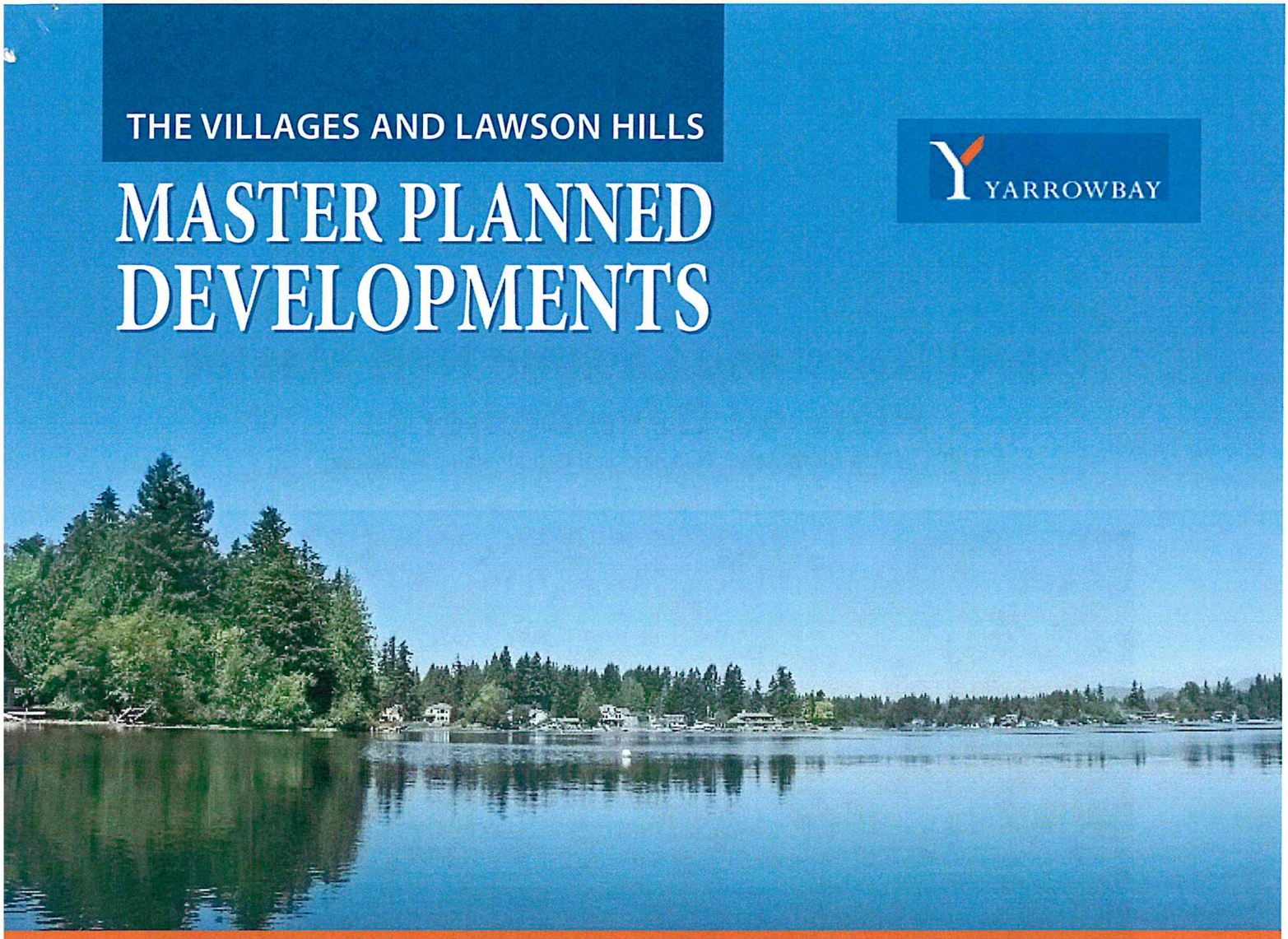
THE VILLAGES AND LAWSON HILLS

MASTER PLANNED DEVELOPMENTS

YARROWBAY



2011-2014 Stormwater, Baseline and Groundwater Monitoring

TETRA TECH

FINAL REPORT
March 17, 2015

Yarrow Bay

FINAL

The Villages and Lawson Hills Master Planned Developments

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PREPARED FOR

Yarrow Bay

YARROWBAY

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EXECUTIVE SUMMARY

Objectives for this project were the water quality sampling requirements set forth in the No Net Phosphorus Implementation Plan section of Exhibit "O" to The Villages and Lawson Hills Master Planned Development (MPD) Development Agreements (DAs), which requirements were enhanced by the City of Black Diamond Hearing Examiner in The Villages MPD Preliminary Plat 1A decision, and to report a total phosphorus baseline. Those objectives are the focus for products developed from three years of baseline monitoring, storm event monitoring, and groundwater monitoring. Specifically, the objectives for this project were the following:

- To perform analysis of water quality sampling and flow data;
- To determine hydrograph separation (baseflow versus stormflow);
- To describe the relationship between stream flow and nutrient concentration in the water (correlation analysis or sometimes referred to as "smearing");
- To determine phosphorus loading from baseflows at three sites on Rock Creek; and
- To identify any additional sampling deemed necessary to provide for an acceptable error of 0.05.

Water quality sampling was initiated 2011 and continued through beginning of 2014, generating a substantial increase in water quality observations during a variety of storm events and representing different stages of the hydrograph (water level fluctuation) including base flow at Rock Creek sites. Water quality conditions were coupled with a substantial number of flow observations used to develop flow rating curves (tools used to predict flow by using automated, continuous water level monitoring devices). Development of flow-rating curves was completed using a data set generated during a water year when rain events were more numerous and intense (Water year 2013/2014) and rating curves validated by comparing against previous monitoring years (2011/2012 and 2012/2013). The appearance of beaver dams that obstructed flows were previously not included in calculating flow over the calendar year and would affect estimates for total annual nutrient loads by underestimating potential for maximum loads in years when beaver dams are absent.

Hydrograph separation was completed using a web-based application called WHAT (Web-based Hydrologic Analysis Tool, described more fully in Section 2.2 below. A hydrograph separating base flow from runoff flow (or storm flow) was defined for all three Rock Creek monitoring sites. Results show consistently that storm flow conditions represent approximately one-third the total annual TP load among all sites. Base flow conditions are relatively constant at a site with similar hydrologic patterns between years, so are a standard expression that can be compared between years for determining advent of drought.

Flow measurements and TP samples were collected simultaneously at several points throughout the calendar year for each of the Rock Creek sites. The flow record had several points at which Total Phosphorus (TP) was correlated and a regression model developed. The predictive model had a strong correlation between flow and TP ($R = 0.83$) and was used to calculate average daily loads and then summed to determine total annual load for TP at each Rock Creek site.

Total annual TP load estimates in this study reflect current background conditions at each of the three Rock Creek sites. Any differences from previous studies (Carroll and Pelletier. 1991) describing background conditions reflect changes in the drainage and human activity that influence the Rock Creek drainage area. TP loading increases from the uppermost Abrams Avenue site to the lowermost SE 312th Street site (406.76 kg/year) on Rock Creek as a function of inputs to each of the wetlands directly above the site and the assimilation capacity for nutrients by the wetlands. Approximately one-third of the Total Phosphorus load at the lowermost location on Rock Creek is contributed by stormwater and the same ratio for contribution of TP from stormwater exists at the remaining two sites on this creek. Jones Lake serves as a large nutrient sink for drainage areas above this location and is exemplified in the lower nutrient load passing by the Abrams Avenue site. Input of nutrient below this location increases as assimilation capacity, or capacity of retention, of nutrients is lower in the wetland above ABDR and SE 312th Street sites on Rock Creek. Total annual TP load from Lawson Hills (Plat 2B) is 2.12 kilograms/year and from The Villages (Plat 2C) is 1.86 kilograms/year.

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
ABDR	Auburn-Black Diamond Road
DA	Development Agreement
HYSEP	Hydrologic Separation Tool developed by USGS
kg/yr	Kilograms per year
MPD	Master Planned Development
MWV-29	Monitoring Well in Area V29 (part of Plat 2C)
NO3+NO2-N	Nitrate+Nitrite-Nitrogen
QAPP	Quality Assurance Project Plan
SRP	Soluble Reactive Phosphorus
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WHAT	Web-based Hydrologic Analysis Tool

1.0 INTRODUCTION

Water quality conditions in lakes and streams are a reflection of the geochemical watershed/basin characteristics and surrounding landscape. The landscape, in turn, is directly impacted by human activity that changes hydrology and destabilizes surrounding soils and vegetation patterns. These features of a drainage area influence the quantity of nutrients transferred from terrestrial to aquatic environments, the length of time transfer occurs, and locations in a stream or lake where nutrient introduction is detectable. Historic disturbance in a drainage area affects nutrient dynamics in the aquatic ecosystem and are reflected in current water quality conditions.

Some areas of The Villages and Lawson Hills MPDs are in the Rock Creek drainage that supplies water to Lake Sawyer and is part of a Lake Sawyer TMDL. The combined input of total phosphorus (TP) from several sources like the larger Ravensdale Creek drainage, Rock Creek drainage, non-point sources (e.g., on-site septic systems surrounding the lake), and air deposition should not produce in-lake steady state TP concentrations higher than 16 µg/L (Carroll and Peletier,1991). Rock Creek is characterized by three large wetlands over its length between Jones Lake and Lake Sawyer. The upper end of this Rock Creek reach receives water from the smaller Ginder Creek drainage. The downstream wetlands function differently from stream ecosystems by sequestering and releasing nutrients. Timing for sequestration and release as well as the mechanism for this process in wetlands differs from that in flowing water. The unique properties of these three wetlands are taken into account as reflected in objectives of this study and how data are interpreted. This more intensive water quality monitoring program provides greater detail on how Rock Creek can influence Lake Sawyer TP concentration under stormflow conditions and baseflow conditions, representing a greater effort to characterize storm events beyond previous Washington Department of Ecology studies.

1.1 OBJECTIVES

Objectives for the three-year monitoring effort were to summarize results from routine baseline monitoring and storm event monitoring at select sites on Rock Creek in the Lake Sawyer drainage from 2011-2014. The following are products expected to be developed resulting from the monitoring effort:

- Analysis of water quality sampling and flow data;
- Define hydrograph separation (baseflow versus stormflow);
- To describe the relationship between stream flow and nutrient concentration in the water (correlation analysis or sometimes referred to as "smearing");
- To determine phosphorus loading from baseflows at three sites on Rock Creek; and
- To identify any additional sampling deemed necessary to provide for an acceptable error of 0.05.

The objectives listed above are a result of several directives outlined by the Black Diamond Hearing Examiner and Black Diamond City Council for The Villages and Lawson Hills MPDs. Exhibit "O" of The Villages and Lawson Hills MPD DAs, contains the following requirement:

- Monitoring: Prior to construction of the first MPD Implementing Project, the Master Developer shall cause to occur three water quality samples in three separate months during the wet season at three locations within Rock Creek to be mutually agreed to by the City and Master Developer. This sampling data shall be provided to the City and be used to establish an interim baseline phosphorous load that will then be further refined by the Baseline Monitoring section below.

Note: During the 2011-2012 water year, three water quality samples were collected in three separate months (December 2011, January 2012, and March 2012) during the wet season at three locations within Rock Creek to characterize pre-development conditions and establish an interim baseline phosphorus load that would then be further refined by the 2012-2013 Baseline Monitoring Program (set forth below). *See* TetraTech's Technical Memorandum titled "The Villages and Lawson Hills MPDs

Pre-Construction Stormwater Monitoring in Rock Creek and the Establishment of an Interim Baseline Phosphorus Load" dated July 23, 2012 for more information. The interim baseline phosphorus load would be established following completion of additional monitoring during 2013-2014 water year.

> Baseline Monitoring: Prior to construction of the first implementing project within the Lake Sawyer drainage basin, the Master Developer, in conjunction with the City of Black Diamond shall review, plan and institute the following:
>
> 1. Monitor pre-development phosphorus levels at pre-determined locations within the project drainage basins. Monitoring is to occur consistently over the course of at least one water year (October to September) in accordance with the procedures and criteria outlined in Chapters 6 through 12 of the QAPP (see Exhibit "O" to the DAs). Use data collected over the water year to establish a baseline phosphorus load from the project. This load should be factored to an average year rainfall volume for future comparisons of phosphorus loads for years where the rainfall is more or less than the average.

Note: This Baseline Monitoring requirement (above) was satisfied by the 2012-2013 Baseline Monitoring Program that was summarized in the 2012-2013 Phosphorus Monitoring Report. However, pursuant to the City of Black Diamond Hearing Examiner's Decision for The Villages MPD Preliminary Plat 1A, dated December 10, 2012, the Baseline Monitoring Program is required to be expanded for the Villages Preliminary Plat 1A beyond this Baseline Monitoring requirement set forth above (and in Exhibit "O" to the Villages and Lawson Hills MPD Development Agreements). Specifically, the Expanded Baseline Monitoring Program for The Villages Preliminary Plat 1A is required to include "a significant increase in the amount of sampling to provide for an acceptable error of 0.05 and the use of hydrograph separation, flow and nutrient correlation, and other techniques to estimate separate loadings for base flows." The Expanded Baseline Monitoring Program that was approved by the City on July 19, 2013 includes the following approach:

- Storm event monitoring at three Rock Creek locations during three separate storm events in the 2013-2014 water year. Three samples collected at each site during each storm event (total of 9 samples for each of the three sites = 27 total samples).
- Flow monitoring data will be generated at the time of sampling and will be used to estimate separate loadings for base flows.
- This expanded baseline monitoring program significantly increases the amount of sampling in Rock Creek and is sufficient to provide for an acceptable error of 0.05.

Analysis of the water quality sampling and flow data from water years 2011-2012, 2012-2013, and 2013-2014 will include development of hydrograph separation, flow and nutrient correlation, and other techniques to estimate separate phosphorus loadings for base flows

1.2 MONITORING SITES

Several monitoring sites and frequencies of sample collection were used from 2011-2014 in order to characterize the entire extent of the drainage area. Seven sites were the main focus for stormwater monitoring in 2011. These sites were sampled again in 2012-2013 and identified as either stormwater sites or baseflow monitoring sites. In 2014, the focus was narrowed to four sites in drainage areas immediately surrounding the development area and draining into Lake Sawyer. Groundwater monitoring on the development site was also performed in 2014. Figure 1 displays these samplings sites and their relative locations to each other and Lake Sawyer, as well as the beaver dams that were observed during the 2013 sampling events.

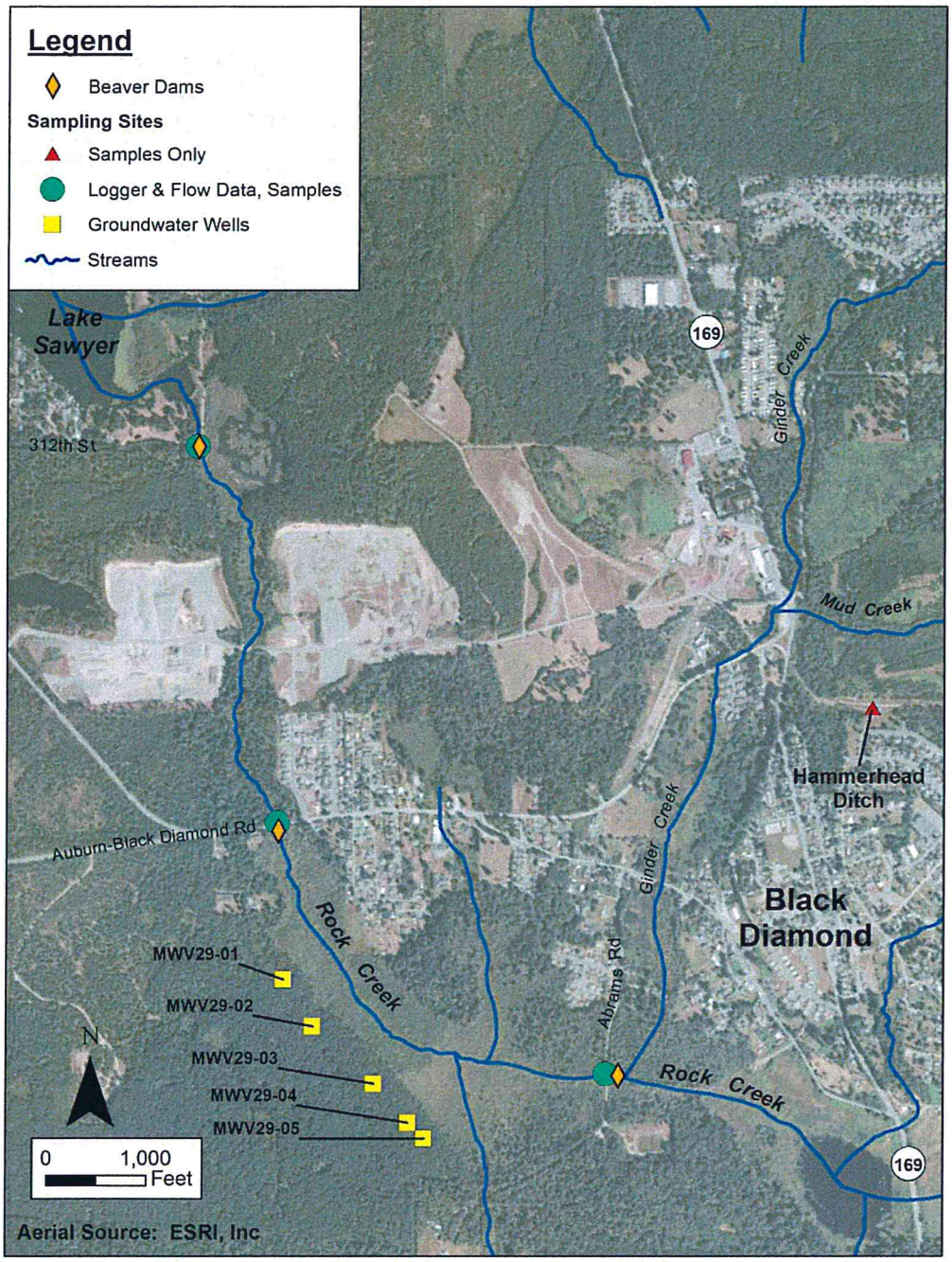

Figure 1. 2014 Sampling Sites in the Rock Creek Drainage Area

1.2.1 Stormwater Monitoring Sites

Four sites were monitored consistently beginning in 2011 and ending in 2014. These sites were the focus for describing baseline and stormflow conditions used to eventually describe total phosphorus (TP) annual loading. Site locations are identified in Figure 2 through Figure 8. Descriptions are provided for each site in order to indicate setting characteristics that were important for interpreting monitoring results.

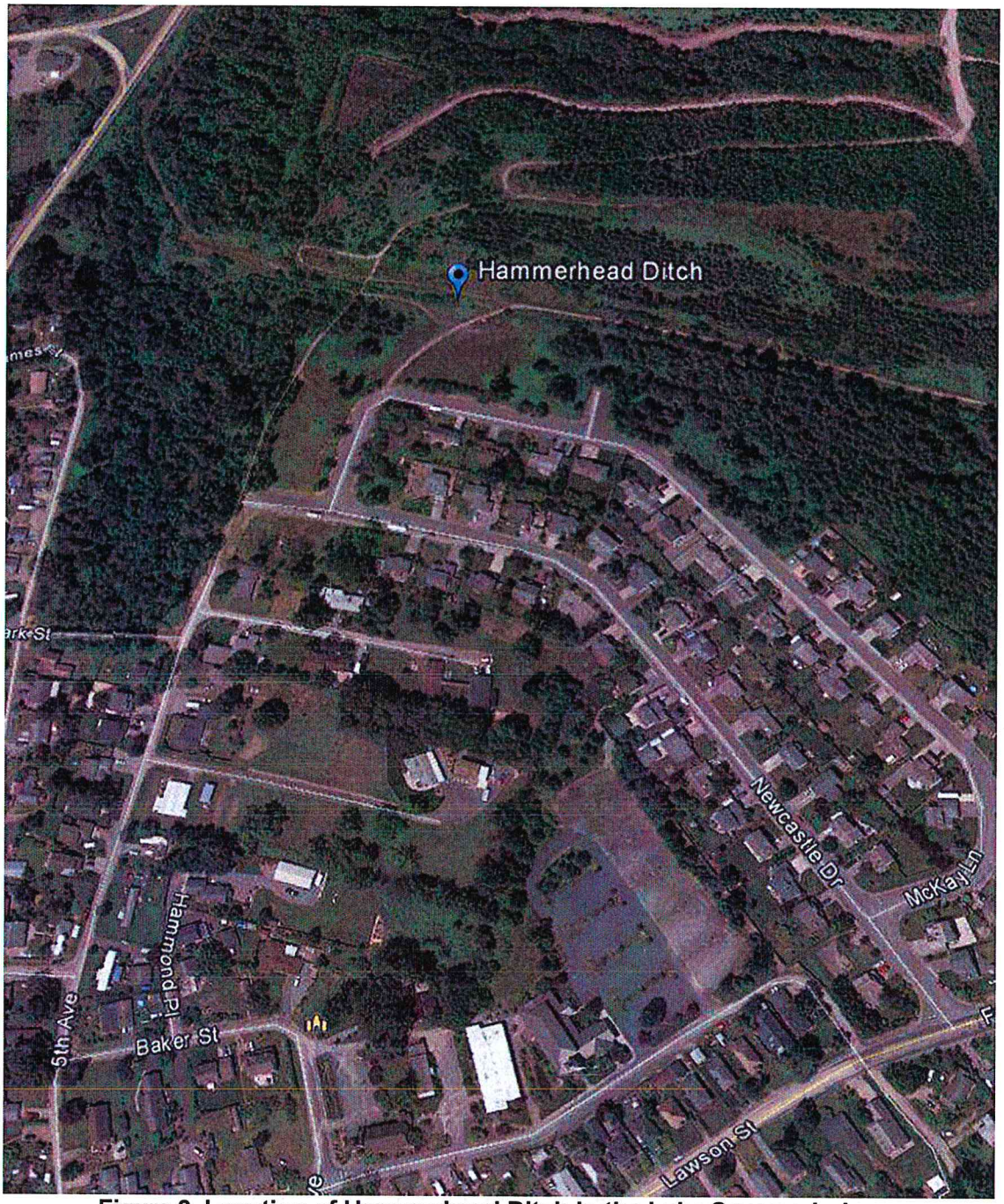

Figure 2. Location of Hammerhead Ditch in the Lake Sawyer drainage.

Figure 3. Location of monitoring sites on lower Rock Creek; SE Auburn-Black Diamond Road (ABDR), and SE 312th Street.

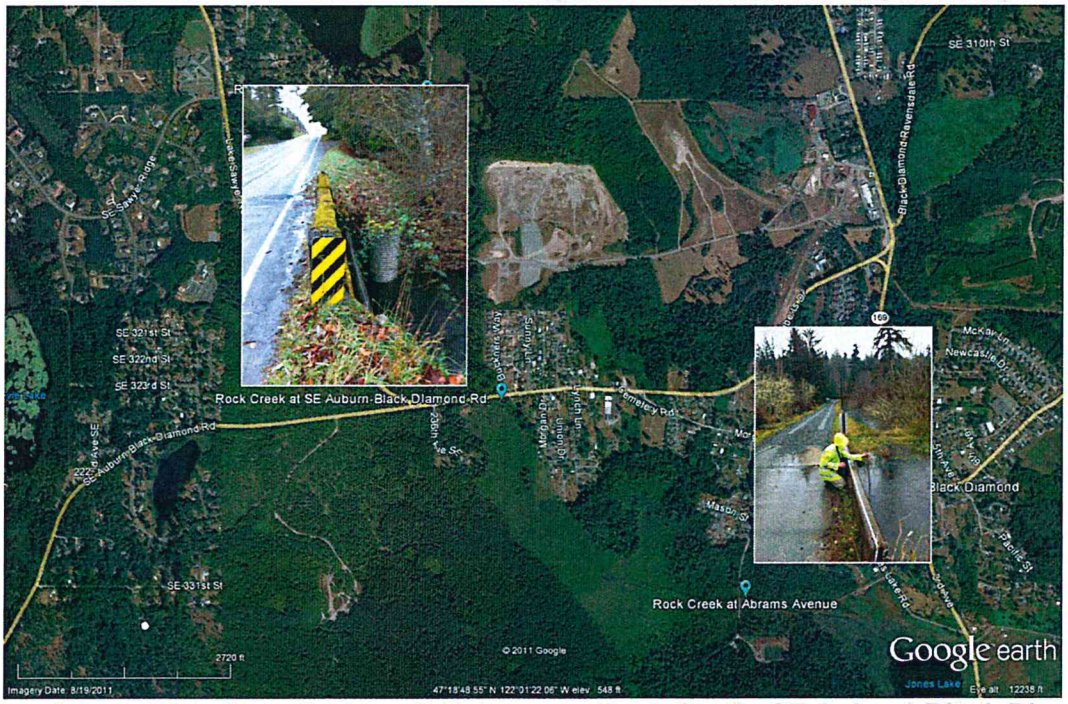

Figure 4. Location of monitoring sites on upper Rock Creek; SE Auburn-Black Diamond Road (ABDR), and Abrams Avenue.

