DEPARTMENT OF TRANSPORTATION

Characterization of Runoff Quality from Paved Low-Volume Roads and Optimization of Treatment Methods

John Gulliver, Principal Investigator
St. Anthony Falls Laboratory
Department of Civil, Environmental and Geo- Engineering
University of Minnesota

SEPTEMBER 2020

Research Project
Final Report 2020-27

LRRB
LOCAL
ROAD RESEARCH
BOARD

To request this document in an alternative format, such as braille or large print, call 651-366-4718 or 1-800-657-3774 (Greater Minnesota) or email your request to ADArequest.dot@state.mn.us. Please request at least one week in advance.

Technical Report Documentation Page

1. Report No. MN 2020-27	2.	3. Recipients Accession No.
4. Title and Subtitle Characterization of Runoff Quality from Paved Low-Volume Roads and Optimization of Treatment Methods		5. Report Date September 2020
		6.
7. Author(s) Poornima Natarajan, Peter T. Weiss, John S. Gulliver		8. Performing Organization Report No.
9. Performing Organization Name and Address St. Anthony Falls Laboratory and Department of Civil, Environmental and Geo- Engineering University of Minnesota 2 Third Ave SE, Minneapolis, Minnesota 55455		10. Project/Task/Work Unit No. CTS#201812
		11. Contract (C) or Grant (G) No. (c) 1003325 (wo) 23
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Office of Research & Innovation 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155-1899		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes http://mndot.gov/research/reports/2020/202027.pdf		

16. Abstract (Limit: 250 words)

Vehicular traffic contributes a large fraction of the pollutant load in stormwater runoff from roadways. While runoff concentrations have historically been characterized for urban roads with high average daily traffic (ADT), the runoff quality from paved rural roads that have relatively low ADT is largely unknown. In this study, runoff from low-volume roads (ADT < 1500) in Minnesota was monitored at 10 locations during 174 rainfall events in 2018 and 2019. The initial concentrations of total suspended solids (TSS), total phosphorus (TP), nitrate+nitrite, and heavy metals in the runoff, and the relationship between measured concentrations and site-specific conditions were analyzed. Concentrations were strongly influenced by the surrounding land use and soil type. Sites with agricultural lands had higher mean TSS, TP, and zinc concentrations, and lower nitrite+nitrate concentrations than wooded sites, which can be related to the type of soil that would get transported onto the roadways. When compared to existing urban runoff quality data, the estimated event mean concentrations (EMCs) in rural road runoff were substantially lower for copper and zinc and marginally lower for TSS, TP and nitrate+nitrite. Based on detailed cost-benefit analysis of various roadside treatment options, roadside drainage ditches/swales are recommended for cost-effective treatment of runoff from low-volume roads over ponds, sand filters and infiltration basins. Example road widening projects were also modeled to determine how stormwater management requirements can be achieved using drainage ditches/swales.

17. Document Analysis/Descriptors low volume roads, runoff, swales, metals, drainage, water quality management		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 263	22. Price

CHARACTERIZATION OF RUNOFF QUALITY FROM PAVED LOW-VOLUME ROADS AND OPTIMIZATION OF TREATMENT METHODS

FINAL REPORT

Prepared by:

Poornima Natarajan
John S. Gulliver
St. Anthony Falls Laboratory, and
Department of Civil, Environmental, and Geo- Engineering
University of Minnesota, Minneapolis, MN 55455

Peter T. Weiss
Department of Civil and Environmental Engineering
Valparaiso University, Valparaiso, IN 46383

SEPTEMBER 2020

Published by:

Minnesota Department of Transportation
Office of Research & Innovation
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

ACKNOWLEDGMENTS

This research project was funded by the Local Road Research Board (LRRB), with John Welle (Aitkin County Highway Department) serving as the technical liaison and David Glyer (MnDOT Office of Research and Innovation) as the project coordinator. The support and assistance from John and David throughout this project was greatly appreciated. Participation by volunteer industry professionals in the Technical Advisory Panel was also appreciated. The assistance from the project team members in Aitkin County (John Welle), Cass County (Darrick Anderson, Kris Lyytinen, Tom Boege, Joshua Howe, and Jay Kennedy), Clearwater County (Dan Sauve), Fairbault County (Mark Daly, William Goo, Bryan Schaper, and John Oswald), Polk County (Rich Sanders), St. Louis County (Carol Andrews and Sam Cook) was also greatly appreciated. Joe Triplett (Chisago County Public Works) helped with the site selection in Chisago County. The St. Anthony Falls Laboratory (SAFL) staff and students including Peter Corkery, Peter Olson, Sam Wang, Aaron Ketchmark, and Matt Hernick assisted with field sampling at the Chisago County sites.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ADT = average daily traffic

AADT = annual average daily traffic

ADP = antecedent dry period

Cd = cadmium

Cr = chromium

CSAH = County State Aid Highway

Cu = copper

EMC = event mean concentration

MIDS = Minimum Impact Design Standard

mg/L = milligram/liter

MN = Minnesota

MPCA = Minnesota Pollution Control Agency

Ni = nickel

NO_2+NO_3 = nitrite+nitrate

Pb = lead

RL = reporting limit

RSC = Roadside Swale Calculator

SAFL = St. Anthony Falls Laboratory

TSS = total suspended solids

TP = total phosphorus

µg/L = microgram/liter

UMN = University of Minnesota

Zn = zinc

EXECUTIVE SUMMARY

Stormwater runoff from roads carries with it solids, nutrients (phosphorus and nitrogen species), and metals that have accumulated on the road surface and are washed off with the runoff during rainfall events. In urban settings, a large fraction of the runoff constituent load originates from vehicular traffic on the road. Studies have characterized stormwater runoff from paved urban roads with high volumes of average daily traffic (ADT) (ADT in tens of thousands and greater) and have found that higher traffic volumes generally result in higher concentrations and loads of the runoff constituents. Other important variables found to influence runoff characteristics have been surrounding land use, atmospheric deposition, antecedent dry period, road surface texture, rainfall intensity, rainfall duration, and number of vehicles passing during the rainfall event (Kayhanian et al. 2007, Kayhanian et al. 2012, Wang et al. 2013, Huber et al. 2016).

Although runoff constituent concentrations are well reported for high ADT roads, little is known about runoff quality from paved rural roads that have relatively low ADT values (< 1500 vehicles/day). It can be hypothesized that with different ADTs and different surroundings and land uses, concentrations in runoff from urban and rural roads could be different.

The main goal of this study was to characterize stormwater runoff quality from paved, rural, low-volume roads with ADT of less than 1500. The objectives were to 1) characterize runoff constituent concentrations for low-volume roads and use this information to 2) identify and provide recommendations on stormwater treatment practices that are best suited to low-volume roads in rural settings.

Ten sampling sites along low-volume roads in six rural Minnesota counties were selected for this study. The sites had a variety of surrounding land use and soil type to investigate the influence of these variables on the runoff quality. Runoff samplers were installed at the edge of the pavement to collect the initial runoff (first 1 L) from rainfall events. Sample collection was performed by a team of personnel from each county and the samples were analyzed for various runoff constituents.

Initial runoff from 174 rainfall events was sampled during 2018 and 2019. The initial runoff constituent concentrations were variable at each monitoring site and across the ten sites over the sampled events. The TSS concentrations varied from 3.1 to 1900 mg/L (mean = 164 mg/L ± 234 SD), total phosphorus (TP) concentrations ranged from 0.01 to 2.5 mg/L (mean = 0.34 ± 0.37 mg/L) and nitrite + nitrate ranged from 0.015 to 2.7 mg/L (mean = 0.43 ± 0.41 mg/L). Zinc concentrations were between 10 and 1174 μg/L (mean = 168 ± 167 μg/L), and copper concentrations were between 2.5 and 92 μg/L (mean = 15 ± 14 μg/L). Other metals (cadmium, chromium, lead, and nickel) were below measurable levels in a majority of the samples collected from all sites. Samples collected from the Mississippi River headwaters showed that the low-volume road runoff concentrations of all analyzed constituents were higher and affected by the adjoining land.

Runoff from sites surrounded by agricultural land contained higher mean TP but significantly lower mean nitrite + nitrate concentrations than the sites with wooded land cover. The mean zinc level at the

agricultural sites was more than twice the mean concentration at the wooded sites. Farm soil, phosphorus attached to soil particles and galvanized farm equipment containing zinc were the likely reasons for the higher concentrations at the sites surrounded by farmlands. Furthermore, there were differences between sites with sandy loam and loam soil types. The overall mean TSS, TP and metal levels in the initial runoff were higher at sites with loam soil, possibly because finer soil particles can be easily transported by wind and vehicle tires and can stick to metals. It must be noted that most of the sites with agricultural land use also had loam soil and thus produced similar effects on the runoff quality at these sites. However, a clear linear correlation was not observed between the initial runoff constituent concentrations and ADT, antecedent dry period, and rainfall depth in this study.

The initial concentrations in the low-volume road runoff were converted to event mean concentrations (EMCs) using and the EMC:first flush concentration ratio reported in Stenstrom and Kayhanian (2005) so that comparison could be made with the existing high-volume road runoff concentrations. The estimated EMCs of TSS, TP, nitrate+nitrite, copper, and zinc in the runoff from the low-volume roads monitored in this study were lower than those in high-volume roads studied in the US that have ADT ranging from 200 to 328,000 vehicles/day (NURP 1983, FHWA 1990, Maestre and Pitt 2005, Kayhanian et al. 2007). Substantial differences were observed for nitrate+nitrite, copper, and zinc between the low- and high-volume roads, indicating the effects of surrounding land use and soil type on the runoff quality. These factors are likely to contribute solids (due to erosion or soil transport) and associated constituents (phosphorus and metals) to the low-volume road surface.

The runoff sampling results were also used to develop recommendations on stormwater best management practices (BMPs) most suitable to treat runoff from low-volume paved rural roads. Drainage ditches/swales will be effective stormwater treatment practices to reduce runoff volume and treat the runoff constituents. Runoff infiltrated by a swale can be assumed to have 100% of the constituents removed in the process (MPCA 2018), which increases overall effectiveness in reducing runoff constituent loads. A cost-benefit analysis based on existing knowledge of stormwater BMP cost, design, and performance showed that swales are considerably less expensive to install and maintain compared to other BMPs, especially when the swale is in the right-of-way and purchase of additional land for stormwater treatment is not necessary, and that swales remove more runoff constituents than wet ponds, which are widely used due to their low cost and relatively high removal effectiveness. This means more expensive treatment options likely will not be necessary for low-volume roads, as long as the swales can meet the post-construction permanent stormwater treatment requirement for existing and new road projects established by the Minnesota Pollution Control Agency (MPCA) under the National Pollution Discharge Elimination System Sate Disposal System Program (NPDES/SDS).

The MPCA’s Minimal Impact Design Standards (MIDS) requirement for linear projects (one acre or more) is that 1.1 inches of runoff from the net increase in impervious area be captured and retained (MPCA 2020). The ability of swales to meet the volume retention requirements was investigated by modeling five road widening project examples using the MIDS calculator and the Roadside Swale Calculator (RSC) for confirmation and comparison. If the MIDS calculator determined that the new road would not meet the capture requirement using swales alone, stormwater BMPs that could help meet requirements were investigated and proposed. As an example, additional required capture volume can be provided by adding non-permeable check dams and a bioretention base as part of the swale main channel BMP, which would not require the purchase of additional right-of-way. Some discrepancies were found in the MIDS calculator results based on the number of road segments set up in the model, and also because the MIDS calculator does not give adequate credit for infiltration on the side slopes of swales. The RSC provided slightly different results; however, the RSC has only a 1.64 ft swale bottom width and requires that the side slope be extended to account for a larger bottom width. It is recommended that calculations be done using both the MIDS and RSC calculators since both methods have their own limitations.

CHAPTER 1: INTRODUCTION

Stormwater runoff from roads carries with it constituents that have accumulated on the road surface and are washed off with runoff during rainfall events. The runoff constituents of concern include nutrients such as phosphorus and nitrate, total suspended solids (TSS), and metals such as copper, cadmium, and zinc. These constituents can originate from human activity such as traffic and buildings or from natural sources, such as the soil, and from atmospheric deposition. The vehicular sources include engine wear and exhaust, lubricants, rusting, and tire wear. For example, zinc has been found to mostly originate from tires, brake pads, galvanized items and asphalt pavements, copper from brake pads, lead from soils near roads (due to our lead-based gasoline legacy) and cadmium from deicing salts (Davis et al. 2001, Murphy et al. 2015, Huber and Helmreich 2016). Atmospheric deposition can contain nutrients, particulates, heavy metals and hydrocarbons.

In urban settings, a large fraction of the runoff constituent load originates from vehicular traffic on the road. Several studies have been performed to investigate the relationship between traffic volume (ADT) and runoff constituent concentrations and loads. Most of the studies have focused on paved urban roads with high volumes of average daily traffic (ADT) values in the tens of thousands or greater. As expected, higher traffic volumes generally result in higher concentrations and loads of the runoff constituents (Barrett et al. 1998, Gan et al. 2008). Other variables such as surrounding area land use, wet and dry atmospheric deposition, antecedent dry period, road surface texture, rainfall intensity, rainfall duration, number of vehicles passing during the rainfall event, similar characteristics of the previous storm, and others were also found to be important but variable in their importance in affecting runoff characteristics for high ADT roads. The level of impact of the various factors on the runoff quality has, however, been variable among the studies because of the complex correlations among the factors (Kerri et al. 1985, Driscoll et al. 1990a, b, Irish et al. 1998, Drapper et al. 2000, Kayhanian et al. 2003, Kayhanian et al. 2007, Kayhanian et al. 2009, Trenouth and Gharabaghi 2016).

Nevertheless, very little has been reported on the stormwater runoff quality from paved rural roads with relatively low ADT values. Low-volume roads are broadly “rural highways with less than 400 ADT and urban residential streets with less than 400 ADT and speeds of 30 mph or less” (MnDOT 2018), although other guidelines define low-volume roads to be “functionally classified as a local or minor collector road with design ADT of 2000 vehicles per day or less” (Coghlan 1999, AASHTO 2019). It is estimated that more than 80% of the roads in the US have traffic volumes of 2000 vehicles/day or less (AASHTO 2019). In this project, two-lane asphalt paved rural roads with less than 1500 ADT are considered low-volume roads.

With low-volume rural roads and high-volume urban roads having vast differences in ADT values and surrounding land use, it can be hypothesized that there may be differences in stormwater runoff quality between these two road classifications. The process of build-up and wash-off of runoff constituents involves many variables and is still poorly understood. Two of the important factors that can impact runoff quality, surrounding area land use and atmospheric deposition, may be linked, according to some studies (Kayhanian et al. 2003, Gunawardena et al. 2012, Moffet 2017). To protect the quality of water bodies that receive stormwater runoff, current regulations generally require treatment of road runoff to improve its quality and/or otherwise reduce the negative impact on receiving water bodies, regardless of differences in ADT and other factors such as surrounding land use and ground cover.

The main goal of this study was to investigate stormwater runoff quality from low-volume, paved rural roads with ADT up to 1500. The objectives were to 1) characterize runoff constituent concentrations from low-volume roads with less than 1500 ADT and with various surrounding land uses and use this information to 2) provide recommendations to optimize stormwater treatment for paved roads in rural settings.

To achieve the objectives, low-volume road runoff was sampled at 10 different locations in rural Minnesota over a period of two years. With low vehicular traffic, runoff quality was expected to be dependent on surrounding land use, soil type, or ground surface cover (e.g., agricultural crop, forest, etc.). Thus, runoff samples were collected from a variety of rural areas to investigate the influence of these variables on the runoff quality. The runoff sampling results were used with the existing knowledge of stormwater best management practice (BMP) design and performance to develop recommendations and guidelines on treatment practices most suitable and cost-effective to treat runoff from low-volume, paved rural roads. Roadside drainage ditches/swales, sand filters and wet ponds were investigated as the potential BMP option to satisfy the permanent stormwater treatment requirements for existing and new road projects.

CHAPTER 2: LITERATURE REVIEW

The scientific literature was reviewed on studies that have investigated stormwater runoff water quality characteristics from high and low traffic volume roads, and that have investigated the variables that impact the water quality of road stormwater runoff. In addition to average daily traffic (ADT) or average annual daily traffic (AADT), other factors such as adjacent or surrounding land use, antecedent dry period (ADP), and rainfall volume or intensity, may be important among others. The studies reviewed have reported traffic volumes in ADT, which is typically the average daily traffic for a time period greater than one day but less than one year, or in AADT which is the total yearly traffic volume divided by 365.

2.1 SOURCES OF RUNOFF CONSTITUENTSF

The constituents in roadway stormwater runoff can originate from human activity such as traffic and buildings or from natural sources such as the soil. Studies that have investigated, primarily for roads with ADTs above 1500, were reviewed for the sources of constituents in stormwater runoff. One such study was by Davis et al. (2001) who estimated loading of cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn) from various sources in developed areas. Sources that were considered were building siding, building roofs, vehicle brakes, tires, oil leaks, wet deposition, and dry deposition. Brakes were determined to be a major source of copper and tires were a major source for zinc. Atmospheric deposition was important for cadmium, copper, and lead but results were determined to vary depending on vehicle and building densities.

Gunawardena et al. (2012) investigated sources of atmospheric total suspended particulate matter, polycyclic aromatic hydrocarbons (PAHs), and metals in the Gold Coast region of Australia. Zinc was found to have the highest concentration in the atmosphere during both weekdays (when traffic was heavy) and during weekends (when traffic was lighter). During weekdays, traffic was the major source of PAHs, but land use was the major source during weekends. Lead, which was the most commonly detected metal, was determined to have originated from adjacent soil that was previously contaminated by leaded gasoline when its use was common. Overall, traffic was found to be the main source of atmospheric metals with traffic congestion and heavy duty traffic volume being the most important variables.

Gunawardena et al. (2013) investigated variables that affected wet and dry deposition of solids and heavy metals at two sites in Gold Coast, Australia. Zinc deposition was most correlated with traffic volume while cadmium, copper, nickel, and lead were correlated with traffic congestion. