Buffer*

Due to the focus of this project being the WPA and surrounding areas, the initial step was to select a 1-kilometer buffer around the WPA boundary for analysis (Figure 6.b). This buffer was chosen because it is likely that all surface runoff flowing through the WPA would originate within this buffer.

2.2.2 *DEM Fill*

The next step was to create a depressionless DEM using the Fill tool in ArcGIS (Figure 6b). Considering the basic fact that water flows downhill, grids with a higher value will flow to grids with a lower value. Generally, landscapes will have low points, or depressions, that do not drain. These depressions will cause errors in future steps, as a continuous flow network is required (Jenson, 1988). The Fill tool fills these depressions in the DEM by locating the depressions and replacing the elevation values in those cell(s) with the next highest value (Figure 6a).

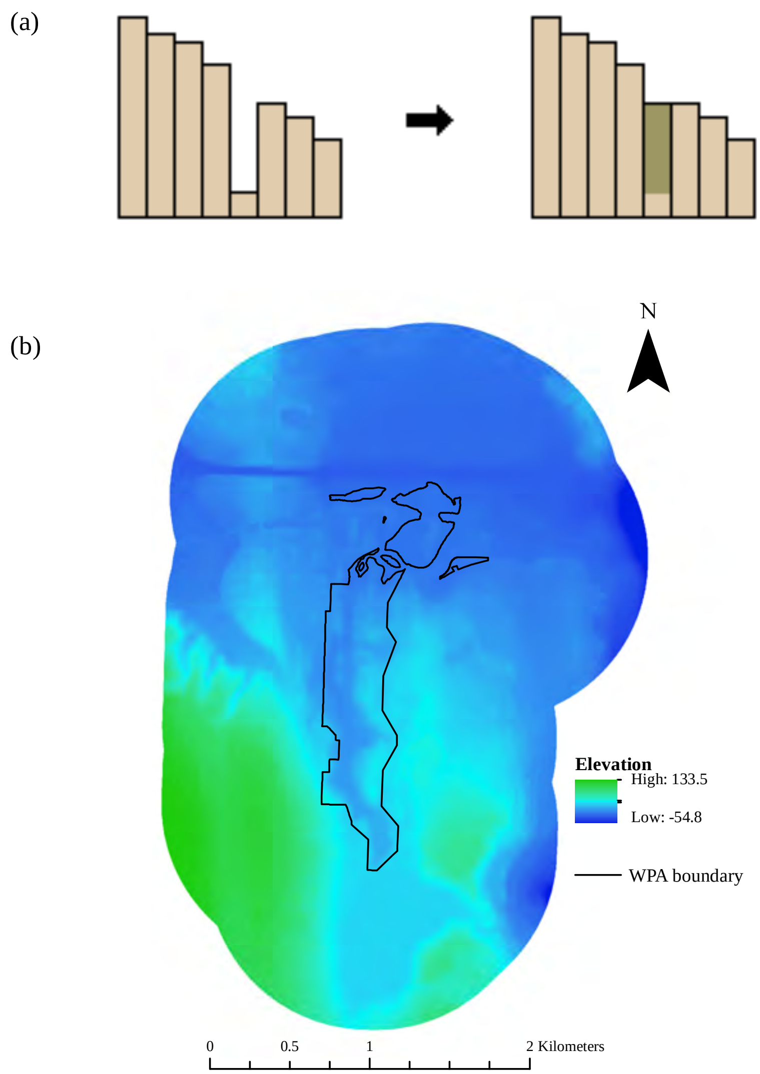

Figure 6. (a) Profile view of sink before and after running Fill operation (ArcGIS Pro, 2016), (b) Depressionless DEM with 1 km buffer around WPA

2.2.3 *Flow Direction*

Next, the direction of surface runoff flow is calculated using the Flow Direction tool. Flow direction is needed to create the drainage network. This step calculates which direction each cell flows by creating a 3x3 grid around each cell. The lowest value surrounding the cell determines the flow direction. A numerical value is then assigned to the cell based on the flow direction. This value has no meaning other than the direction of flow and is used only because ArcGIS software requires numeric values for raster data. Figure 7 shows the WPA depressionless DEM after the flow direction calculation (Jenson, 1988).

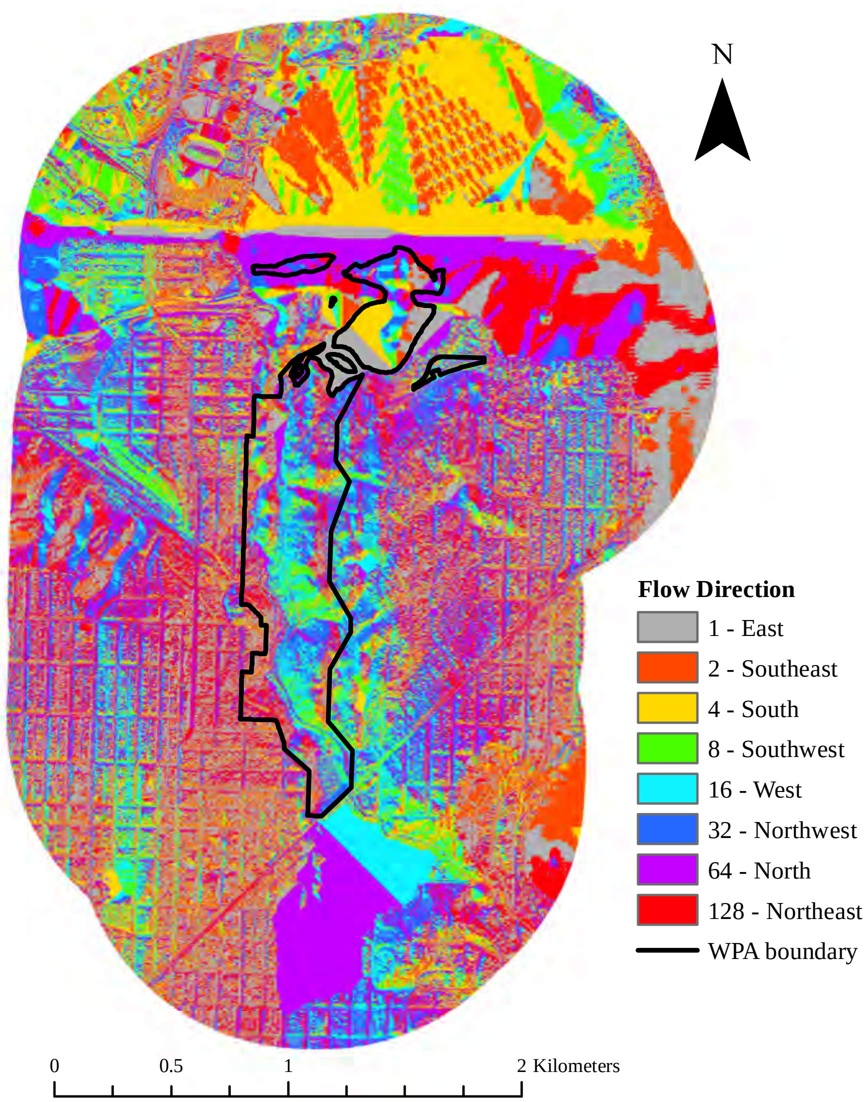

Figure 7. DEM after conversion to flow direction raster

2.2.4 *Flow Accumulation*

Creating the flow accumulation layer is the next step in the process. Using the flow direction raster, the Flow Accumulation tool calculates how many upstream cells are flowing through each cell. Each cell is given a value corresponding to the total number of upstream cells (Figure 8). The resulting layer is a grid with the highest value cells creating a network of drainage channels, or streams, and cells with a value of "0" representing ridges (Jenson, 1988).

Flow direction Flow accumulation

Figure 8. Flow accumulation raster derived from flow direction (ArcGIS Pro, 2016)

2.2.5 *Flow Accumulation Threshold*

Next, a threshold is chosen to differentiate the drainage channel cells from all other cells. This threshold will set all cells with values above the threshold to "1" and all values below the threshold to "0". This effectively creates a streams layer. According to Jenson (1988), "Because all cells in a depressionless DEM have a path to the data set edge, the pattern formed by highlighting cells with values higher than some threshold delineates a fully connected drainage network. As the threshold value is increased, the density of the drainage network decreases".

The threshold value represents the minimum number of cells flowing into a flow accumulation cell. If the threshold is too low, the flow accumulation will be too fine and will not accurately represent true drainage channels. Conversely, if the threshold is too high, true drainage channels will be omitted. The process of choosing a threshold was conducted through trial and error and field checks. Four thresholds were chosen: 2,500, 5,000, 7,500 and 10,000 cells. A threshold of 2,500 was too fine, showing channels that do not exist in the field. A threshold of 10,000 cells was too coarse, omitting known drainage channels. A threshold of 5,000 cells was chosen as it presented more detail than 7,500 cells, but not so much that false drainage channels were created (Figure 9).

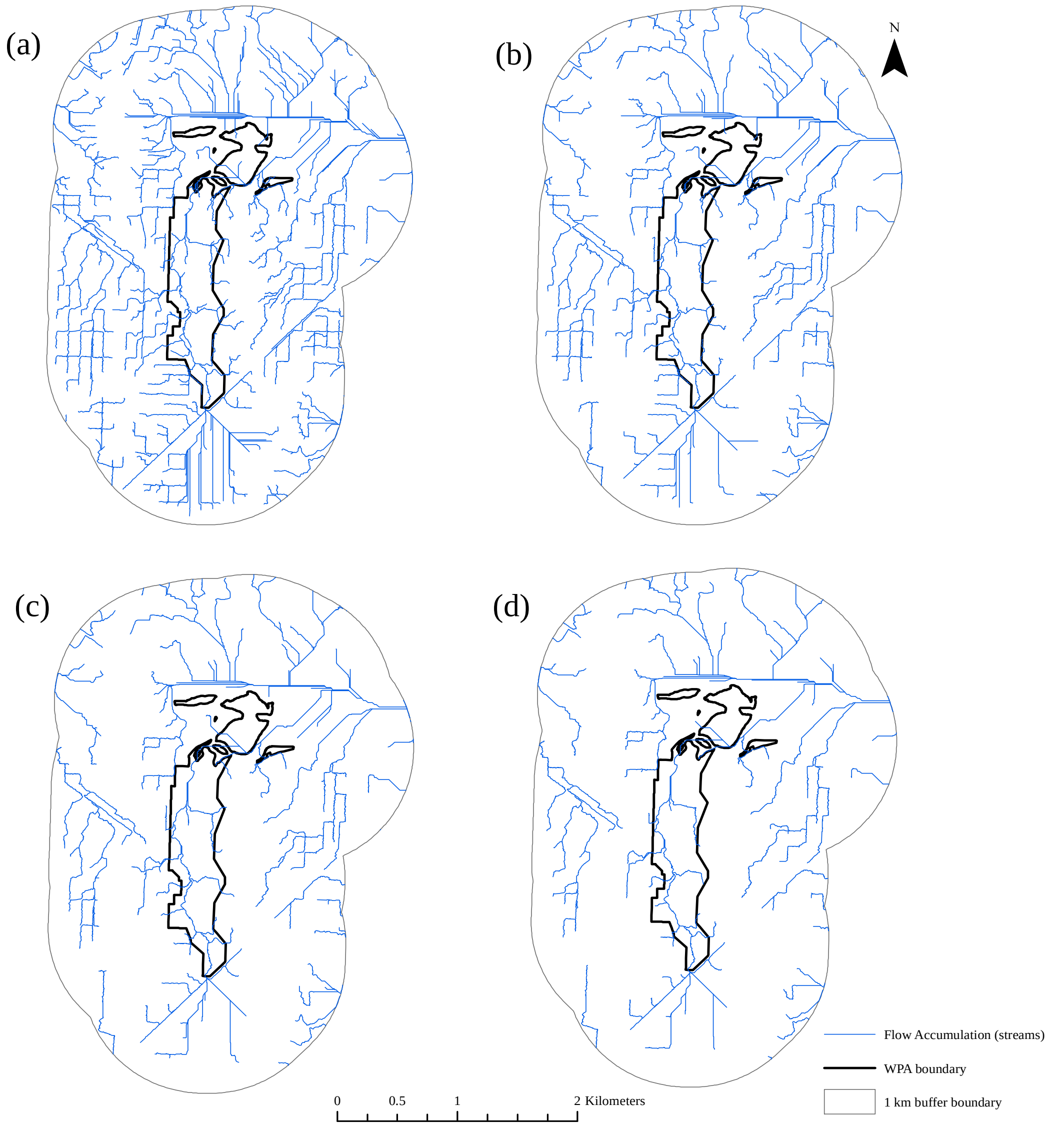

Figure 9. Stream layers at various flow accumulation thresholds: (a) 2500, (b) 5000, (c) 7500, and (d) 10000 cells

2.2.6 *Pour Point Selection and Watershed Delineation*

The selection of pour points and watershed delineation are the final steps. All of the water from within the watershed will flow through the pour point. The pour point defines the lowest point in the watershed and must be located on a flow accumulation cell. The chosen pour points will be the basis for the watershed or sub-watershed delineation. They must be digitized as vector data and converted to raster in order to work with the watershed tool.

Pour points chosen for this analysis can be classified into three categories: watersheds, major sub-watersheds, and minor sub-watersheds. The main watersheds within the WPA have pour points that flow directly into Lake Washington from Arboretum Creek. The major sub-watersheds have pour points on the small tributaries that flow into Arboretum Creek. The minor sub-watersheds have pour points within the major sub-watersheds at the WPA boundary. The purpose of the minor sub-watersheds is to determine the area of runoff flowing directly into WPA drainages. Finally, the watersheds are delineated using the watershed tool. This operation takes into account the pour points, flow direction and flow accumulation.

2.2.7 *Land Use and Land Cover Analysis*

The land use and land cover (LULC) analysis utilizes a 1-meter LULC raster data set provided by the UW Precision Forestry Cooperative. This dataset, covering all land within the city of Seattle, is classified into 5 land uses and land covers: buildings, impervious surfaces, trees (canopy cover), grass, and water. In ArcGIS, setting the work environment to mask the LULC layer on each watershed and performing a raster calculation yields the number of cells in each LULC classification. Although all five classifications affect stormwater runoff, particular attention is given to impervious surfaces and canopy cover as they greatly affect urban watersheds. Impervious surfaces negatively impact urban watersheds by increasing stormwater runoff and changing (Paul, 2001), while tree canopy cover reduces runoff through interception and root uptake and transpiration (Sanders, 1986).

2.3 Accuracy

The "accuracy and detail of hydrologic info that can be extracted form a DEM is directly related to the quality and resolution of the DEM itself" (Jenson, 1988). The resolution of the DEM provided by UW RSGAL is 1.8 meters (6 feet). Each cell square in the raster is 1.8 m by 1.8 m. This resolution of the DEM directly influences the size of the surface features that are included in the analysis. Features smaller than 1.8 meters will not be visible. The LULC raster data has a resolution of 1 meter.

3. RESULTS

The results of the GIS watershed analysis can be classified into three categories: 1) Main watershed, (2) major sub-watersheds, and (3) minor sub-watersheds. The main watershed is delineated from a pour point at the mouth of Arboretum Creek. The major sub-watersheds are delineated from pour points at the mouths of the main tributaries flowing into Arboretum Creek or smaller streams flowing directly into Lake Washington. The minor sub-watersheds are delineated from pour points at flow accumulation locations that coincide with the WPA boundary. See Appendix A for land use and land cover for all delineated watersheds.

3.1 Main Watershed

The main watershed draining the WPA and surrounding area flows through Arboretum Creek and is referred to as the Arboretum Creek watershed (Figure 10.a). It appears that the main watershed exceeds the 1 km buffer. However, due to the 2012 construction of the Madison Valley Stormwater Project (MVSP) at the south end of Washington Park, a large portion of runoff from this water shed is collected in a large stormwater storage facility and diverted prior to flowing into the Arboretum Creek watershed. Therefore, a watershed was delineated to represent the water flowing into this facility, which can then be omitted from the Arboretum Creek watershed and subsequent sub-watersheds (Figure 10.b). Section 4.1.3 will address the MVSP in more detail.

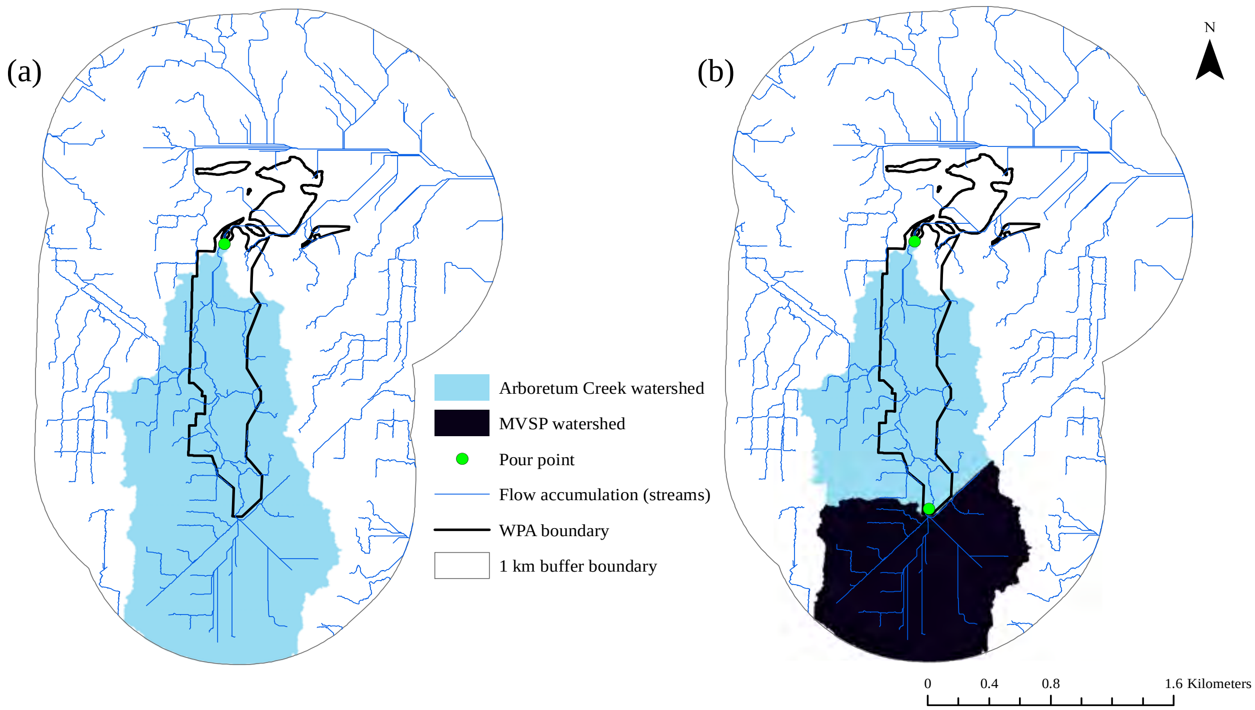

Figure 10. Extent of (a) Arboretum Creek watershed and (b) the area diverted into the catchment watershed

Table 1. Main watershed areas

Watershed	Cells	Square Feet	Acres
Arboretum Creek (total)	814,338	29,316,168	673.01
MVSP	387,753	13,959,108	320.46
Arboretum Creek with MVSP omitted	426,585	15,357,060	352.55

3.2 Sub-watersheds

Eight tributaries flowing into Arboretum Creek were identified as sub-watersheds within the Arboretum Creek watershed: 1) the Woodland Garden, 2) Azalea Way, 3) Rhododendron Glen, 4) Japanese Garden, 5) Birch Parking Lot, (6) the Hollies, (7) Pinetum Trail and the (8) Pinetum Sequoia sub-watersheds (Figure 11). Many of these tributaries are seasonal in nature and flow through a system of catch basins and culverts prior to outflow into Arboretum Creek. A ninth sub-watershed is delineated from a catch basin located near the Stone Cottage at the intersection of Arboretum Drive and Lake Washington Boulevard. This catch basin diverts a section of the

Japanese Garden sub-watershed into an underground pipe that daylights directly into the beginning of Arboretum Creek. This is explained in detail in section 4.1.3.

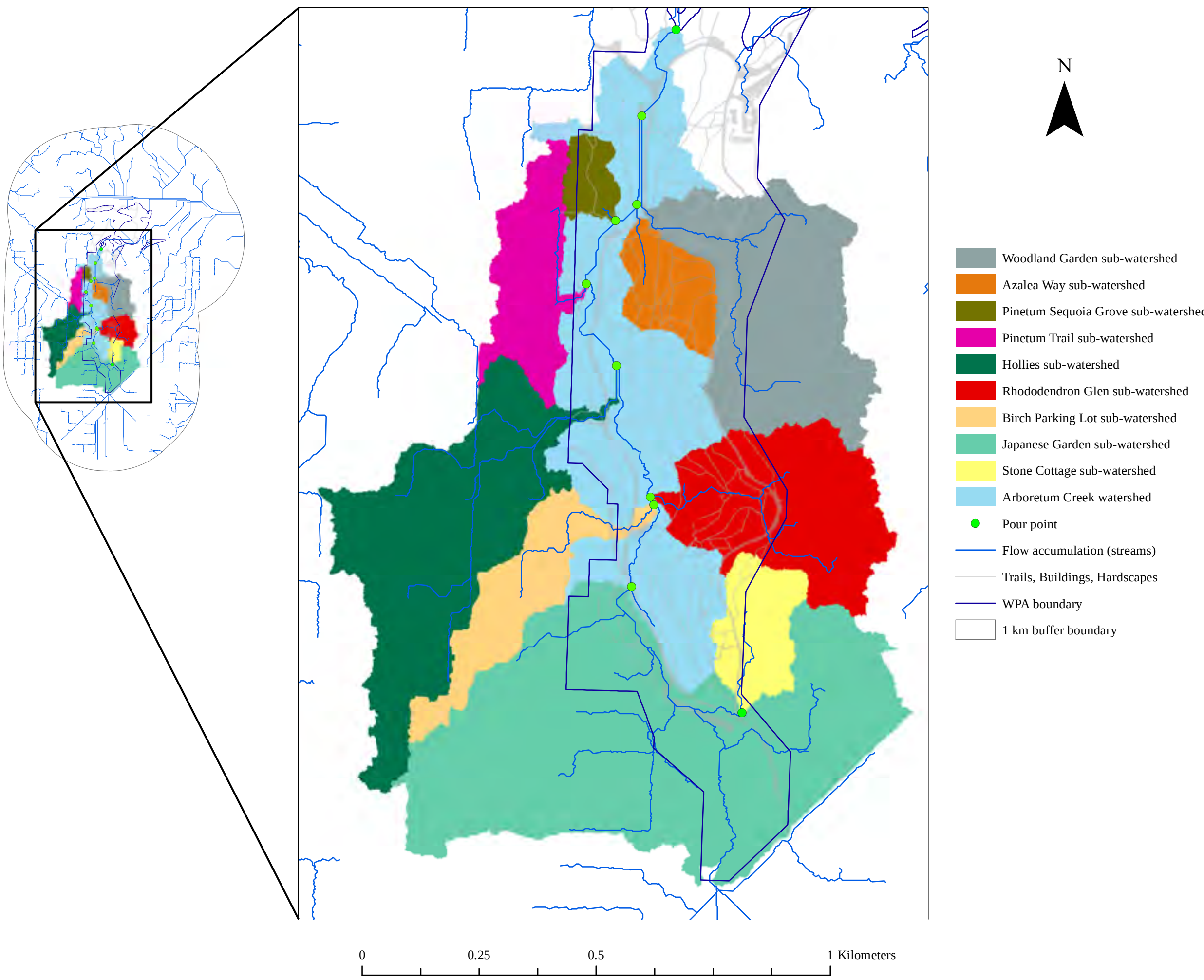

Figure 11. Sub-watersheds of Arboretum Creek (MVSP has been omitted)

Table 2. Sub-watershed areas

Sub-watershed	Cells	Square Feet	Acres
Woodland Garden	50,407	1,814,652	41.66
Azalea Way	11,960	430,560	9.88
Pinetum Sequoia Grove	5,366	193,176	4.43
Pinetum Trail	20,043	721,548	16.56
Hollies	61,500	2,214,000	50.83
Rhododendron Glen	39,360	1,416,960	32.53
Birch Parking Lot	20,538	739,368	16.97
Japanese Garden	136,578	4,916,808	101.33
Stone Cottage	13,967	502,812	11.54

3.3 Boundary Sub-watersheds

This subset of the Arboretum Creek sub-watersheds shows the origin of surface runoff that enters the WPA through pour points on the WPA border (Figure 12). A potential use for the minor sub-watersheds is in water quality testing. Testing water quality at multiple points along a stream can help determine the source of pollutants. A site on the WPA boundary should test positive for a pollutant if that pollutant originated from outside the WPA boundary. Furthermore, a watershed delineated from a pour point on the test site will define the area of pollutant origination. Note that Japanese Garden boundary sub-watersheds B and C include area within the WPA boundary. Care must be taken when drawing conclusions about the source of contaminants when watersheds cross property lines. Further testing and watershed delineation may be warranted when this occurs.

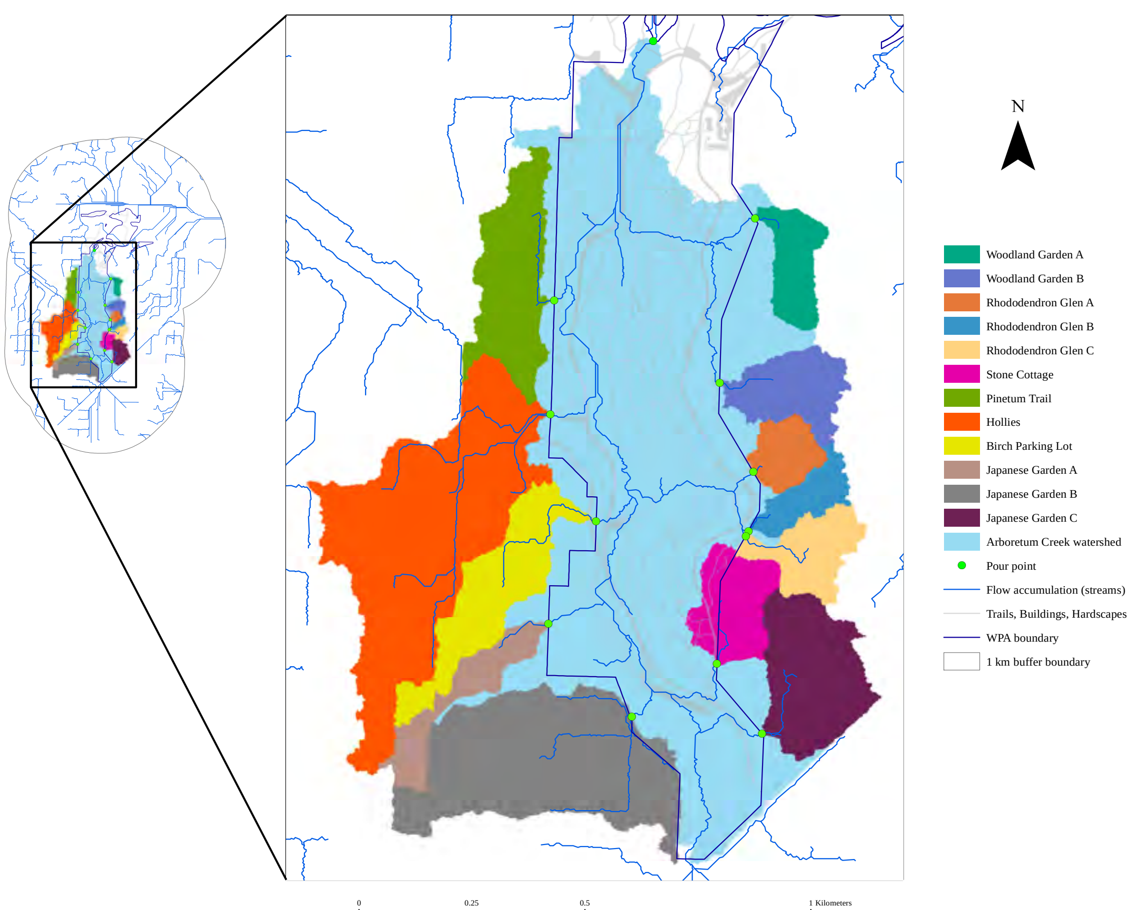

Figure 12. Boundary sub-watersheds

Table 3. Boundary sub-watershed areas

Boundary sub-watershed	Cells	Square Feet	Acres
Woodland Garden A	7,975	287,100	6.59
Woodland Garden B	11,113	400,068	9.18
Rhododendron Glen A	6,020	216,720	4.98
Rhododendron Glen B	5,855	210,780	4.84
Rhododendron Glen C	9,612	346,032	7.94
Pinetum Trail	19,648	707,328	16.24
Hollies	60,478	2,177,208	49.98
Birch Parking Lot	19,058	686,088	15.75
Japanese Garden A	9,462	340,632	7.82
Japanese Garden B	45,387	1,633,932	37.51
Japanese Garden C	20,067	722,412	16.58
Stone Cottage	11,351	408,636	9.38

3.4 Minor watersheds

The minor watersheds are small watersheds within the WPA boundary that flow directly into Lake Washington separate from the Arboretum Creek watershed system. They are located in the northeast corner of the WPA and cover the Graham Visitor's Center and landscape, the northernmost section of Azalea Way, Arboretum Drive and Foster Island Road (Figure 13).

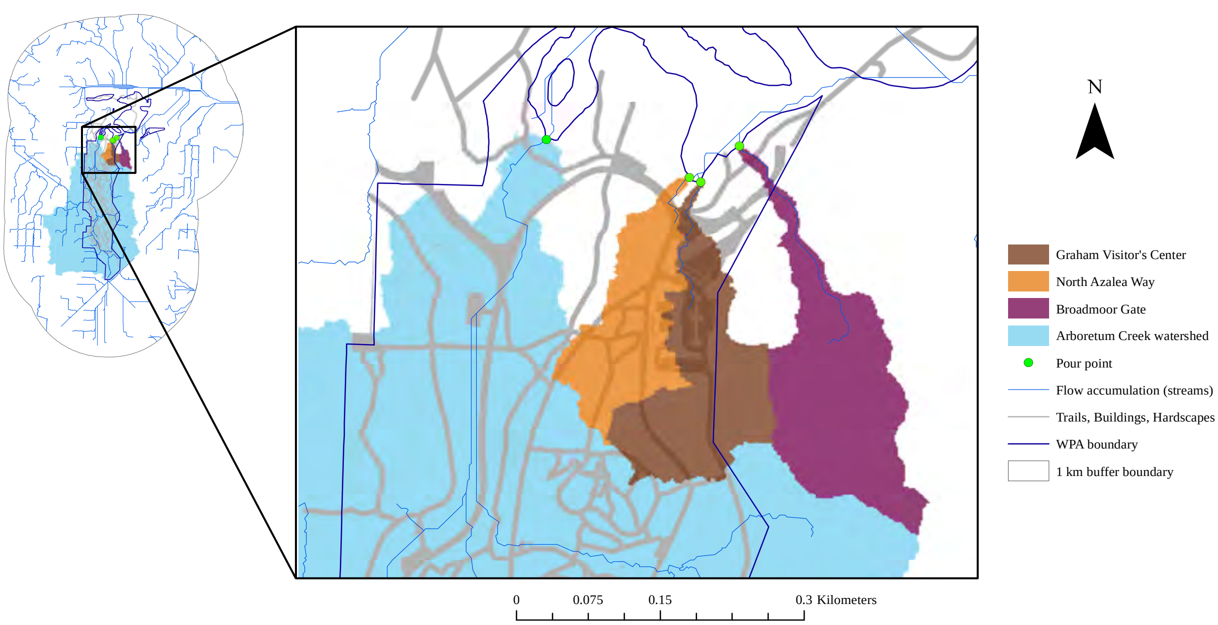

Figure 13. Minor watersheds

Table 4. Minor watershed areas

Minor watershed	Cells	Square Feet	Acres
North Azalea Way	5,545	199,620	4.58
Graham Visitor's Center	7,434	267,624	6.14
Broadmoor Gate	9,101	327,636	7.52

The delineation of these watersheds left vacant areas over portions of the UWBG Oak collection and the WPA maintenance facility. Because the Oak collection and maintenance facility areas have observed drainage issues, it is odd that (1) no flow accumulation appeared in these areas at any of the thresholds and (2) these areas are not contained within adjacent watersheds. Therefore, any flow accumulation in this area must be under the lowest accumulation threshold of 2500 cells. Further testing yielded results when the threshold was adjusted down to 750. This allowed the Oaks and Maintenance Facility minor watersheds to be delineated (Figure 14).

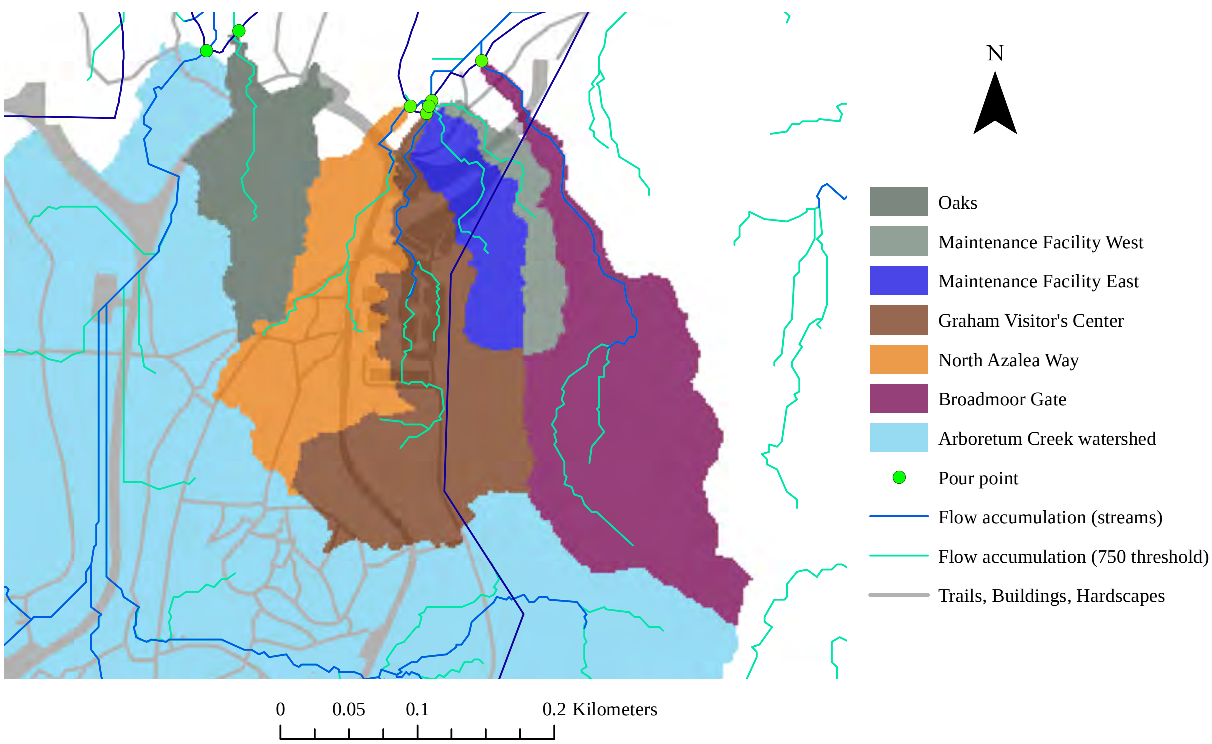

Figure 14. Minor watersheds, including maintenance facility watersheds delineated with flow accumulation threshold of 750 cells

Table 5. Minor watershed (750 cell threshold) areas

Minor watershed (750 cell treshold)	**Cells**	**Square Feet**	**Acres**
Maintenance Facility East	1,441	51,876	1.19
Maintenance Facility West	2,318	83,448	1.92
Oaks	3,696	133,056	3.05

4. DISCUSSION

The results of this project defines where stormwater runoff accumulates, delineates the main watershed, a series of sub-watersheds and boundary sub-watersheds and five minor watersheds within 1 km of the WPA, and determines where stormwater runoff enters the WPA. After accounting for MVSP infrastructure that diverts surface water into the combined sewer system, all delineated watersheds fell within the 1-km buffer. Limitations of this GIS analysis include accounting for sewer and other drainage infrastructure, such as catch basins, culverts and drain tiles. Limitations, results and management recommendations are discussed in the following sections.

4.1 Municipal Sewer Systems

The watersheds along the west and southeast boundaries of the WPA overlap with residential areas and surface streets. While Seattle Public Utilities classifies all sewer drains within the WPA as a separated system, meaning that all stormwater is completely separated from solid waste, these residential areas are drained either by a combined sewer or a partially separated storm sewer. The Montlake neighborhood north of Boyer Avenue and the Broadmoor residential area are drained with a partially separated storm sewer. This means that stormwater is partially separated in these areas: roof drains are combined with home side sewers and flow to a wastewater treatment facility, while street drains are separate and flow directly into local water bodies. The combined portion of a partially separated system is equipped with overflow pipes to prevent sewage backups. During heavy precipitation, the combined portion of these systems has the potential to introduce sewage into local water (Seattle Public Utilities, 2014).

The residential areas south of Boyer Avenue and just north of Madison Avenue on the southeast WPA border are drained by a combined sewer system. This system combines all surface water from roof drains and street drains with home sewer systems and drains to a wastewater treatment facility. Similar to the combined portion of partially separated sewer systems, combined sewers are also equipped with overflow pipes that drain into local water bodies. However, combined systems are most affected by heavy precipitation and can lead to sewer overflows into local water bodies (Seattle Public Utilities, 2014).

While the majority of surface runoff in these residential areas is likely captured by the sewer infrastructure, the infiltration of groundwater can have complex effects on surface water at lower elevations (House, 2016). WPA horticulturists have long presumed groundwater seeps play a role in local hydrology and a 2011 soil study in the Holly Collection at the WPA concluded that saturated soils were caused primarily by groundwater seeps (Knight, 2011).

4.2 Traditional Stormwater Management in the WPA

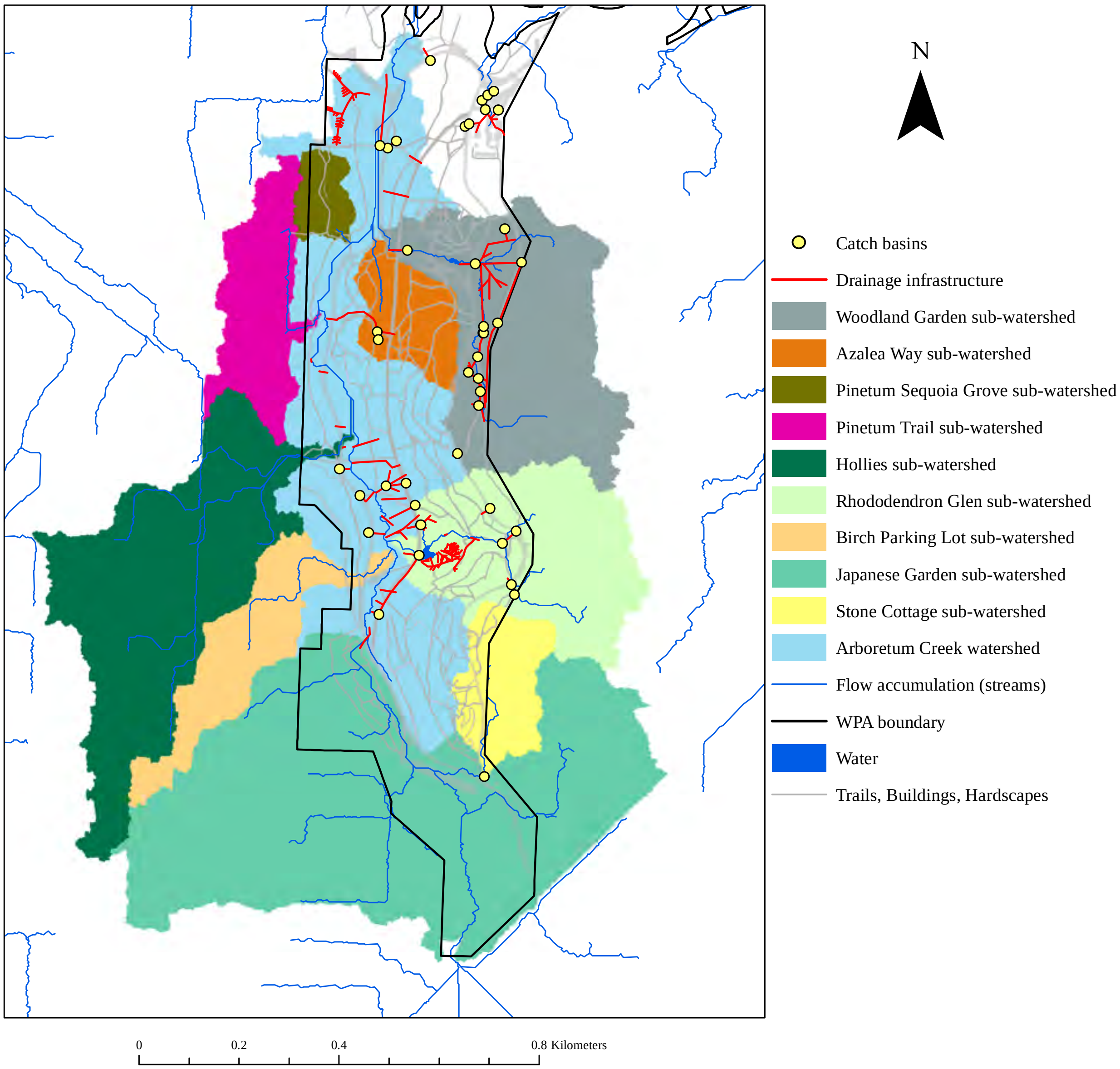

Figure 15. WPA drainage infrastructure

According to WPA drainage plans, 2.6 miles of drain tiles, culverts and pipes are installed throughout the grounds (Figure 15). These systems have been effective at moving stormwater quickly into ponds and Arboretum Creek. While this accomplishes the desired effect of reducing saturated areas, it does not address water quality, erosion and other impacts associated with traditional conveyance and ponding systems (Hinman, 2012).

Interestingly, with the exception of one drain tile system in the Azalea Way sub-watershed, all drainage systems follow the approximate flow accumulation pathway and do not divert runoff out of the respective watershed or sub-watershed. Unlike the combined sewer system that diverts water out of the watershed, the drainage infrastructure within the WPA does not greatly affect the accuracy of the GIS based analysis.

4.3 Low Impact Development and Green Infrastructure

This report outlines potential locations for mitigation actions within the WPA using Low Impact Development (LID) and Green Infrastructure (GI) concepts. Compared to traditional stormwater management (conveyance and pond systems) that moves stormwater quickly through the watershed, LID and GI are intended to manage stormwater as close to the source as possible using landscape features to slow surface runoff by increasing infiltration, evaporation and transpiration (U.S. EPA, 2009). Reducing impervious surfaces, protection of natural features, creation of bioretention features, and green roofs are examples of GI that have been used successfully in the WPA (Figure 16).

a.

b.

c.

Figure 16. LID installations at UWBG: (a) green roof in the WPA, (b) permeable pavers in the WPA and (c) a prairie restoration rain garden at the Center for Urban Horticulture

4.4 Management Recommendations

While the WPA can be viewed as a large vegetative buffer protecting Arboretum Creek from the impacts of urbanization, changes to the watershed have still occurred. Networks of drainage infrastructure have been installed to quickly move stormwater into drainage channels, increased deposition of fine sediments and wetland areas have been altered. The observed responses to these changes within the WPA include the increase in peak storm flow intensity and reduction in stream bank stability. Additional impacts may include loss of temperature control from reduced shading and degraded aquatic habitat (Hinman, 2012). Although, recent construction has incorporated LID and GI concepts, older existing drainage infrastructure is responsible for many of the observed impacts. Rethinking these aging systems in conjunction with new development or as a project in and of itself will improve stewardship of the WPA watershed.

4.4.1 *Woodland Garden Sub-watershed*

The Woodland Garden sub-watershed contains some of the most prominent areas in the WPA. Most notably, the Woodland Garden contains two ponds and a stream connecting the two water features. Within the WPA, this sub-watershed also includes Crabapple Meadow, The WPA Corporation Yard (where mulch, compost and soil are stored), the eastern half of Loderi Valley, the old Field Nursery site, the Mountain Ash Collection, and a small section of the Magnolia Collection. The majority of the Woodland Garden sub-watershed covers area east of the WPA boundary in the Broadmoor Golf Club.

Two main areas of flow accumulation originate in the Broadmoor Golf Club. The north flow accumulation enters the WPA at the Corporation Yard in Crabapple Meadow. This area is seasonally saturated and the constant vehicle traffic results in a very muddy service area. From here, the flow runs directly across the Crabapple Meadow turf into a catch basin in the southeast corner. The south flow accumulation enters the WPA in the Mountain Ash Collection, runs north along the service road and through the old Field Nursery. When it reaches the southwest corner of Crabapple Meadow, the south flow joins the north flow and enters the catch basin and is piped in to the Woodland Garden upper pond.

A third observed runoff entry point into the WPA exists approximately 100 feet south of north entry point (Figure 17). This runoff is quickly captured by a catch basin located approximately 3 feet west of the entry point and is piped directly into the upper pond in the Woodland Garden. Large volume of surface runoff has been observed at this entry point during precipitation events. However, the third entry point is not shown on the GIS analysis. This discrepancy is likely caused by a large grade change that occurred in the Broadmoor Golf Club after the aerial LiDAR data was obtained. In 2007 and 2008, 12,000 cubic yards of soil were excavated to create a lake for the purpose of irrigating the golf course turfgrass. 4,000 cubic yards of soil were used to elevate a tee box located east of the Crabapple Meadow in the WPA and a 24.5-foot tall by 265-foot long retaining wall was constructed to support the tee box (City of Seattle Department of Planning and Development, 2007).

Figure 17. Crabapple Meadow flow accumulation entry point. Note catch basin in foreground and Broadmoor Golf Club retaining wall in background

While a flow accumulation was not shown at the 5000-cell threshold, lowering the threshold down to 400 cells shows surface flow accumulations entering the WPA near this point (Figure 18). Therefore, while this third entry point has always existed at lower flow accumulations, it is likely the construction of the irrigation lake and elevated tee box has increased the flow accumulation at this entry point into the WPA. Current aerial LiDAR data is needed to fully analyze how this construction project has affected flow accumulation in this sub-watershed.

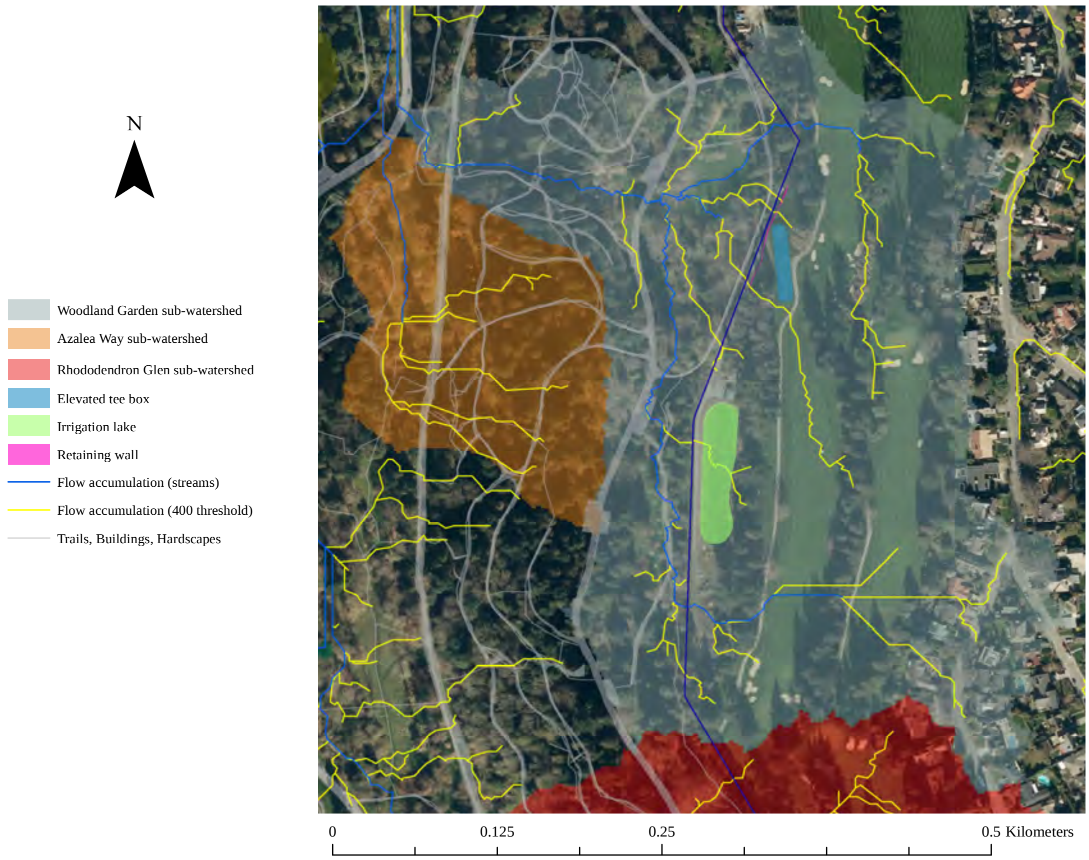

Figure 18. Woodland Garden sub-watershed, flow accumulations with thresholds of 5000 and 400 cells and Broadmoor Golf Club features added in 2007-2008 construction

Two priorities for mitigation in the Woodland Garden sub-watershed are 1) erosion and subsequent sediment loading and 2) contamination of metals in the upper pond. At a minimum, removal of sediment from the catch basin at the WPA entry point and the enclosed culvert draining into the upper Woodland Garden pond is recommended (O'Brien, 2015). Installing bioretention depressions around catch basin culverts would allow suspended sediments to settle prior to entering the enclosed culvert. Currently, two sections of stream are daylighted in this sub-watershed: 1) a section of stream between the upper and lower ponds and 2) a short section of stream between Azalea Way and Lake Washington Boulevard. Increasing the percentage of daylighted stream through Crabapple Meadow in a manner that slowed flow velocity would further reduce sediments from reaching the ponds. Creating a meandering stream would reduce flow velocity and thereby reduce the potential for bank erosion and further sedimentation downstream (Karr, 1978). Additional analysis is required to determine the post-Broadmoor construction channel flow accumulation and the desired channel volume needed to accommodate precipitation events.

The Woodland Garden sub-watershed was one of three sub-watersheds within the WPA selected for water quality testing by Seattle Parks and Recreation (O'Brien, 2015). Turbidity was analyzed at 4 sites within the sub-watershed: 1) WPA entry point near Crabapple Meadow (the third entry point into the Woodland Garden sub-watershed), 2) upper Woodland Garden Pond, 3) the stream draining the upper pond, and 4) the lower Woodland Garden pond. Testing was limited to 2 days in March 2015 and found elevated levels of turbidity at all sites. The report concludes the turbidity to be a result of localized erosion from channelization around the third entry point into the WPA and the adjacent gravel road on Broadmoor Golf Club property. Much of this sediment settles in the upper Woodland Garden pond and may contribute to turbidity lower in the sub-watershed. Gravel trails through the Woodland Garden also likely contributed to the elevated turbidity at testing sites lower in the watershed (O'Brien, 2015).

Nutrient (Nitrogen), metal (copper and zinc) and pesticide concentrations were tested from the upper Woodland Garden pond. Nitrogen (nitrate and nitrite) levels were "considered representative of a minimally impacted reference condition" and below aquatic criteria for British Columbia, Canada (no standards exist for Washington State). However, copper concentrations exceeded the estimated acute and chronic range suitable for freshwater life and zinc concentrations exceeded the chronic range suitable for freshwater life. The toxicity of these metals is dependent on water hardness, which was not tested as part of the Seattle Parks and Recreation testing. Water hardness was estimated from King County and City of Seattle data to be between 40-70 mg/L (O'Brien 2015). This water hardness range was used as the basis for the range of acute and chronic metal concentrations suitable for freshwater life according to the Washington Administrative Code (Washington State Legislature, 2011). Further testing is required to determine the actual water hardness at the testing site in order to determine accurate criteria for copper and zinc levels suitable for freshwater life. The report identifies surface runoff from roads as a primary source of metals in waterways. Specifically, automobile brakes and tires appear to be significant sources of copper and zinc in urban runoff (Davis, 2000 and McKenzie, 2009). The pesticides chlordane and dieldrin were found in concentrations that exceed the chronic range suitable for freshwater life according. However, the report concludes that these chemicals “found in our environment from past uses and are likely present on the project site as a legacy issue” as chlordane and dieldrin were effectively banned in the 1980’s (O’Brien, 2015).

4.4.2 *Azalea Way Sub-watershed*

Figure 19. Azalea Way sub-watershed

The Azalea Way sub-watershed occupies the area southwest of the Woodland Garden sub-watershed, including middle section of Azalea Way, the western half Loderi Valley, the Asiatic Maple Collection, the majority of the Magnolia Collection, the east-facing slopes of Honeysuckle Hill and Yew Hill and the low-lying site of the Nut Collection (Figure 19). The high flow accumulation in this sub-watershed is relatively short and begins in the valley created by Azalea Way and Honeysuckle Hill, also known as the Nut Flats (Figure 20).

Soils in the flow accumulation area are seasonally saturated causing low visitor traffic in this area during the winter months. The planned route of a multi-use trail will run along the east slope of Honeysuckle Hill and will add approximately 4,500 ft^2 of impervious surface through this sub-watershed. Using permeable surface in place of asphalt will reduce surface runoff. Adding bioretention depressions along the downhill side of the new trail are recommended to offset the surface runoff created by the trail. The exact location of these features will depend on the final grading and the desired retention volume.

Figure 20. Azalea Way sub-watershed flow accumulation area in the Nut Flats

4.4.3 *Pinetum Sequoia Grove Sub-watershed*

The Pinetum Sequoia Grove sub-watershed occupies the majority of the Pinetum from the Stone Bridge and Newton Street Entrance, along the western boundary to the playground at Lynn Street. The 5000-cell flow accumulation is relatively short (approximately 150 feet) in this sub-watershed. Thus the 400-cell flow accumulation is included to show the flow route of surface runoff (Figure 21).

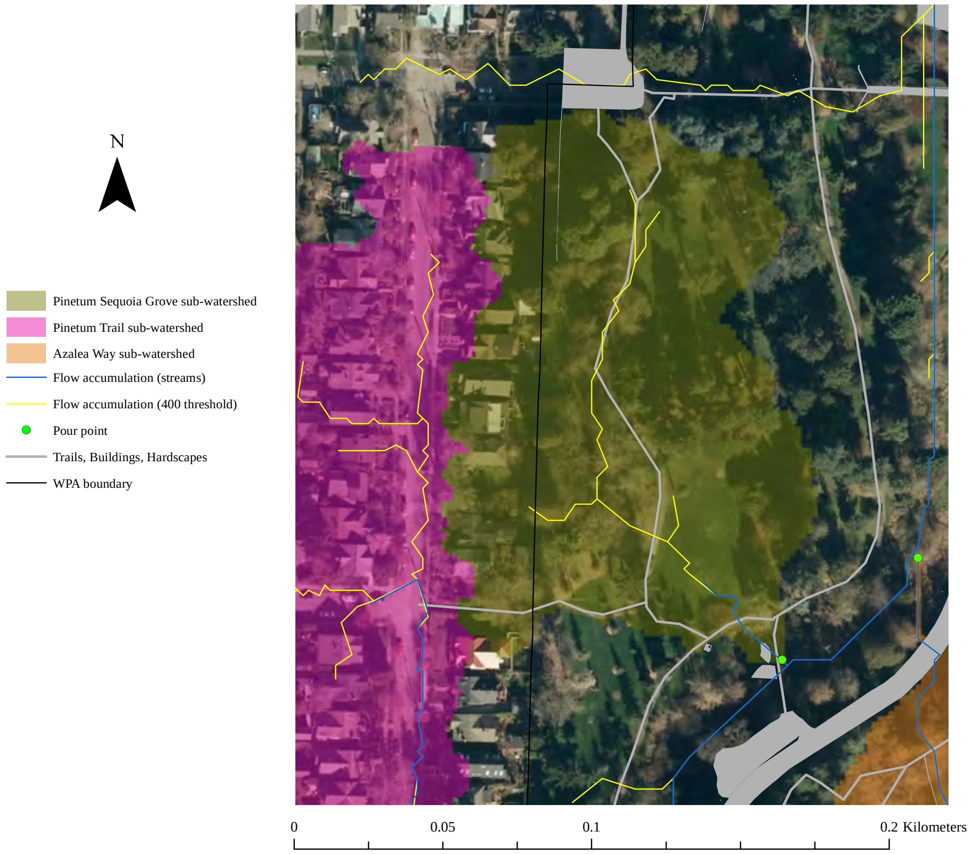

Figure 21. Pinetum Sequoia Grove sub-watershed

The primary stormwater impact in this sub-watershed is flooding of turf and trail areas following heavy precipitation (Figure 22). Mitigation recommendations include installation of a bioretention depression located to the south of current flood zone and west of the trail. This depression would facilitate the storage and infiltration of surface runoff from the flood zone. The overflow would drain into the existing flow accumulation to the south and enter Arboretum Creek near the Stone Bridge.


Figure 22. Flooding of trails and turf areas in Pinetum Sequoia Grove sub-watershed

4.4.4 *Pinetum Trail Sub-watershed*

The Pinetum Trail sub-watershed covers a residential area in the Montlake neighborhood between Lynn Street, 26th Avenue, Boyer Avenue and 24th Avenue (Figure 23). This residential area has a partially combined sewer system and all runoff that is captured by sewer drains is routed into this system (Seattle Public Utilities, 2014). The portion of this sub-watershed that covers WPA property is less than 1% of the total sub-watershed area and covers the point where the flow accumulation joins with Arboretum Creek. This 6,115 square foot area is characterized by upland area along the WPA boundary that drops off sharply to the gravel service road. Arboretum Creek runs north roughly parallel to the service road. WPA surface runoff impacts are limited to minor erosion of the gravel service road. LID recommendations in this area are limited due to the small area, steep slope from the WPA boundary to Arboretum Creek. Any green infrastructure in this sub-watershed would be better suited to the residential area. While this may benefit the WPA and Arboretum Creek, it would be more helpful in slowing runoff and reducing stormwater input to the separated portion of the sewer system.

Figure 23. Pinetum Trail sub-watershed

4.4.5 *Hollies Sub-watershed*

The Hollies sub-watershed covers a residential area in the Stevens neighborhood that is connected to the combined sewer system (Seattle Public Utilities, 2014). Stormwater captured by street drains will be conveyed with solid waste to a treatment facility. The majority of the flow accumulation in the upper sections of the sub-watershed flow along residential streets, indicating that most of the stormwater runoff is diverted into the combined sewer. The lower section drains to the north of the actual Holly Collection along Boyer Ave and Lake Washington

Blvd. However, significant runoff collects in the adjacent Holly Collection to the east of the sub-watershed. A UW soil study concluded that the source of this surface water was from ground water seeping from upland areas, possibly from damaged residential side sewers, a natural spring or a perched water table. Further study is needed to determine the effects of stormwater runoff and infiltration from this watershed on the impacted site. A UW Restoration Ecology Network (UWREN) student group assessed the impacts and installed a series of bioretention ponds to contain surface water and direct it into existing drainage infrastructure. While the project has been successful, ongoing success relies on continued maintenance.

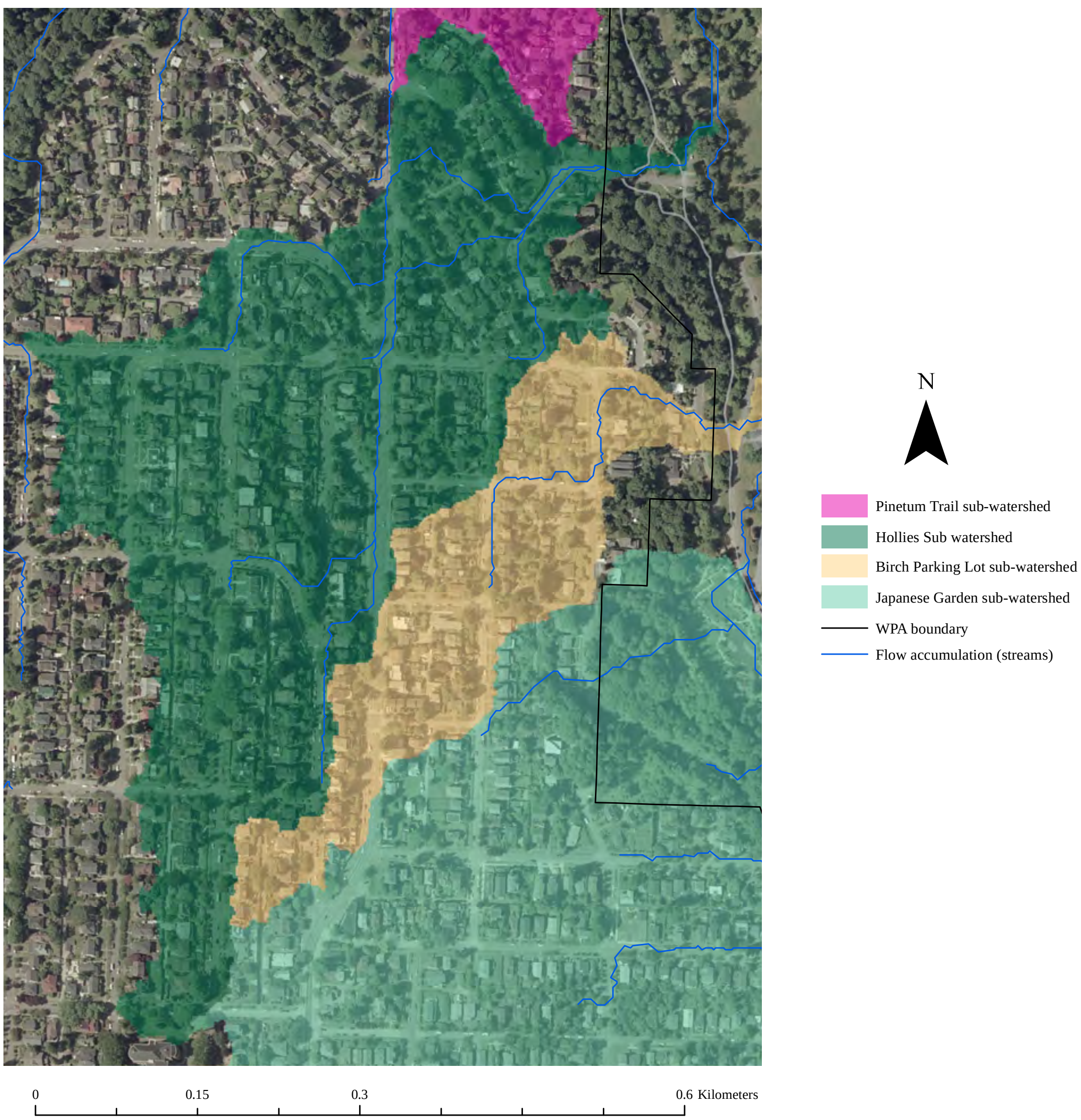

Figure 24. Hollies sub-watershed

4.4.6 *Rhododendron Glen Sub-watershed*

The Rhododendron Glen sub-watershed competes with the Woodland Garden sub-watershed for the most prominent areas in the WPA. The main features of the Rhododendron Glen are the dramatic valley beginning near Arboretum Drive and the *Hydrangea* Collection and dropping west through the *Ericacae* Collection (Medbury, 1990). The flow accumulations in the Rhododendron Glen sub-watershed originate in the Broadmoor Golf Club. Three accumulations cross the WPA boundary where they are captured by catch basins conveying the water further into the sub-watershed. A series of catch basins (Figure 25a) feed the main stream (Figure 25b) drops rapidly through this valley into the upper pond (Figure 25c). The upper pond outflow drops quickly through a narrow channel before leveling out and flowing into the lower pond. This lower pond is adjacent to Azalea Way and has high visibility amongst WPA visitors. The outflow of the lower pond is a catch basin where water is conveyed in a culvert until it is daylighted west of Azalea Way. From there a meandering stream finally joins Arboretum Creek (Figure 25d).

a.


b.


c.


d.


Figure 25. Rhododendron Glen photos: (a) a catch basin along WPA boundary, (b) the main stream, (c) the upper pond (filled with sediment), and (d) Rhododendron Glen stream (right) joins Arboretum Creek (left)

The stormwater impacts in the Rhododendron Glen sub-watershed are sedimentation of ponds (Figure 25c) and erosion causing streambank instability, specifically between the upper and lower ponds. The main stream drops 51 feet in elevation from the beginning of the main stream to the upper pond (540 feet), and another 26 feet between upper pond and the lower pond (330 feet). The relatively steep slope of 0.08 over the 870 feet and the linear shape of the upper stream sections cause a higher flow velocity resulting in the observed erosion and sedimentation. Using LID to slow the upper sections of stream can minimize impacts. A series of retention gardens between the upper most stream section between the culvert and the upper and lower ponds will allow sediments to settle and slow flow velocity. Installing the stream in a meandering manner that increases stream length will further slow flow velocity during high precipitation events.

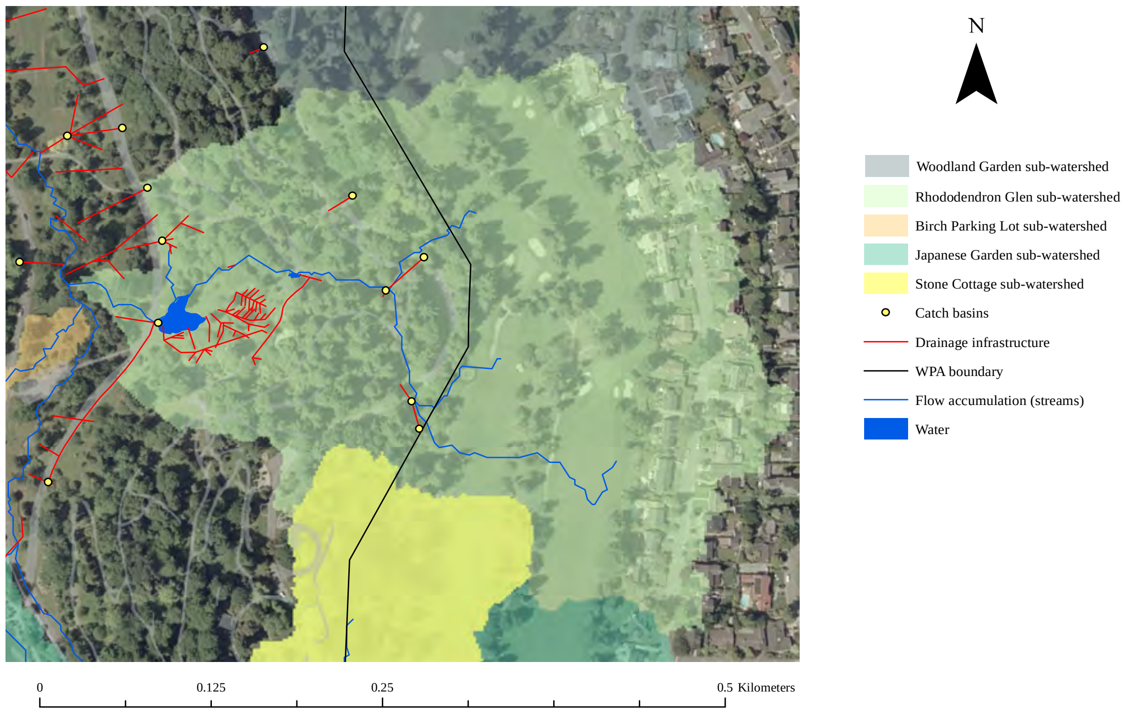

Figure 26. Rhododendron Glen sub-watershed

The Rhododendron Glen sub-watershed is the second WPA sub-watersheds selected for water quality testing by Seattle Parks and Recreation (O'Brien, 2015). Turbidity was analyzed at 4 sites within the sub-watershed: 1) WPA entry point at the catch basin near the WPA boundary 2) the upper pond, 3) the lower pond, and 4) the lower stream entry to Arboretum Creek. Testing was limited to 2 days in March 2015 and found only "background turbidity levels" except in one sample from the upper pond that resulted in elevated turbidity levels. The report concludes this stream system is relatively stable although high precipitation events will increase likely turbidity levels (O'Brien, 2015) and are likely responsible for the sedimentation occurring in the upper and lower ponds. No nutrient or pesticide sampling was conducted in this sub-watershed.

4.4.7 *Birch Parking Lot Sub-watershed*

This sub-watershed covers a sliver of the Stevens neighborhood between the Hollies and Japanese Garden sub-watersheds (Figure 27). The majority of the upper section of the sub-watershed drains into the combined sewer. The small section east of Lake Washington Boulevard near the current parking lot occupies a low, flat area that flows northeast into

Arboretum Creek. This area will likely change dramatically with the construction of the Arboretum Loop Trail and the new Birch parking lot. Expanded impervious surfaces will increase the runoff into lower sections of this watershed. Opportunities for LID and GI here include using permeable hardscapes and bioretention swales along the downhill sections of the trail and parking area. Further rain gardens can be installed along the flow accumulation to slow runoff and reduce sedimentation prior to reaching Arboretum Creek.

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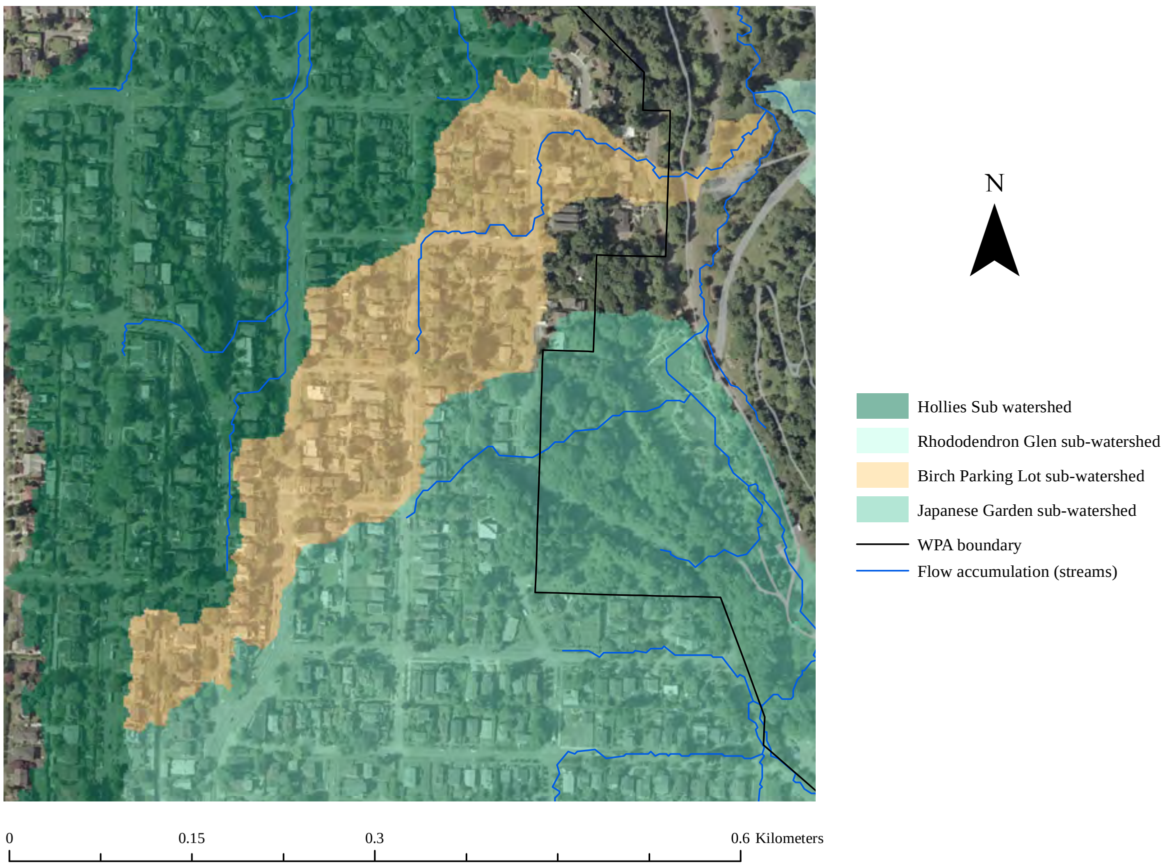

Figure 27. Birch Parking Lot sub-watershed

4.4.8 *Japanese Garden and Stone Cottage Sub-watersheds*

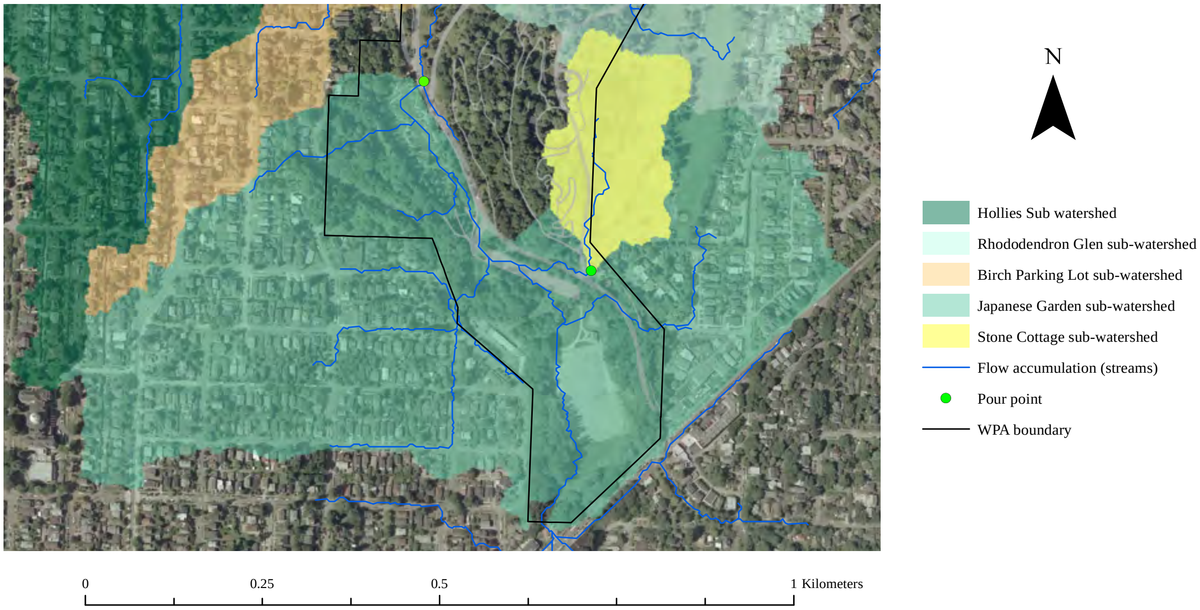

Figure 28. Japanese Garden and Stone Cottage sub-watersheds

The Japanese Garden watershed includes the Japanese Garden and adjacent greenbelt, portions of the Stevens, Harrison/Denny Blaine and Broadmoor neighborhoods, as well as the WPA athletic fields (Figure 28). The original delineation is the largest sub-watershed of Arboretum Creek. The flow accumulations in the Japanese Garden sub-watershed originate in the Stevens neighborhood and the ball field area of Washington Park. Much of the runoff from the neighborhood is likely diverted into sewer infrastructure, while the rest flows into the Japanese Garden pond. The outflow of the pond is a catch basin that conveys water directly into the beginning of Arboretum Creek, along with input from the Stone Cottage sub-watershed. Drainage infrastructure appears to be minimal in this watershed and the any LID installations would reduce flow velocity to Arboretum Creek. Locations for LID would be along the flow accumulation prior to entering the Japanese Garden pond.

Although, it includes two areas that can effectively be omitted from the sub-watershed: (1) the MVSP watershed area and (2) the Stone Cottage watershed. The MVSP, referenced in Section 3.1, diverts water out of the Arboretum Creek watershed. According to Seattle Public Utilities Drainage and Wastewater documents (2012):

> "Over the past several decades, there have been a number of instances of flooding and sewer back- ups in Madison Valley during times of heavy rainfall. Storm events that hit the city and the Madison Valley neighborhood in 2004 and 2006 were especially severe, causing some residents to have up to five feet of water in their basements and flooding in their backyards. The Madison Valley Long Term Solution project will provide stormwater flood control facilities to greatly reduce the potential for flooding in the Madison Valley area."

In 2012, this project created new drainage infrastructure below the surrounding surface streets flowing directly into 2.2 million gallons of stormwater storage located at the south end of the WPA (Figure 29). This project effectively drains a significant portion of the neighborhood surrounding the south end of the WPA into the combined sewer line that drains to the Discovery Park Sewage Treatment Facility (Seattle Public Utilities, 2012). Because this project diverts this stormwater out of the Arboretum Creek watershed, a watershed representing the water collected by the MVSP was created. The MVSP watershed is then clipped, or omitted, from the main Arboretum Creek watershed, as well as the Japanese Garden sub-watershed (Figure 10).

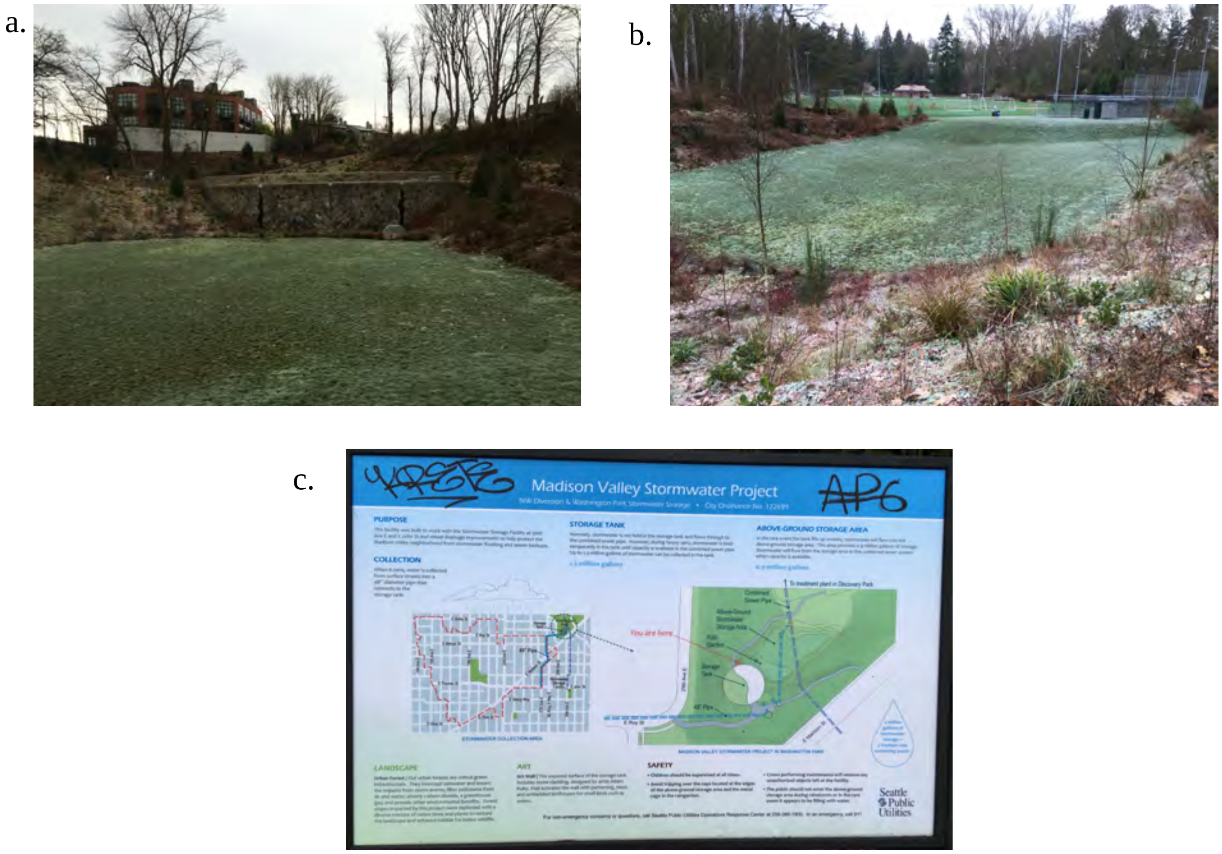

Figure 29. The Madison Valley Stormwater Project completed in 2012 by Seattle Public Utilities: (a) stormwater storage tank, (b) aboveground overflow retention area and (c) interpretative sign

The Japanese Garden sub-watershed also includes the 11.54-acre Stone Cottage watershed. The flow accumulation in this basin is fed from a seasonal pond on the border of the WPA and the Broadmoor Golf Club adjacent to the Pacific Connections Australia Entry Garden. The seasonal pond drains into a small creek that flows south along the WPA boundary into a catch basin near the historic Stone Cottage, located at the corner of Arboretum Dr. and Lake Washington Blvd (Figure 30). According to Seattle Parks and Recreation, this pipe carries stormwater north and east until it daylights into what is considered the beginning of Arboretum Creek. This culvert diverts surface runoff out of the Japanese Garden sub-watershed, however, unlike the MVSP catchment, it remains within the main Arboretum Creek watershed. Delineating a watershed from a pour point placed on this catch basin defines an area that is essentially another sub-watershed of Arboretum Creek, including the seasonal pond that can be considered the headwaters of Arboretum Creek. After subtracting the MVSP and Stone Cottage watersheds, the resulting Japanese Garden sub-watershed remains the largest sub-watershed draining into Arboretum Creek at (Table 2).

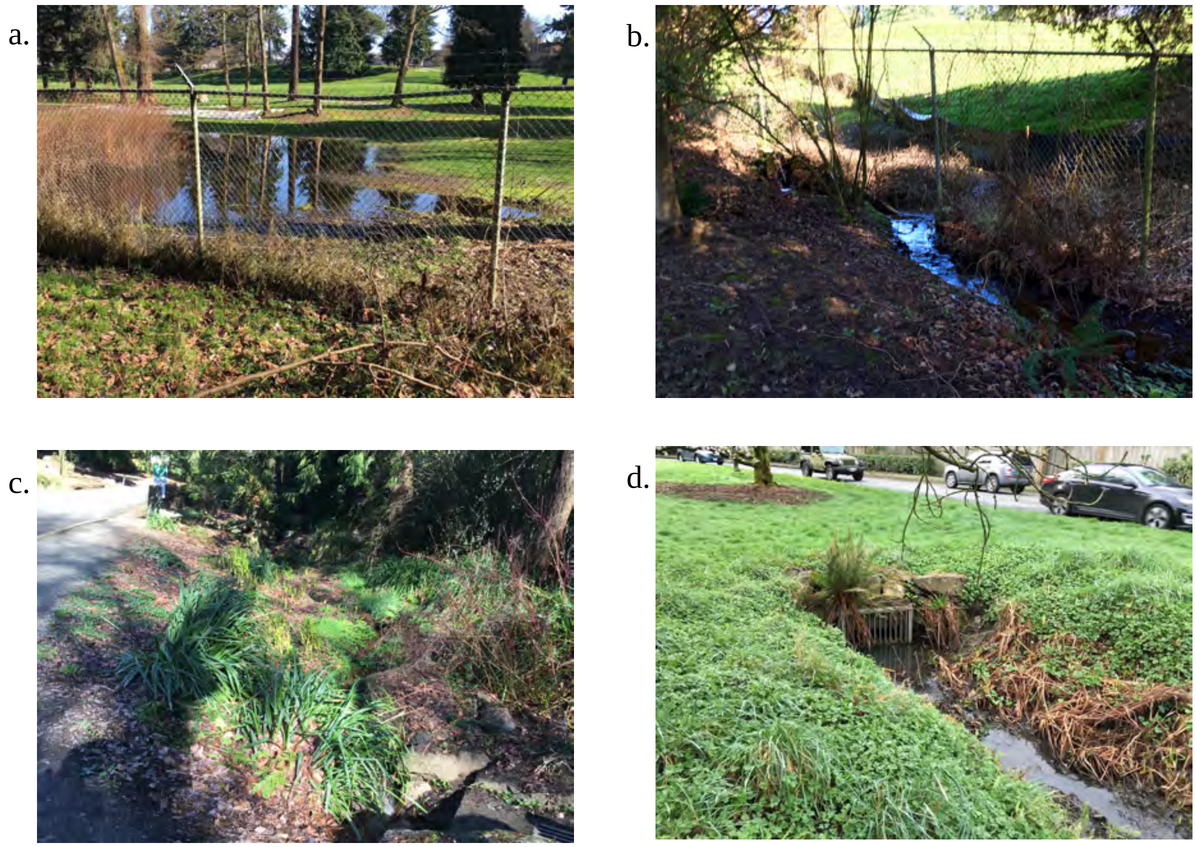

Figure 30. Stone Cottage watershed photos: (a) seasonal pond along WPA boundary, (b) outflow stream, (c) flowing into catch basin (lower right corner), and (d) outflow into Arboretum Creek

The Stone Cottage sub-watershed is the third WPA sub-watershed selected for water quality testing by Seattle Parks and Recreation (O’Brien, 2015). Turbidity was analyzed at 3 sites within the sub-watershed: 1) the seasonal pond on the WPA boundary with Broadmoor Golf Club, 2) the section of stream that enters the WPA and 3) the catch basin at the lowest point of the Stone Cottage sub-watershed. Testing was limited to 2 days in March 2015 and found only low turbidity levels due to gentle slope and slow flow velocity (O’Brien 2015).

Nutrient (Nitrogen), metal (copper and zinc) and pesticide concentrations were tested at the section of stream that enters the WPA. Nitrogen (nitrate and nitrite) levels were within the upper normal range for Puget Sounds streams. Neither, copper and zinc levels exceeded toxicity thresholds. Dieldrin, a banned pesticide, was found in concentrations that exceed the chronic range suitable for freshwater life and is likely a legacy from previous use as it is currently banned (O’Brien, 2015).

4.4.9 *Minor Watersheds*

The minor watersheds are small when compared to the other watersheds, but they occupy an important area within the WPA. The North Azalea Way and GVC watersheds in particular have implications for future development. The North Azalea Way watershed collects stormwater runoff from a 4.58-acre area extending from the eastern section of the Oak collection, to the west edge of the GVC landscape, in addition to the north section of Azalea Way. The flow accumulation of this watershed drains along the east side of Arboretum Drive. As the stormwater heads north towards Union Bay, surface runoff is likely picked up by sewer catchment located at the intersection of Foster Island Drive and Arboretum Drive. Any future development in this vicinity should take into account potential erosion and impacts to the sewer drain, especially if gravel trails are installed. A series of swales, or rain gardens, installed would divert water to already existing low areas located east of Arboretum Drive and the flow accumulation area.

The GVC watershed collects surface runoff from a 6.14-acre area that extends from the northeast edge of the Joe Witt Winter Garden and the area north of Crabapple Meadow, to the eastern half of the GVC landscape and the maintenance facility, as well as an area in Broadmoor. The 5000-threshold flow accumulation begins in the north end of the GVC parking lot and flows east of the maintenance facility before heading across the Foster Island Drive parking lots and into Union Bay. However, when the flow accumulation is adjusted down to 2500, the flow accumulation begins near the Apiary and flows north along the Broadmoor fence before heading west and flowing right through the existing greenhouse facility and into the GVC parking lot. In reality, surface runoff does not run through the greenhouse. This is a limitation of the GIS analysis caused by the original DEM, which does not account for buildings. Planning for the retention and redirection of stormwater is recommended when selecting designs for the proposed construction of UWBG Education Building. Designing functional rain gardens into the landscape would provide an opportunity for UWBG to create a unique visitor experience by expanding the typical rain garden plant palette used in the Pacific Northwest.

The Broadmoor Gate watershed collects stormwater from 7.52 acres almost entirely within Broadmoor property. Surface runoff flows through the entrance gate and northeast through the UWBG Hornbeam Collection. The likely impacts during heavy precipitation events are erosion of the gravel trail that leads to Foster Island. Installation of one rain garden located along the flow accumulation between Foster Island Drive and the gravel trail would minimize runoff and erosion. The function of this rain garden in various rain events would depend on the desired storage volume.

Delineation of the main Arboretum Creek watershed and the three minor watersheds left two small areas with known stormwater impacts undelineated: the north end of the Oak collection and the WPA maintenance facility. Neither area had a 5000 cell flow accumulation. Reducing the flow accumulation threshold to 750 cells yielded one flow accumulation in the Oaks and two flow accumulations near the WPA maintenance area.

The impacts observed in the north end of the Oak Collection are limited to standing water after heavy precipitation leading to saturated soils well into early summer, thus restricting maintenance in the adjacent areas. A catch basin was installed to mitigate the impacts, but it appears to have been installed too far north. A bioretention garden located south of the existing catch basin would contain surface water allowing maintenance to occur in adjacent areas. Directing the rain garden outlet into the existing catch basin would allow stormwater to filter pollutants before being conveyed into Union Bay.

Of the two flow accumulations near the WPA maintenance facility; the western flow is the most problematic. A slow trickle of water routinely flows downhill into the WPA maintenance facility, along the employee parking area, through the gates and onto Foster Island Road. This road receives relatively heavy use and constant erosion occurs through the winter at the point where run off meets the road. Seattle Parks and Recreation staff repair this small stretch of road numerous times annually. The amount of damage caused seems disproportionate to the small flow accumulation. This may be due to supplemental source of water other than precipitation, such as equipment maintenance and cleaning, as well as high percentage of impervious surface. The land cover for this western WPA maintenance facility watershed has 17.3% impervious surface and 9.2% buildings for a combined impervious surface of 26.5%. The eastern WPA maintenance facility watershed, which has no observed stormwater impacts, has a combined total of 7% impervious surfaces. LID mitigation options include replacing impervious surfaces with permeable options, capturing and utilizing runoff from gutters, and placing bioretention gardens at the edge of hardscapes along the flow accumulation.

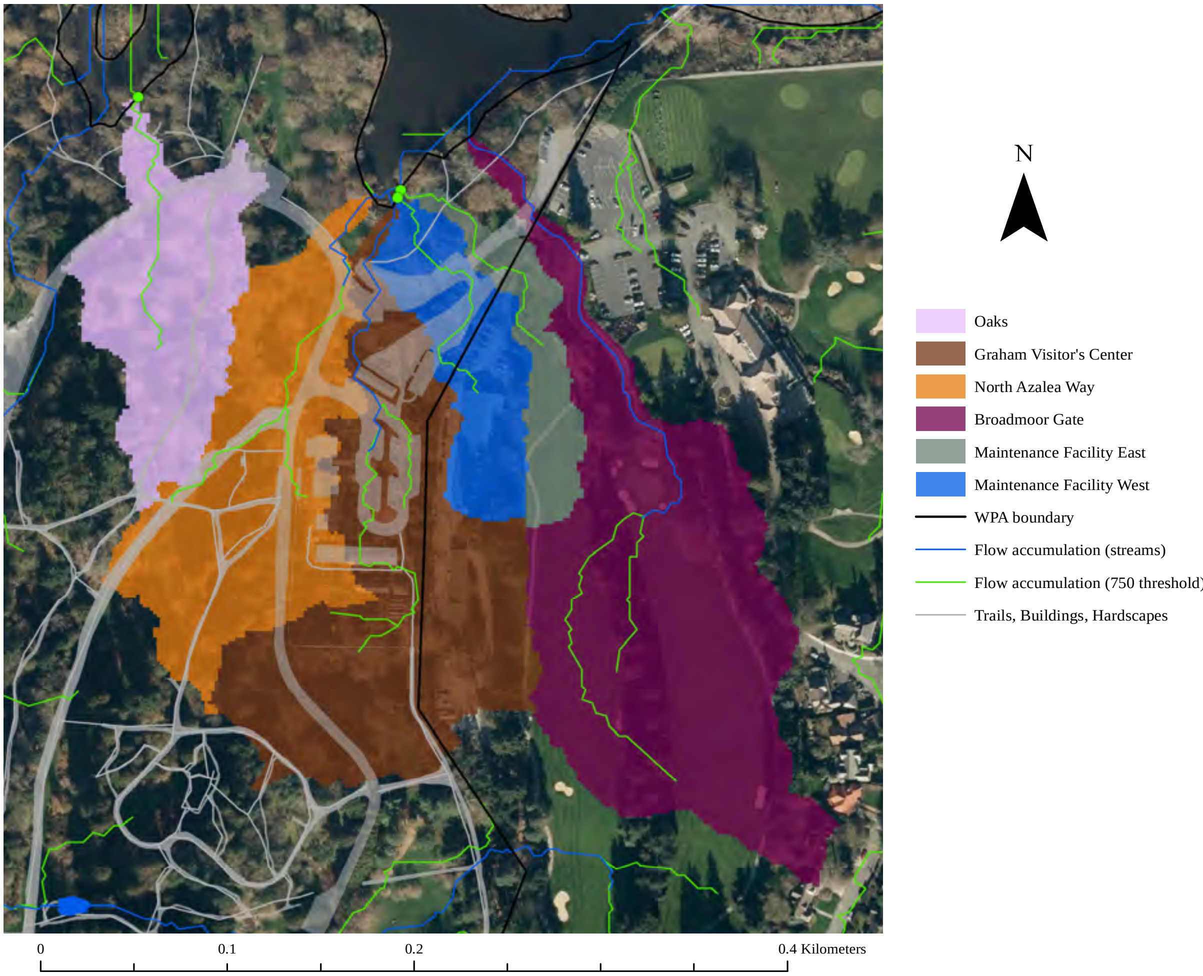

Figure 31. Minor watersheds (Maintenance Facility West, Maintenance Facility East and Oaks watersheds delineated on 750 cell flow accumulation threshold)

5. CONCLUSION

The overarching goal of this project was successful: remote sensing and GIS technology were used to determine areas of stormwater runoff accumulation, all significant watersheds and sub-watersheds in the WPA were delineated, and points of runoff entry into the WPA were defined. This analysis will be useful to UWBG land managers by describing in detail how stormwater moves through the WPA and serving as a guide for locations of LID installations. As urbanization increases and land use surrounding the WPA changes, this approach to understanding runoff offers a relatively quick method of displaying and communicating changes to drainage networks.

5.1 Limitations

While the main goals were met, limitations of this approach were also evident. Sewer infrastructure significantly alters drainage and infiltration regimes. This analysis does not offer a way to easily summarize the effects of sewer infrastructure. The example of the MVSP catchment was relatively simple in that it was one large catch basin. However, in many of the sub-watersheds on the west side of the WPA covered residential streets that contained many catch basins. A possible way to resolve this problem would be to delineate watersheds from pour points on each drain. Then erasing these watersheds from the main watershed would give a more accurate representation of stormwater runoff flowing into Arboretum Creek.

Another limitation of this project is the rapid pace of new development and the less rapid pace of new remote sensing data. Several development projects have been completed within and surrounding the WPA following the collection of LiDAR data used for this analysis. In addition to the irrigation reservoir and elevated tee box constructed in the Broadmoor Golf Club, several phases of the Pacific Connections garden have been completed in the south end of the WPA. All of these developments include grade changes and some degree LID and traditional drainage infrastructure. As technology progresses and the costs of flying aerial LiDAR eventually decrease, updated high-resolution elevation data will more accessible to land managers.

5.2 Next Steps

Further action is recommended in three main areas: water quality testing, updating the stormwater drainage analysis with current LiDAR data and implementation of LID concepts:

- Additional water quality testing throughout the year is recommended to monitor pollutants that are applied at different times. Continued testing at the boundary sub-watershed pour points will indicate pollutants that originate outside the WPA boundary.
- Updating the flow accumulation networks to current conditions is necessary to successfully manage stormwater in the Arboretum Creek watershed.
- Implementation of LID concepts in the WPA will decrease overall runoff, slow stormwater inputs into Arboretum Creek and demonstrate a commitment to sustainable practices in the WPA.

As the general public become more aware of the significance of our watershed health, addressing stormwater impacts will be critical to the stewardship of the WPA, Arboretum Creek and the surrounding communities.

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Appendix: Land Use and Land Cover for all Delineated Watersheds

Main Watershed:

Land Use/ Land Cover	**Main Watershed (Arboretum Creek)**
Buildings	10.2%
Impervious Surfaces	13.8%
Trees (Canopy Cover)	58.8%
Grass	17.0%
Water	0.2%

Sub-watersheds:

Land Use/ Land Cover	**Woodland Garden Sub-Watershed**
Buildings	3.1%
Impervious Surfaces	3.9%
Trees (Canopy Cover)	71.4%
Grass	21.6%
Water	0.0%

Land Use/ Land Cover	**Azalea Way Sub-watershed**
Buildings	0.0%
Impervious Surfaces	0.5%
Trees (Canopy Cover)	98.4%
Grass	1.1%
Water	0.0%

Land Use/ Land Cover	**Pinetum Sequoia Grove Sub-watershed**
Buildings	7.7%
Impervious Surfaces	0.9%
Trees (Canopy Cover)	87.1%
Grass	4.3%
Water	0.0%

Land Use/ Land Cover	Pinetum Trail Sub-watershed
Buildings	25.3%
Impervious Surfaces	18.4%
Trees (Canopy Cover)	42.8%
Grass	13.6%
Water	0.0%

Land Use/ Land Cover	Hollies Sub-watershed
Buildings	18.8%
Impervious Surfaces	23.1%
Trees (Canopy Cover)	40.8%
Grass	17.3%
Water	0.0%

Land Use/ Land Cover	Birch Parking Lot Sub-watershed
Buildings	18.6%
Impervious Surfaces	24.6%
Trees (Canopy Cover)	38.5%
Grass	18.3%
Water	0.0%

Land Use/ Land Cover	Rhododendron Glen Sub-watershed
Buildings	6.2%
Impervious Surfaces	5.0%
Trees (Canopy Cover)	65.1%
Grass	23.4%
Water	0.3%

Land Use/ Land Cover	Japanese Garden Sub-watershed
Buildings	12.1%
Impervious Surfaces	19.5%
Trees (Canopy Cover)	48.5%
Grass	19.4%
Water	0.4%

Land Use/ Land Cover	Stone Cottage Sub-watershed
Buildings	0.4%
Impervious Surfaces	2.8%
Trees (Canopy Cover)	59.5%
Grass	37.3%
Water	0.0%

Minor Watersheds:

Land Use/ Land Cover	Graham Visitor's Center Minor Watershed
Buildings	8.1%
Impervious Surfaces	12.8%
Trees (Canopy Cover)	59.8%
Grass	19.3%
Water	0.0%

Land Use/ Land Cover	North Azalea Way Minor Watershed
Buildings	6.1%
Impervious Surfaces	6.3%
Trees (Canopy Cover)	77.2%
Grass	10.4%
Water	0.0%

Land Use/ Land Cover	Broadmoor Gate Minor Watershed
Buildings	0.7%
Impervious Surfaces	6.3%
Trees (Canopy Cover)	38.6%
Grass	54.4%
Water	0.0%

Land Use/ Land Cover	Oaks Minor Watershed (750-cell threshold)
Buildings	6.6%
Impervious Surfaces	90.6%
Trees (Canopy Cover)	2.8%
Grass	0.0%
Water	0.0%

Land Use/ Land Cover	Maintenance Facility East Minor Watershed (750-cell threshold)
Buildings	0.0%
Impervious Surfaces	7.0%
Trees (Canopy Cover)	40.9%
Grass	52.1%
Water	0.0%

Land Use/ Land Cover	Maintenance Facility West Minor Watershed (750-cell threshold)
Buildings	9.3%
Impervious Surfaces	17.2%
Trees (Canopy Cover)	49.5%
Grass	24.0%
Water	0.0%