1.2.1.1 Hammerhead Ditch

The Hammerhead Ditch site is located on the proposed development site. Water is only present in the ditch during times of high storm flows. Resulting flow remains a trickle or forms a small pool of water following adequate water recharge. The ditch originates from a former coal mining site with runoff comprising flow in Hammerhead Ditch following adequate rainfall. Sampling the Hammerhead Ditch site is shown below in Figure 5 to illustrate how the small pool of sampleable water forms.

Figure 5. The Hammerhead Ditch stormwater sampling site.

1.2.1.2 Abrams Road

The Abrams Road site is the uppermost location on Rock Creek where baseline monitoring and stormwater monitoring was completed. The site hydrology is influenced by wetland pools created by beaver dams (*Castor canadensis*). Challenges for measuring stream flow at this site included passage of water beneath Abrams Road through a culvert during low flows. High flow conditions are measured by water flowing through the culvert and water flowing over Abrams Road. Figure 6 below shows flow measured through the culvert beneath Abrams Road. The site visit during this date was during a moderate storm event where water was not flowing over the road and dividers on the road margin.

Figure 6. Measuring flow at the Abrams Road site on Rock Creek.

1.2.1.3 Auburn-Black Diamond Road (ABDR)

The Auburn-Black Diamond Road site is located downstream of the Abrams Road site and is in the middle of the Rock Creek reach sampled for TP loading estimates. This site drains a large wetland complex adjacent to the Villages MPD. The upper area of this portion of Rock Creek is an extensive wetland with water level that appears to partially be regulated upstream of the Auburn-Black Diamond Road by a sil (upstream of the road). The ABDR site upstream of the road is shown in Figure 7 below.

Figure 7. Monitoring location at the Auburn-Black Diamond Road.

1.2.1.4 SE 312th Street

The SE 312th Street stormwater monitoring site is the most downstream site, and captures flow from the surrounding drainage area before it is discharge into Lake Sawyer. At times of high flow, the culvert is inaccessible and flow measurement collection is impossible due to extremely high flows. A photo of this site is shown below in Figure 8.

Figure 8. The 312th Street stormwater monitoring site.

1.2.2 Baseflow Monitoring Sites

Baseflow monitoring was conducted at 7 sites in the Lake Sawyer drainage from 2012-2013. These sites included 3 of the stormwater monitoring sites mentioned above (Abrams Road, Auburn Black Diamond Road, and 312th Street), and four sites on the upstream side of the drainage area. The four sites included Mud Creek, Ginder Creek, the stormwater detention basin along SR 169, and Ginder Creek along Roberts Drive. All four of these sampling sites are shown below in Figures 9 through 12. Level loggers were established at each of these sites to document fluctuations in water level during storm events and during dry periods. Results from the water level fluctuation monitoring at each of the sites indicated hydrology patterns during both wet weather and dry weather conditions.

Table 1. Locations for Rock Creek and Ginder Creek monitoring during storm events and dry periods.

SITE NAME	LATITUDE	LONGITUDE
Rock Creek at SE 312th Street	47°19'44.76"N	122°01'21.31"W
Rock Creek at SE Auburn-Black Diamond Road	47°18'43.32"N	122°01'30.76"W
Rock Creek at Abrams Avenue	47°18'17.31"N	122°00'44.12"W
Ginder Creek at Robert's Drive	47°18'58.12"N	122°00'27.38"W
Storm Drain along SR 169	47°19'04.87"N	122°00'17.52"W
Mud Creek above SR 169	47°19'03.82"N	122°00'15.97"W
Ginder Creek above SR 169	47°19'05.59"N	122°00'16.76"W

Figure 9. Ginder Creek above SR 169 monitoring location.

Figure 10. Mud Creek above SR 169 monitoring location.

Figure 11. Storm drain along SR 169 monitoring location.

Figure 12. Ginder Creek below Robert's Drive monitoring location.

1.2.3 Groundwater Monitoring Sites

Five groundwater sampling wells, MWV29-01-MWV29-05 were installed prior to the 2014 monitoring season. The purpose of sampling these wells was to determine groundwater quality characteristics during storm events and dry periods. These sites were sampled in order to identify similarities between groundwater and surface water chemistry in nearby surface water (primarily Rock Creek) and the potential for presence of the development to transfer TP to surface water baseflow. All wells sampled contained water throughout most of the sampling period except for well MWV29-01 which did not fill an adequate level for sampling. Groundwater site locations are reported by geospatial coordinates in Table 2 and visually on an aerial image in Figure 13. The groundwater well sampling apparatus is shown in Figure 14.

Table 2. Locations for area V28 and V29 groundwater monitoring sites

SITE NAME	LATITUDE	LONGITUDE
MWV29-01	47°18'27.60"N	-122°01'30.90"W
MWV29-02	47°18'22.90"N	-122°01'26.70"W
MWV29-03	47°18'17.19"N	-122°01'18.00"W
MWV29-04	47°18'13.30"N	-122°01'13.10"W
MWV29-05	47°18'11.70"N	-122°01'10.80"W

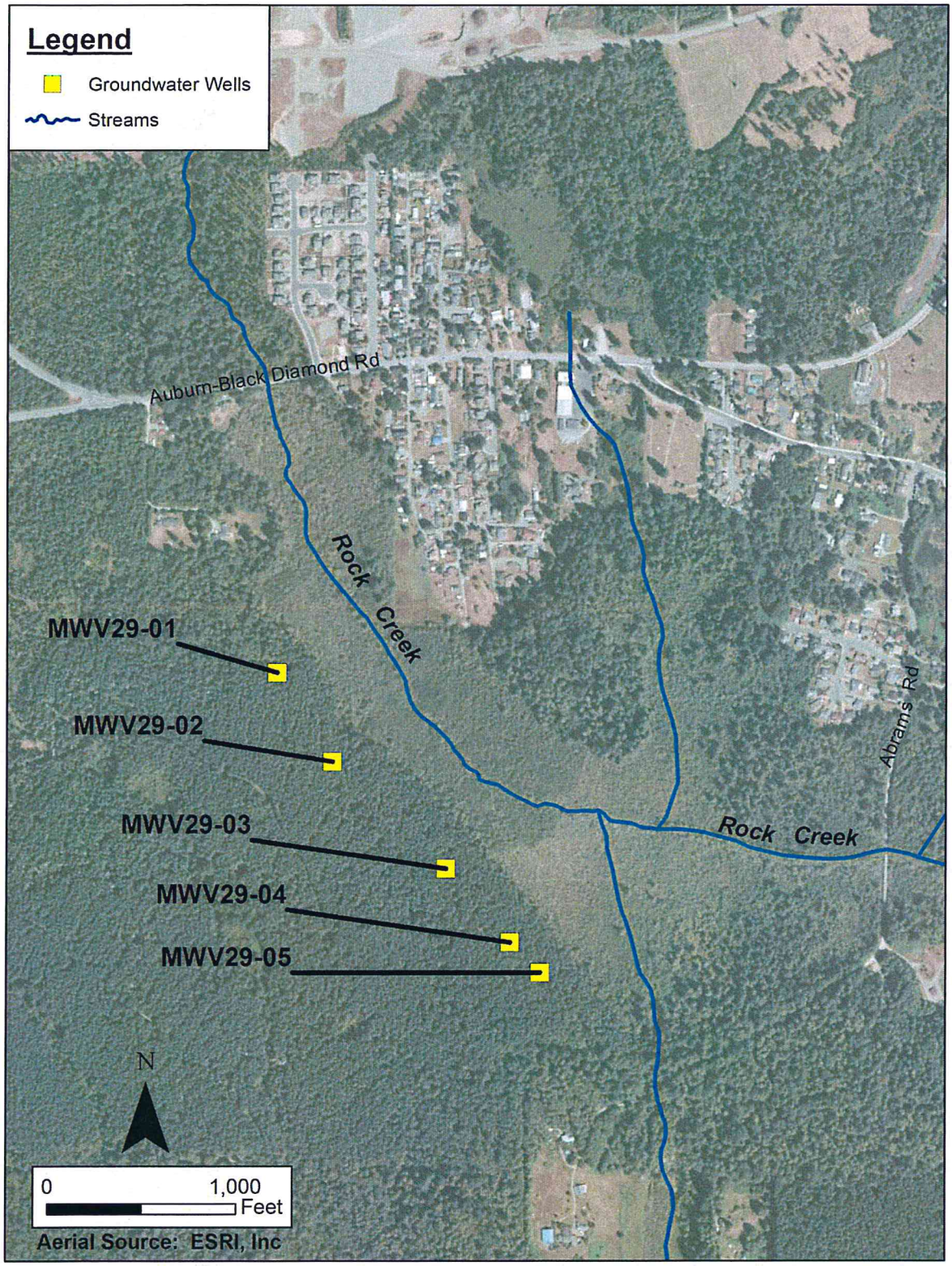

Figure 13. 2014 Groundwater well monitoring sites.

Figure 14. Groundwater well sampling apparatus in use at MWV29-02.

2.0 METHODS

Several technical products were developed from 3 years of monitoring data to address the objectives of this study. Technical products were developed from field measurements and laboratory sample analysis in order to achieve several goals. The sequence for development of technical products is found in Figure 15.

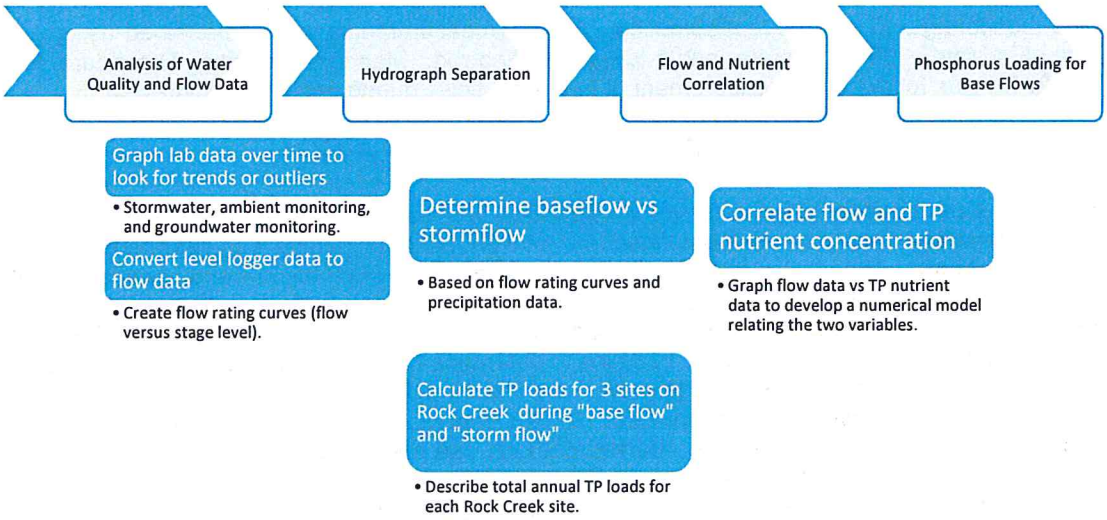

Figure 15. Sequence of technical product development addressing objectives for the monitoring program.

2.1 WATER QUALITY SAMPLING AND FLOW MEASUREMENT

Water quality monitoring began November of 2011 through March 2014 resulting in a total of 26 separate visits to each of the Rock Creek locations. The separate visits were categorized as baseline monitoring (monthly visits for one calendar year) or storm event sampling (3 storm events in 2011-2012; 6 storm event in 2012-2013; and 3 storm events in 2013-2014). Baseline monitoring included 14 separate visits to characterize water quality conditions with a single grab sample (14 baseline monitoring visits in total) and 12 storm event monitoring visits were made during this time period (3 grab samples were made at a site for each of the separate storm event visits). All samples collected during these events were analyzed for TP, soluble reactive phosphorus (SRP), ammonia-nitrogen, nitrate and nitrite (NO3 + NO2)-nitrogen, total nitrogen (TN), total suspended solids (TSS), and turbidity. Sample integrity was maintained using standard protocols for handling containers by rinsing twice with the sample water prior to sample collection (unless jars contained preservative) and all samples were collected from the main line of flow in the channel (known as the thalweg). Field parameters (e.g., temperature, pH, conductivity, and dissolved oxygen) were measured during each sampling event using a multi-parameter probe; the OTT Hydrolab® MS5 instrument.

In addition to the baseline monitoring and storm event sampling, 11 visits were made to collect groundwater samples between January 2014 and April 2014. Samples were collected at four of the five piezometer locations described in Section 1.2.3 to characterize baseline nutrient concentrations in groundwater and at nearby Rock Creek surface locations. One of the five groundwater piezometers, MWV29-01, was consistently dry throughout the monitoring period and was not sampled. The remaining four wells contained water during the 12-week monitoring period, except for periodic intermittent dry conditions. Two of the four groundwater wells were selected during each event, with sampled wells rotating weekly and selected based on presence of water in a well. Well sampling results were uniformly distributed in order to collect an approximately equal number of observations from each.

Samples were collected from wells using a peristaltic pump and specific set of collection protocols in order to minimize contamination from the collection apparatus. WDOE (2014) Standard Operating Procedure EAP078 was used for well sampling that included purging of a well of 3-5 times the casing volume (when possible) prior to collection of the final sample for laboratory analysis. All samples were analyzed for TP, SRP, ammonia-nitrogen, NO3 + NO2-N, TN, TSS, and turbidity. Field parameters (e.g., temperature, pH, conductivity, and dissolved oxygen) were collected using an OTT Hydrolab® MS5 multi-parameter probe.

Flow measurements were made at the same locations that surface water samples were collected during baseline monitoring and storm event sampling. All flow measurements were determined using a Marsh McBirney Flo-Mate® 2000 flow meter and a top-set wading rod. Standard Operating Procedure, EAP024 (WDOE 2012) was followed for measurement of in-stream flows during each sampling event.

2.2 HYDROGRAPH SEPARATION

To evaluate the contributions of baseflow versus stormflow from the Rock Creek watershed to Lake Sawyer, hydrograph separation analysis was completed and total phosphorus loading was determined under each of the flow conditions. The initial step in this analysis included defining total flow and baseflow resulting in determination of the stormflow component at each of the Rock Creek locations. Several methods were examined for separating the baseflow from stormflow components from total flow. These methods used for this determination involved mathematical modeling to determine the base flow/storm flow relationship. The U.S. Geological Survey developed a widely-used application called HYSEP that can use three different methods for determining hydrograph separation: 1) fixed interval, 2) sliding interval, and 3) local minimum methods. The fixed interval and sliding interval methods use the lowest discharge over a user-defined period (fixed or sliding, respectively) and qualify flow above lowest discharge as surface runoff. The Local Minimum method uses values of the surrounding intervals to determine the lowest discharge, and then connects the adjacent lowest discharges to define base flow.

In 2005 The University of Purdue created a tool called WHAT (Web-based Hydrograph Analysis Tool) that also allows for the use of three hydrograph separation methods: the Local Minimum Method mentioned above, the BFLOW digital filter method, and the Eckhardt digital filter method. The WHAT tool facilitates a quick and efficient way to perform hydrograph separation analyses blending flow data generated by the U.S. Geological Survey and data collected from local efforts like those from this project. Evaluation of the Local Minimum method indicates a tendency to overestimate base flow, but the BFLOW and Eckhardt methods provide an increased accuracy when estimating hydrograph separation in contrast to the methods offered by the earlier HYSEP program. A comparison of differences in determining hydrograph separation is demonstrated in Figure 16 through Figure 18 from the SE 312th Street level logger data using WHAT output from three methods previously described.

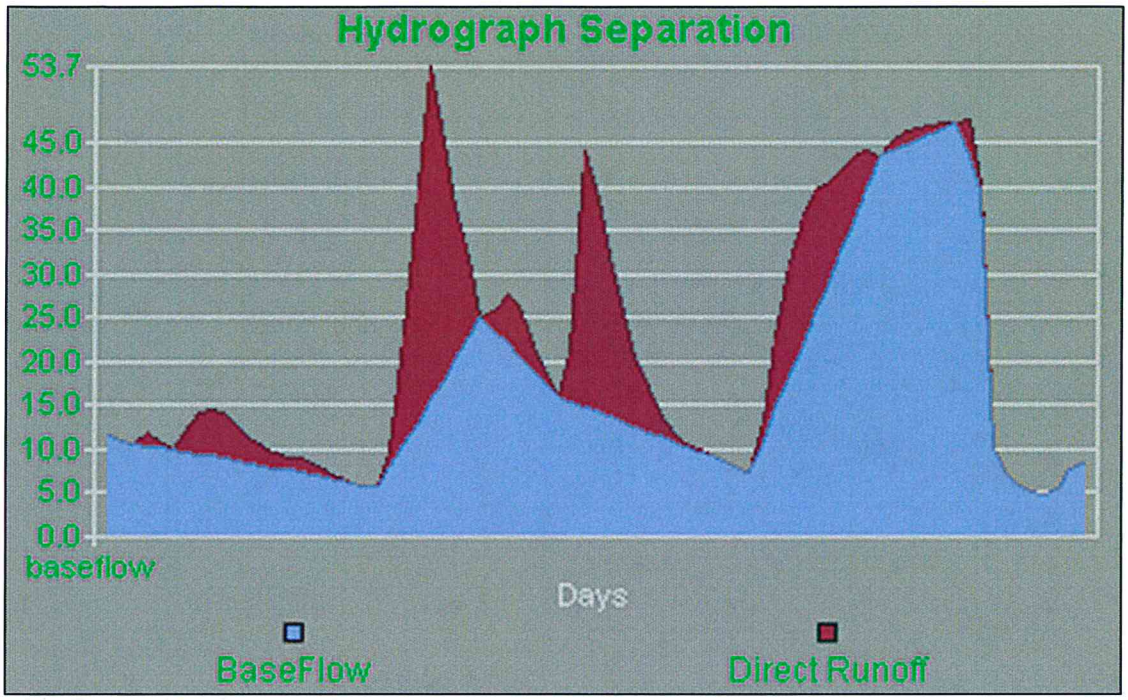

Figure 16. WHAT output using the Local Minimum method for hydrograph separation for a portion of the results collected from SE 312th Street Rock Creek location.

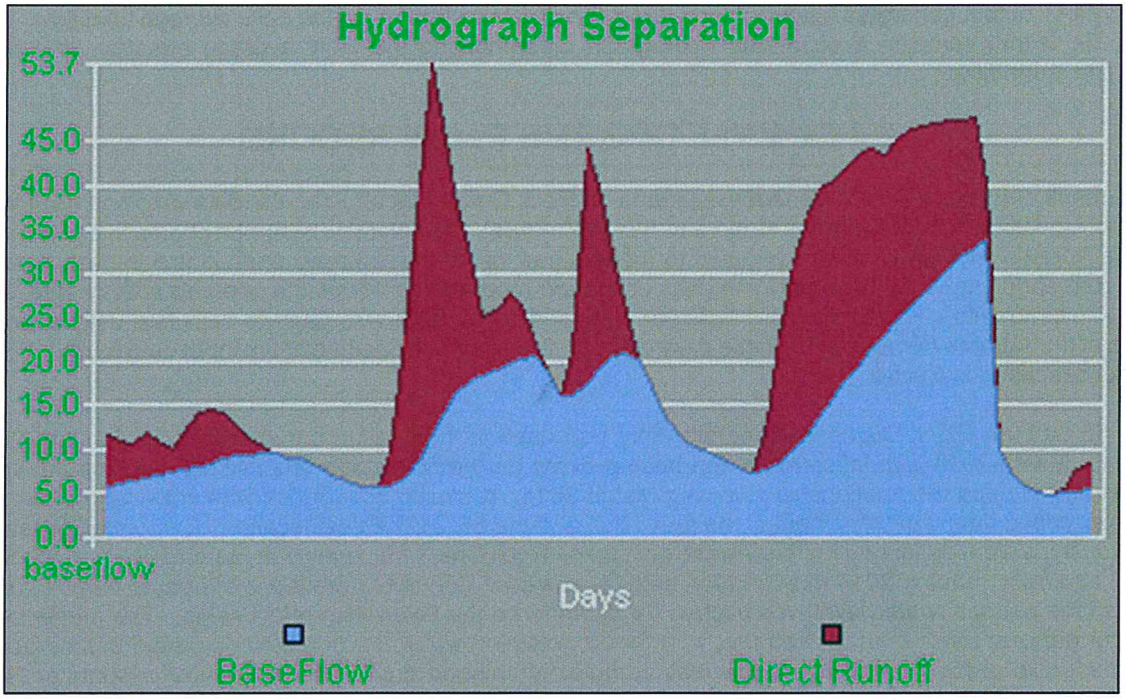

Figure 17. WHAT output using the BFLOW method for hydrograph separation for a portion of the results collected from the SE 312th Street Rock Creek location.

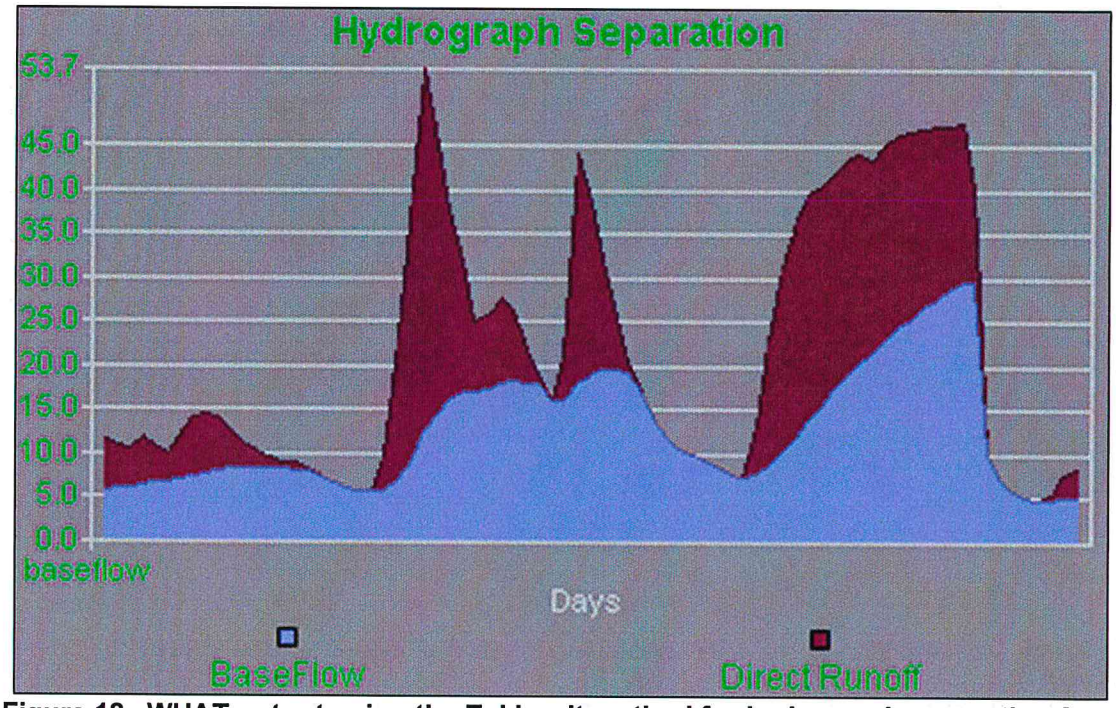

Figure 18. WHAT output using the Eckhardt method for hydrograph separation for a portion of the results collected from the SE 312th Street Rock Creek location.

The WHAT output generates base flow and direct runoff (storm flow) from the daily average total flow. The data file output contains a separated hydrograph differentiating the daily average baseflow and daily average storm flow.

2.3 COMPLETING THE FLOW RECORD

As a result of beaver (*Castor Canadensis*) dams on Rock Creek that affected the data obtained from level loggers at Auburn Black Diamond Road and SE 312th Street, the complete stage level data set generated at the Abrams Avenue location was used to make a flow rating curve based on field flow measurements and corresponding water level data that was continued recorded on 15 minute intervals with on-site level logger instruments. The relationship between flow and water level was used to calculate daily average flows at the Abrams Avenue site. These daily average flows were the source of the input data for the WHAT model described in Section 2.4.

The SE Auburn Black Diamond Road site only had useable flow rating curve data from January 2014 through March 2014 with influence of the beaver dams on the flow-stage relationship, backing up water levels and altering the relationship following March 2014. A similar occurrence with flow-stage alteration was described during development of the rating curve at the SE 312th Street location. Complete flow-stage relationships were described for this lowest location on Rock Creek from between March 2013 through May 2013 and from January 2014 through March 2014; however, due to the presence of beaver dams outside these time periods, water level was backed up and altered the flow-rating relationship. The presence of beaver dams at these sites slowed flow to a trickle, retaining water for an extended period of time acting like hydraulic control structures. Flow was completely stopped during the dry period in summer 2013 through the culvert at SE 312th Street and into Lake Sawyer with the presence of a beaver dam inside the culvert.

Altered flow records from presence of beaver dams occurred at two locations on Rock Creek and were corrected by determining a relationship for both the SE Auburn Black Diamond Road (ABDR) site and the SE 312th Street site with flow records from the same time period as from the Abrams Avenue site. Abrams Avenue is the most upstream site and the majority of the flow passing through this site would also pass

through SE Auburn Black Diamond Road and SE 312th Street sites. In an attempt to account for the inflows to Rock Creek that are downstream of the Abrams Avenue site but upstream of either the Auburn Black Diamond Road and/or the SE 312th St, a comparison was made between the flows at the Abrams Avenue site and flows during time periods at those sites where there was no beaver dam influence. This comparison was used to develop a correlative relationship between average daily flows from Abrams Avenue. The missing flow records from ABDR and the SE 312th Street were reconstructed using the correlative relationships in order to develop complete annual records for each site. It is important to note that these calculations are based on the absence of beaver dams and the intensity of flow at Abrams Avenue on any given day.

2.4 CALCULATING PHOSPHORUS LOADING FOR BASEFLOW AND STORMFLOW

Total phosphorus concentrations from all relevant 2013-2014 grab samples that were collected during periods when beaver dams did not influence flow and TP concentrations were used to develop a regression model between TP and flow at Rock Creek sites. Figure 19 describes the relationship between TP concentrations and flow from all sites on Rock Creek. The regression model developed from this relationship is used to predict concentrations based on average daily flows over the calendar year at each of the Rock Creek sites.

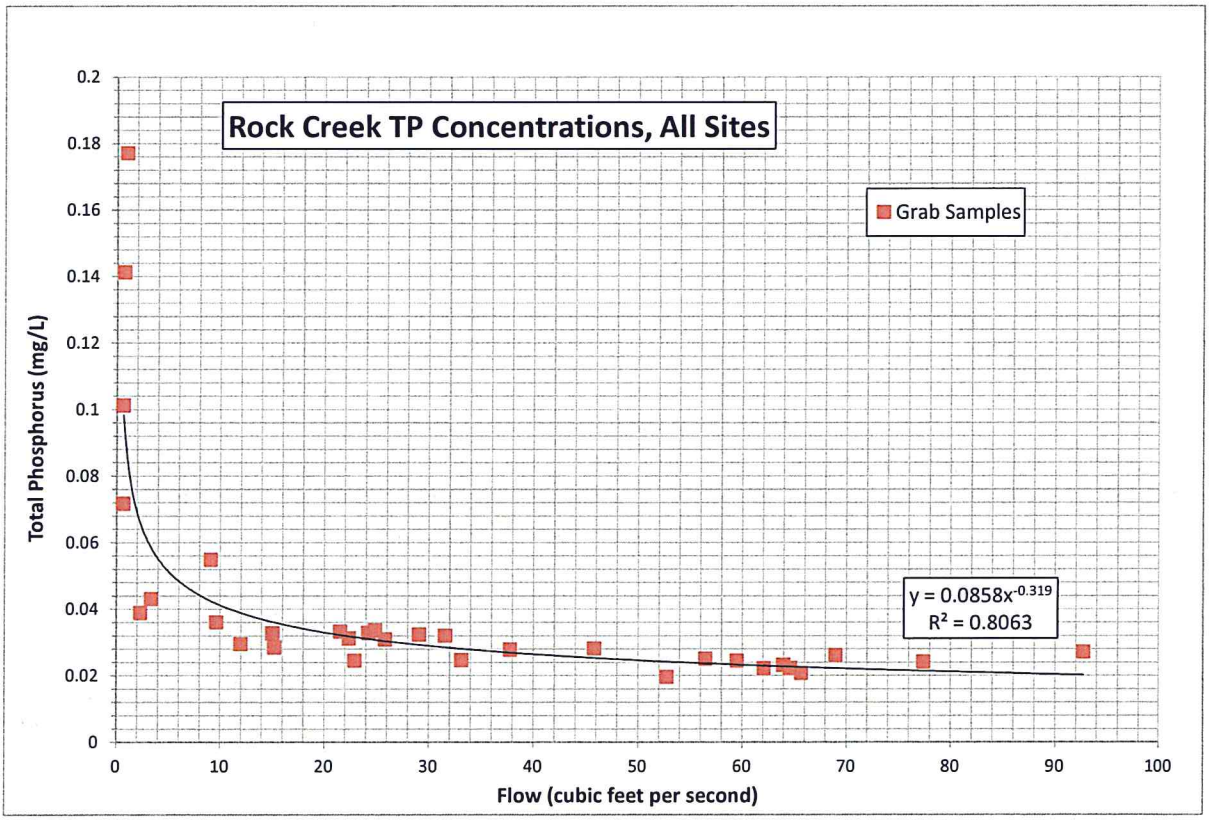

Figure 19. Total Phosphorus as a function of flow based on 34 different grab samples from 2013-2014.

The regression model for the exponential trend line shown in Figure 20 was used to predict TP concentrations based on daily average flows. Validation of the model used to predict TP from flow observations was completed by comparing against a site that was not affected by beaver dam construction at any time during the calendar year. TP loads were calculated using the regression model from the Abrams Avenue data set (validation data set) and compared against the TP Loads calculated by using data from all three Rock Creek sites. Use of data from the combination of all three Rock Creek sites was restricted to

those time periods unaffected by beaver dam construction. Validity of the regression model using data from all three Rock Creek sites was determined by plotting TP loads from the combined sites against TP loads from upstream Abrams Avenue site. A relationship of 1:1 between the two sets of data, or very nearly so, is shown in Figure 20. This means that TP loads calculated by the combined Rock Creek data (all three sites) generates the same result for predicted TP from flow data and that the same regression model can be used for predicting TP concentration from flow at any of the Rock Creek sites.

Using total daily phosphorus and the separation between storm and baseflows from the WHAT model output, annual loads of TP for each site were calculated for both storm and baseflows at the Abrams Avenue, Auburn Black Diamond Road, and SE 312th Street sites.

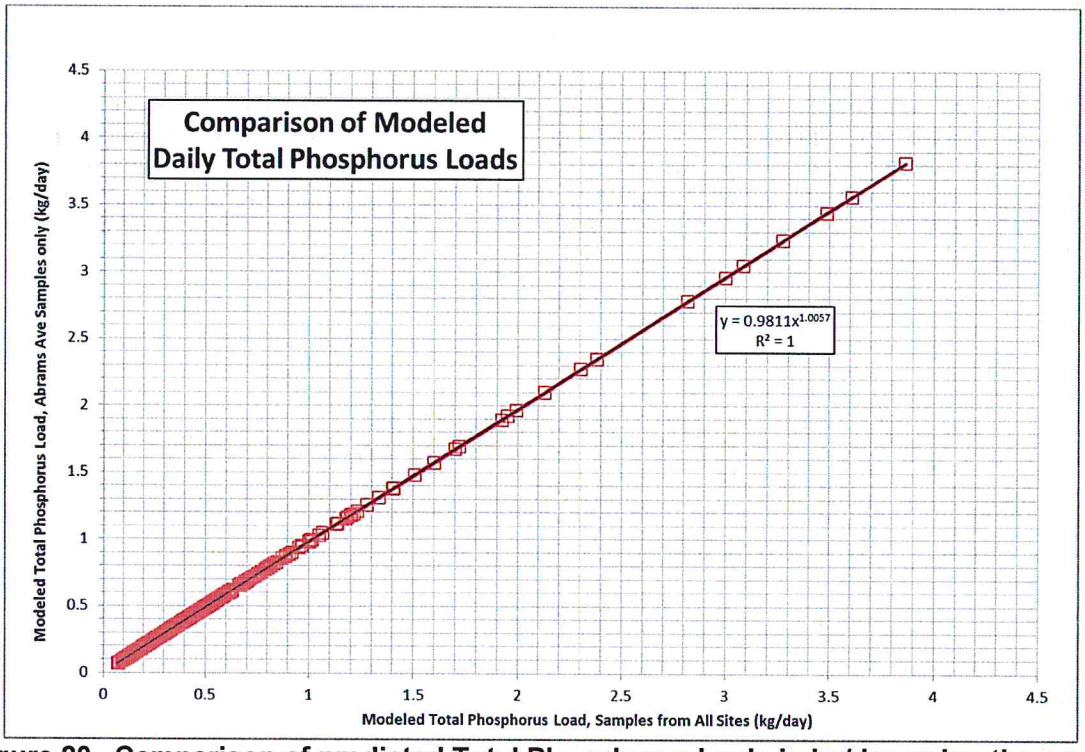

Figure 20. Comparison of predicted Total Phosphorus loads in kg/day using the same input flow value in two regression models (Abrams Avenue model versus the combined data set from all three Rock Creek sites).

2.5 IDENTIFYING ADDITIONAL SAMPLING NEEDS

At the current time, there are no additional sampling needs that would be used to satisfy product development as part of the objectives for this project. Additional water quality monitoring needs are discussed further in Section 3.5 of this report.

3.0 RESULTS

3.1 WATER QUALITY SAMPLING AND FLOW

3.1.1 Surface Water Sampling

Surface water samples and flow measurements were collected during storm events and as base flow monitoring during three separate water years (2011-2012, 2012-2013, and 2013-2014). Data were used to develop flow rating curves, relationship between flow and TP concentrations, and TP annual loading at three Rock Creek sites. Data serving as the basis for development of products in this report are found in the following Technical Memorandums:

- The Villages and Lawson Hills Master Planned Developments: Pre-Construction Stormwater Monitoring in Rock Creek and the Establishment of an Interim Baseline Phosphorus Load. Technical Memorandum. Black Diamond, WA. July 23, 2012. Prepared for Yarrow Bay. Tetra Tech, Inc., Seattle, WA. 16p.
- The Villages and Lawson Hills MPDs: 2012-2013 Pre-Construction Stormwater Monitoring in Rock Creek to Establish the Baseline Phosphorus Load. Technical Memorandum. Black Diamond, WA. November 2013. Prepared for Yarrow Bay. Tetra Tech, Inc., Seattle, WA. 50p. + Appendixes.
- The Villages and Lawson Hills MPDs: 2013-2014 Pre-Construction Stormwater and Groundwater Monitoring in Rock Creek to Establish the Baseline Phosphorus Load. Technical Memorandum. Black Diamond, WA. November 2014. Prepared for Yarrow Bay. Tetra Tech, Inc., Seattle, WA. 34p. + Appendixes.

3.1.2 Groundwater Sampling

The purpose of groundwater well monitoring was to establish a baseline groundwater condition prior to construction activities for comparison with later monitoring efforts. Groundwater well sampling results were included in The Villages and Lawson Hills MPDs Tech Memo dated November, 2014. Since groundwater well sampling sites were located in a dense forest environment with heavy canopy cover, precipitation did not appear to have significant impacts on nutrient concentrations in groundwater with respect to fluctuating quantities of precipitation. Any influence groundwater quality has on surface water at downgradient locations could not be established, but the baseline of information will be useful for comparison against future monitoring data collected from the same locations following construction and development.

3.2 HYDROGRAPH SEPARATION

A diagram displaying annual output of flow (base flow versus storm flow) from the WHAT model is displayed for each of the three Rock Creek sites (Figure 21 through Figure 23). The WHAT model output used daily average flows for both direct runoff (storm flow) and baseflow conditions defined by using data from March 2013 through 2014. The WHAT data output for each site was used to determine total annual phosphorus (TP) loads for each of the three Rock Creek sites. The daily average flows are used in conjunction with predicted TP concentrations from daily average flows to calculate loads on a daily basis.

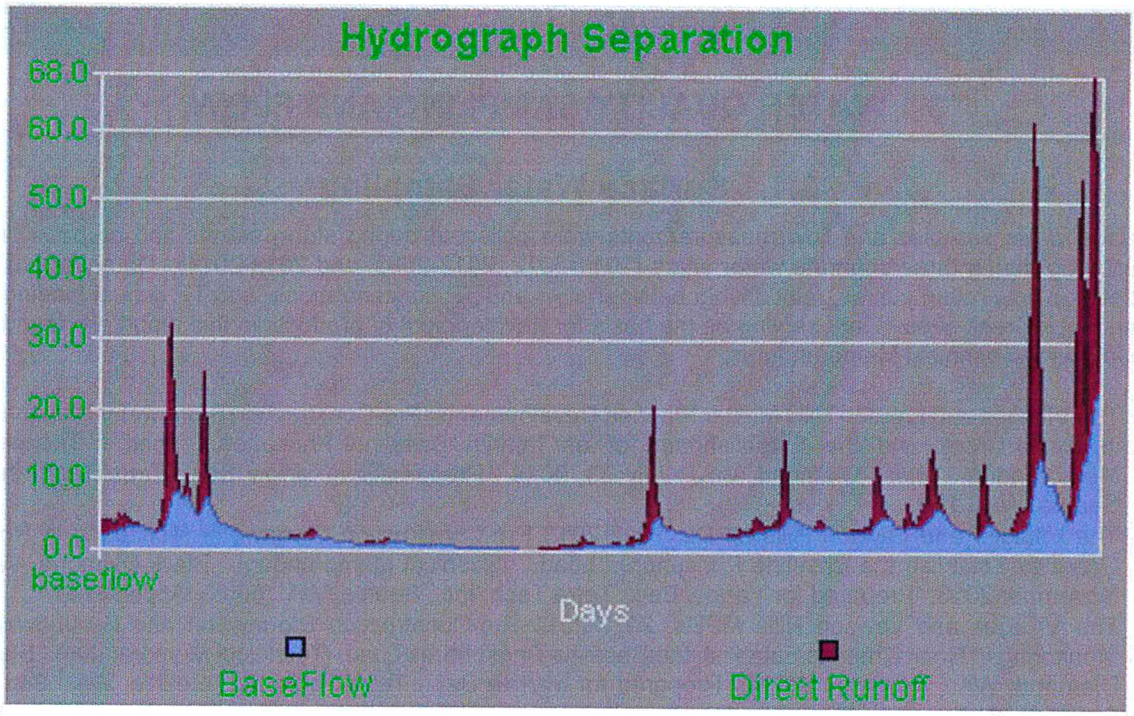

Figure 21. WHAT output of Eckhardt method for hydrograph separation of Rock Creek flows at Abrams Avenue (March 13, 2014 – March 12, 2014).

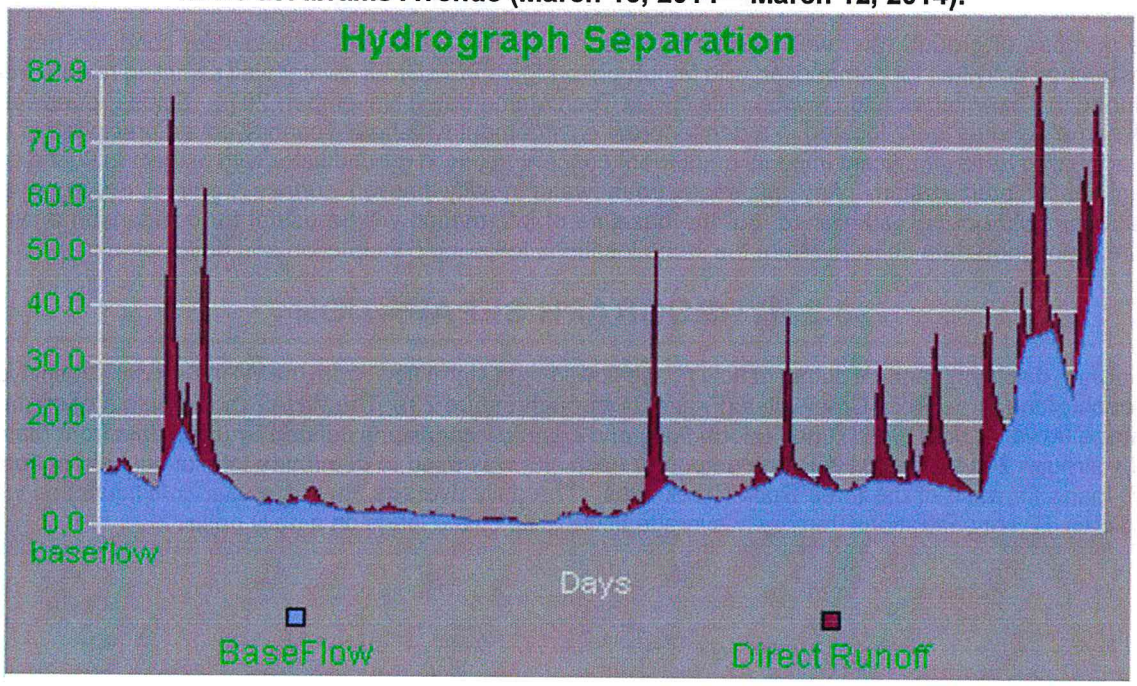

Figure 22. WHAT output of Eckhardt method for hydrograph separation of Rock Creek flows at SE Auburn-Black Diamond Road (ABDR) (March 13, 2014 – March 12, 2014).

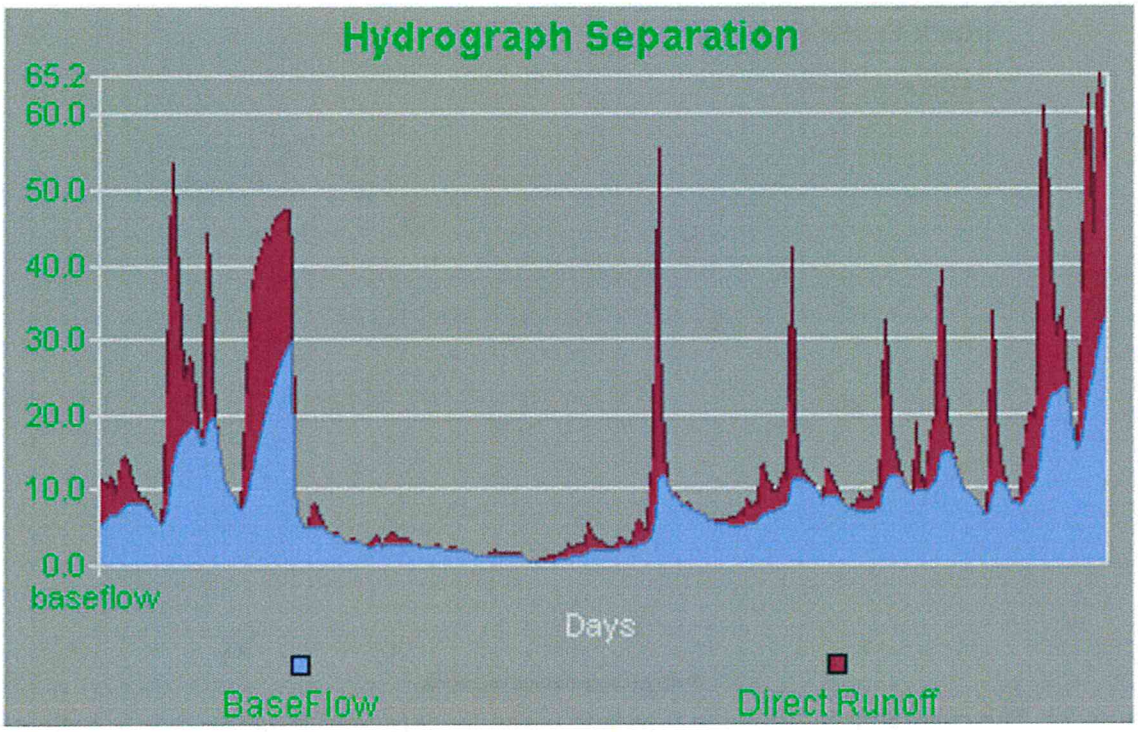

Figure 23. WHAT output of Eckhardt method for hydrograph separation of Rock Creek flows at SE 312th Street (March 13, 2014 – March 12, 2014).

3.3 FLOW AND STAGE RELATIONSHIPS

Figure 24 through Figure 26 describe relationships between flow and water level (or stage) measurements based on continuous data logging devices used to monitor conditions on 15-minute intervals. The relationships between these two variables were described by a regression model and then used to predict flow for each 15-minute interval recorded by the water level devices. The water level measurements collected by data loggers and the flow measurements collected in the field during sampling events from March 2013 through March 2014. Each of the regression models describing the relationship between water level (stage) and flow showed strong correlations (average $R^2 = 0.93$). These models were used to translate all recorded water level data into predicted flow results.

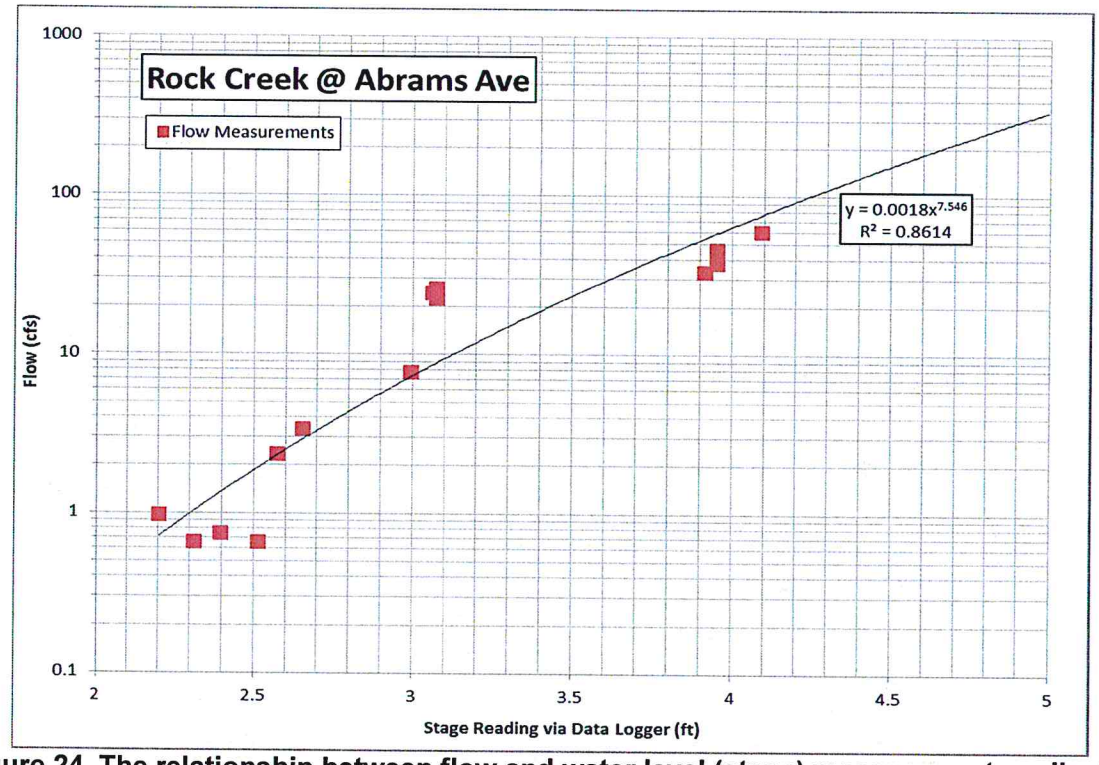

Figure 24. The relationship between flow and water level (stage) measurements collected at Abrams Avenue site on Rock Creek.

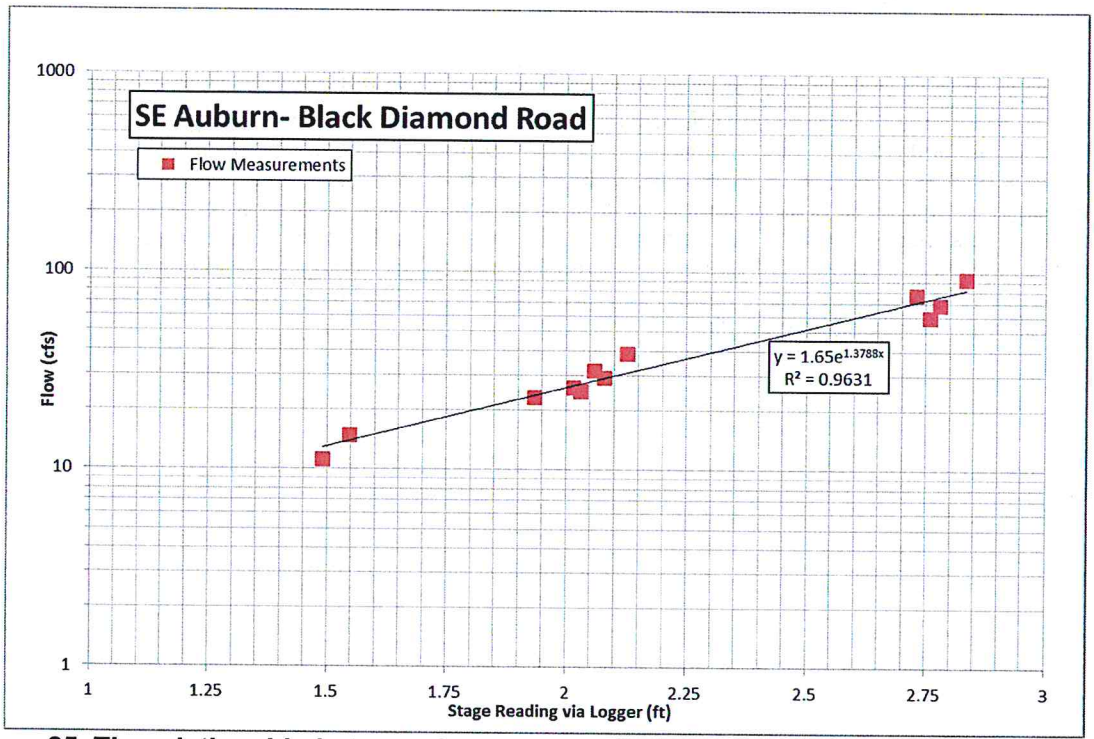

Figure 25. The relationship between flow and water level (stage) measurements collected at SE Auburn Black Diamond Road (ABDR) site on Rock Creek.

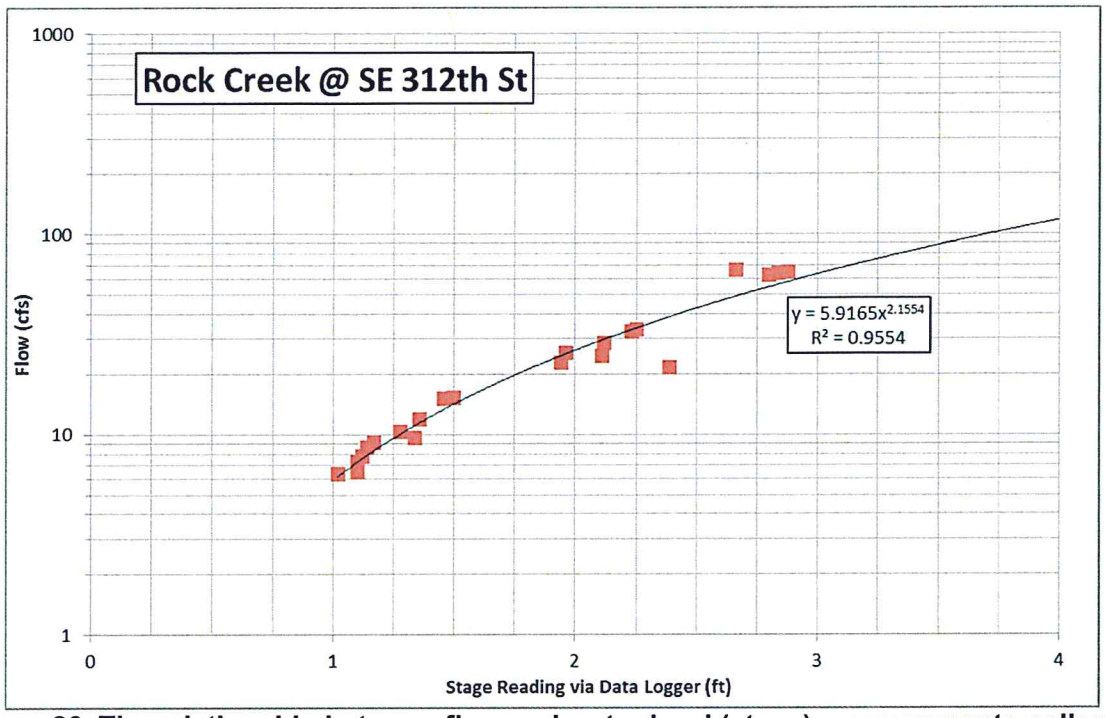

Figure 26. The relationship between flow and water level (stage) measurements collected at the SE 312th Street site on Rock Creek.

3.4 PHOSPHORUS LOADING FOR BASEFLOW AND STORMFLOW

A relationship between TP and flow is described by Figure 27. Strength of the correlation for this model for prediction of TP concentration using flow was R=0.81. This regression model was used to predict TP concentrations using daily average flows and then to calculate total annual TP load at a site by summing the daily average TP load ("average daily flow" x "predicted TP concentration") for all calendar days of the year.

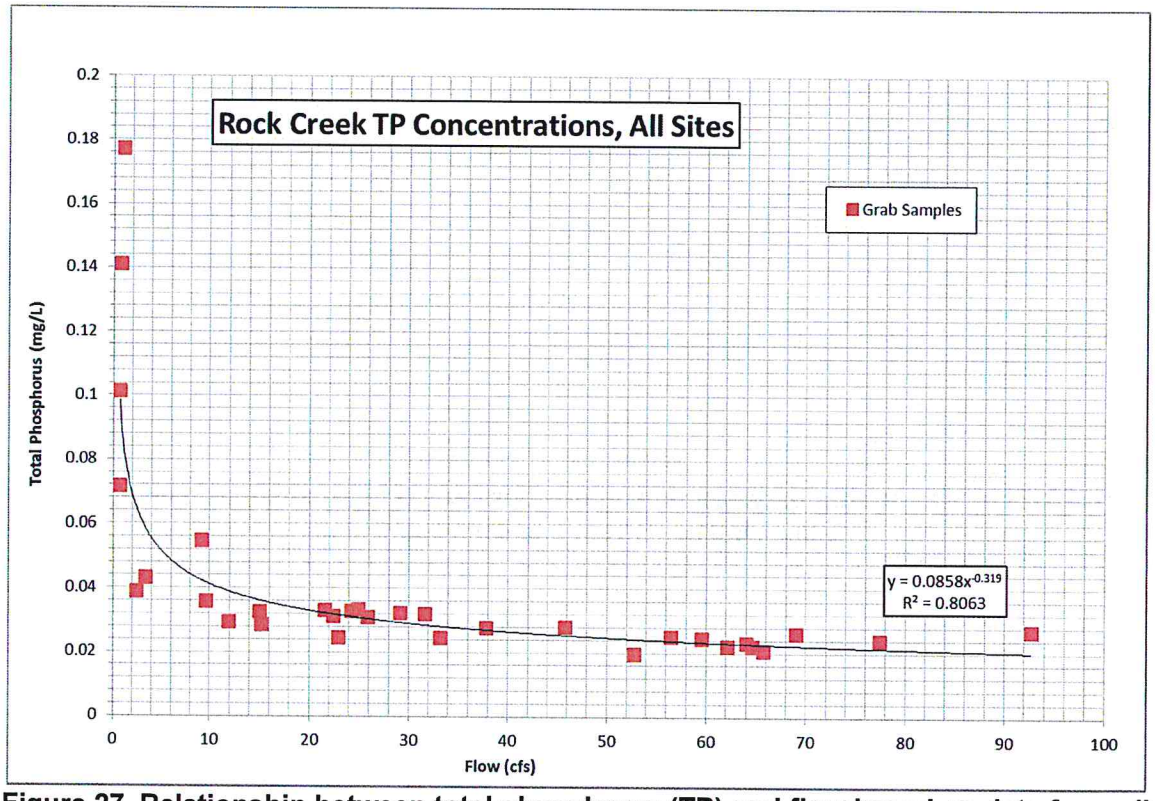

Figure 27. Relationship between total phosphorus (TP) and flow based on data from all Rock Creek sites.

The separation of TP load for baseflow and storm flow was calculated by determining percentage of total annual flow contributed by base flow and by storm flow as generated by the WHAT model. Table 3 shows total annual loads calculated for each Rock Creek site. Annual TP load at the SE 312th Street site (lower-most site before Lake Sawyer) was about 407 kg/yr with the majority of the TP load contributed by baseflow conditions.

Table 3. TP loading estimates at each Rock Creek site

Site	Total TP Load (kg/yr)	Base Flow Load (kg/yr)	Storm Flow Load (kg/yr)
Rock Creek at Abrams Ave	201.69	136.99	64.70
Rock Creek at Auburn-Black Diamond Rd (ABDR)	376.88	263.39	113.49
Rock Creek at SE 312th Street	406.76	272.80	133.96

4.0 DISCUSSION

Several steps for quantifying physical traits like flow and relationship to chemical traits like TP (total phosphorus) were necessary in order to address each of the objectives listed in Section 1.1. Unexpected conditions like the presence of beaver dams impounding Rock Creek at two of the three monitoring locations combined with presence of impounded water behind each of the Rock Creek monitoring sites presented significant challenges to developing tools like flow-rating curves that represent free-flowing stream conditions. Changes in hydrology at the monitoring sites affected by beaver dams also influenced dynamics of nutrients like TP above each of the monitoring sites. Portions of the monitoring record were identified and conditions re-described using predicted values for flow when a Rock Creek site effected by beaver dams no longer represented a free-flowing stream like other portions of the year. The presence of beaver dams were unpredictable between years as was noted by visits to the same sites in previous monitoring years (2011-2012 and 2012-2013), so a conservative approach was used to estimate annual TP load by assuming the potential for free-flowing water throughout the calendar year and without the presence of beaver dams.

Regression model development predicting TP concentrations from flow restricted use of data to those collected during free-flowing conditions and then used to estimate total annual TP load at each of the Rock Creek sites. The unaffected Abrams Avenue level logger data was used to fill in flow gaps during portions of the year when obstructions (beaver dams) occurred at the two lowermost Rock Creek sites (i.e., Auburn Black Diamond Road and SE 312th Street). These gaps were re-described using a relationship between the Abrams Avenue flow pattern and the lower Rock Creek drainage sites.

Despite the influence of the beaver dams, the addition of level loggers to the Abrams Avenue and SE 312th Street sites in March 2013 provided a critical dataset in determining a current estimate of total annual TP load entering Lake Sawyer from Rock Creek at SE 312th Street and the quantity of TP contributed by portions of the drainage upstream of this site. The annual TP load pattern at each of the Rock Creek sites shows how assimilative capacity of upstream wetlands and lakes can differ and the role in nutrient retention. From the total annual TP loading estimates at each Rock Creek site, direct runoff flow (storm flow) contributes approximately one-third of the annual TP load and base flow contributes the remaining two-thirds of the annual TP load.

Taken as a whole, the data collected between November 2011 and March 2014 represents a great deal of new information about the Rock Creek drainage area that did not exist before. The entire system is characterized by relatively small inflows that empty into large wetlands that serve as individual settling basins, with road crossings and beaver dams acting as hydraulic controls that impound the flow at various locations. These factors make the collection of reliable data relative to flow a challenge, but the tools developed during this process will help in further study of the area. In particular, during free-flowing conditions the flow rating curve for the SE 312th St site (where Rock Creek enters Lake Sawyer) can now be used in combination with the staff gage located at the site to obtain a reasonable estimate of total flow at that point. This provides an excellent tool for further analysis of nutrient loading to Lake Sawyer into the future.

Total annual TP load estimates in this study reflect current background conditions at each of the three Rock Creek sites. Any differences from previous studies (Carroll and Pelletier 1991) describing background conditions reflect changes in the landscape and activities that influence the Rock Creek drainage area. TP loading increases from the uppermost Abrams Avenue site to the lowermost SE 312th Street site on Rock Creek as a function of inputs to each of the wetlands directly above the site and the assimilation capacity for nutrients by the wetlands. Jones Lake serves as a large nutrient sink for drainage areas above this location and is exemplified in the lower nutrient load passing by the Abrams Avenue site. Input of nutrient below this location increases as assimilation capacity, or capacity of retention, of nutrients is lower in the wetland above Auburn Black Diamond Road and SE 312th Street sites on Rock Creek.

Monitoring results generated from the 2013-2014 data set represented the most complete record including both flow and TP observations. Flow monitoring was initiated at the remaining two Rock Creek sites (i.e., SE 312th Street and Abrams Avenue) in March 2013 and recorded continuous water level (stage) height

with storm event monitoring occurring during the same period. This monitoring year also had more intense rainfall events with higher 24-hour accumulations and hydrographs at each Rock Creek site that had higher discharges than in previous years. For these reasons, this year was selected as a calibration data set for the regression models. The regression models developed that represent flow-rating curves and TP predictive models using flow as input data showed strong relationships with the calibration data set so additional data would not necessarily improve the predictive capacity of the models. The earlier data collection effort served as an independent data set for validating regression models. The current flow-rating curves have greater utility for estimating flow from staff gage readings and TP concentrations from all Rock Creek sites using flow estimates as input data. Periodic calibration of the regression models should occur as flow patterns are permanently altered from natural or human-induced factors.

4.1 TOTAL PHOSPHORUS LOADING FROM THE VILLAGES (PLAT 2C) AND LAWSON HILLS (PLAT 2B)

Pre-development condition, annual TP runoff volume, loads, and TP concentrations were calculated for The Villages (Plat 2C; V29) and Lawson Hills (Plat 2B; Hammerhead Ditch), as required by Exhibit "O" to The Villages and Lawson Hills DAs. See Paragraph 1 on Page 2 of 3 of No Net Phosphorus Implementation Plan. These TP runoff loads and concentrations will be used as a baseline in order to design the type and size of BMP(s) necessary following completion of construction so that annual loading to Rock Creek does not exceed the TP load reported in Table 4. These TP runoff estimates are compared with TP runoff rates from forested watersheds in the literature.

The Flow-Weighted TP upstream (Abrams Ave.) was slightly higher at 0.044 mg/L than at the two lower sites (Auburn-Black Diamond Rd and SE 312th St. (Table 4). The section of Rock Creek to which runoff from The Villages (Plat 2C) will enter is between Abrams Ave and Auburn-Black Diamond Rd. The Villages MPD (Plat 2C) is till forest land, which is known to yield low rates of TP in runoff as compared with other types of land cover (e.g., residential or urban). TP runoff rates from forest have been reported by several authors (Reckhow and Chapra 1983). Based on export rates reported by these authors, TP in runoff would be expected to be about 0.030 mg/L or higher in forested land cover. The relatively low TP concentrations measured in the 2012 to 2014 stormwater monitoring program in Rock Creek is consistent with the low impervious surface (3%) and high fraction of the watershed that was forested in the mid-1990s (80%) (May and Horner 2000; May et al. 1997).

The annual flow-weighted average was calculated for each of the Rock Creek sites in order to determine annual TP load (Table 4). The annual TP load calculated for the Auburn-Black Diamond Rd site (from stormwater monitoring results from Rock Creek, 2012-2014) represents the location where surface water runoff from The Villages MPD (Plat 2C) enters Rock Creek. The annual TP flow-weighted average concentration is assumed to be influenced by runoff from existing conditions and was used to calculate annual TP load from The Villages MPD (Plat 2C).

Table 4. Annual Flow-weighted TP estimates at each Rock Creek site

Rock Creek Site Names	Total Annual TP Load (kg/yr)	Base Flow Load (kg/yr)	Storm Flow Load (kg/yr)	Total Annual Flow (L)	Total FW Concentration (mg/L)
Abrams Ave	201.69	136.99	64.70	4,538,108,082.36	0.044
Auburn-Black Diamond Rd	376.88	263.39	113.49	10,972,111,680.40	0.034
SE 312th St	406.76	272.80	133.96	11,987,129,048.84	0.034

The total annual runoff from The Villages (Plat 2C) as a fraction of the total annual flow from Auburn-Black Diamond Rd is 0.05% and the annual TP load is assumed to contribute the same fraction of the TP load at this location (Table 5).

Table 5. Annual Flow-weighted TP loading estimates at the Rock Creek site below Plat 2C

TP Annual Load Comparison	Total Annual Flow/Runoff (Acre-Feet)	Total Annual Flow/Runoff (Liters)	Annual Flow-Weighted Concentration (mg/L)	Total Annual TP Load (kg)
Auburn-Black Diamond Rd	8 895.2357	10,972,111,680.40	0.034	376.88
The Villages (Plat 2C)	43.9	54,149,852.70	0.034	1.86

In order to determine the annual TP runoff load, an annual total phosphorus concentration of 0.034 mg/L was used to represent The Villages (Plat 2C) land use characteristics and runoff concentration. This total phosphorus concentration reflects runoff from till forest under existing conditions. Annual water runoff volume from The Villages (Plat 2C) was estimated at 43.90 acre-feet (Triad Associates, 2015). Little to no groundwater contribution from The Villages (Plat 2C) is expected to reach Rock Creek at this location as recharge has been reported to flow toward Crisp Creek and the Green River drainage (AES 2008). The annual TP load was calculated by multiplying annual total phosphorus concentration by the annual water runoff volume from The Villages (Plat 2C). The Villages (Plat 2C) contributes 1.86 kg/year of total phosphorus as runoff toward the Rock Creek drainage. The annual TP load from runoff is reported in Table 5 and Table 6. Similarly, annual TP load is calculated for the Lawson Hills (Plat 2B) site (represented by the Hammerhead Ditch monitoring results). Results from monitoring effort showed much higher concentrations than was the case for The Villages (Plat 2C). Since flow records were not generated from this site as water presence was intermittent and did not flow in quantities that could be reliably measured, the concentration used to calculate total annual phosphorus load makes several assumptions. The geometric mean was used to calculate the annual phosphorus concentration in order to best represent a limited data set that benefits by using a normalized concentration value.

Table 6. Estimates annual total phosphorus runoff from each development area

MPD Area	Annual Phosphorus Concentration (mg/L)	Annual Runoff (ac-ft)	Estimated Total Annual Phosphorus Runoff (kg)
Basin 5 (The Villages)	0.034[1]	43.90	1.86
Hammerhead Ditch (Lawson Hills)	0.073[2]	23.52	2.12

Note: [1] indicates a flow-weighted concentration.
[2] indicates a geometric mean concentration.

Flowing water was not present at the Hammerhead Ditch site during each visit and when flowing was during extreme high precipitation events. Since surface water was not continuously flowing, but concentrations for TP were occasionally high, an annualized expression using the geometric mean was selected for estimating annual TP runoff load. The normalized annual total phosphorus concentration of 0.073 mg/L was used to estimate load from Plat 2B as land use in this area was represented by predominantly till forest (13.17 acres), some till grass (1.5 acres), and a small impervious surface area (0.25 acres). The annual water runoff volume from Lawson Hills MPD (Plat 2B) was calculated as 23.52 acre-feet (Triad Associates, 2015) and used to determine the TP load. The annual TP load was calculated by multiplying the normalized annual total phosphorus concentration by the annual water runoff volume from Lawson Hills MPD (Plat 2B). Lawson Hills MPD (Plat 2B) contributes 2.12 kg/year of phosphorus as runoff to the Rock Creek drainage. The annual TP load from Lawson Hills MPD (Plat 2B) runoff is reported in Table 6 above.

5.0 REFERENCES

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6.0 APPENDIX

Table A6.1 Rock Creek at Abrams Avenue flow and logger water level data

Tab Name	Date	Logger Depth	Discharge
4.23.13	*4/23/13*	*2.99*	*7.71*
5.29.13	*5/29/13*	*2.65*	*3.36*
6.10.13	*6/10/13*	*2.40*	*0.75*
7.10.13	*7/10/13*	*2.31*	*0.65*
8.6.13	*8/6/13*	*2.20*	*0.96*
9.23.13	*9/23/13*	*2.52*	*0.66*
10.21.13	*10/21/13*	*2.57*	*2.33*
1.29.14 1H	*1/29/14 1H*	*3.07*	*22.37*
1.29.14 2H	*1/29/14 2H*	*3.06*	*24.23*
1.29.14 3H	*1/29/14 3H*	*3.07*	*25.82*
2.17.14 1H	*2/17/14 1H*	*4.09*	*59.76*
3.5.14 1H	*3/5/14 1H*	*3.95*	*45.80*
3.5.14 2H	*3/5/14 2H*	*3.95*	*37.76*
3.5.14 3H	*3/5/14 3H*	*3.91*	*33.12*

Table A6.2 Rock Creek at SE Auburn-Black Diamond Road (ABDR) flow and logger water level data

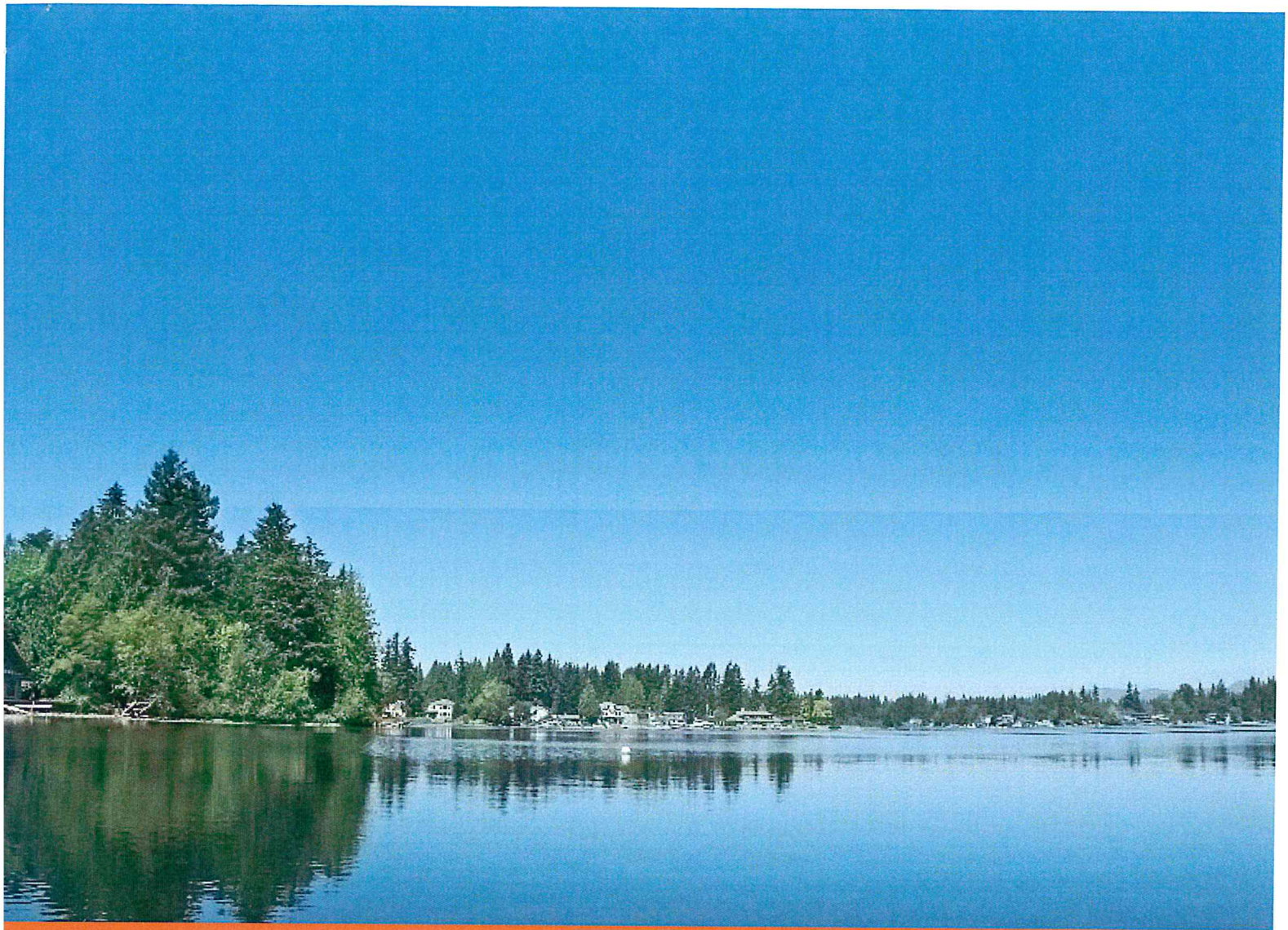
Tab Name	Date	Logger Depth	Discharge
12.28.11	*12/28/2011*	*1.93*	*23.08*
1.11.12	*1/11/2012*	*1.49*	*11.12*
1.24.12	*1/24/2012*	*2.02*	*26.08*
2.8.12	*2/8/2012*	*1.55*	*14.81*
2.21.12	*2/21/2012*	*2.13*	*38.80*
1.29.14 1H	*1/29/14 1H*	*2.03*	*24.87*
1.29.14 2H	*1/29/14 2H*	*2.08*	*29.07*
1.29.14 3H	*1/29/14 3H*	*2.06*	*31.56*
2.17.14 1H	*2/17/14 1H*	*2.834*	*92.69*
3.5.14 1H	*3/5/14 1H*	*2.76*	*59.51*
3.5.14 2H	*3/5/14 2H*	*2.78*	*69.02*
3.5.14 3H	*3/5/14 3H*	*2.73*	*77.40*

Note:
1H = 1st round of samples collected during a storm event.
2H = 2nd round of samples collected during a storm event.
3H = 3rd round of samples collected during a storm event.

Table A6.3 SE 312th Street Rock Creek flow and logger water level data

Tab Name	Date	Logger Depth	Discharge
3.14.13	*3/14/13*	*1.34*	*9.63*
4.10.13	*4/10/13*	*2.39*	*21.52*
4.23.13	*4/23/13*	*1.94*	*22.91*
5.29.13	*5/29/13*	*1.17*	*9.12*
1.29.14 1H	*1/29/14 1H*	*1.36*	*11.95*
1.29.14 2H	*1/29/14 2H*	*1.46*	*15.03*
1.29.14 3H	*1/29/14 3H*	*1.50*	*15.19*
2.17.14 1H	*2/17/14 1H*	*2.66*	*65.70*
3.5.14 1H	*3/5/14 1H*	*2.80*	*62.10*
3.5.14 2H	*3/5/14 2H*	*2.84*	*63.99*
3.5.14 3H	*3/5/14 3H*	*2.88*	*64.62*

Note:
1H = 1st round of samples collected during a storm event.
2H = 2nd round of samples collected during a storm event.
3H = 3rd round of samples collected during a storm event.



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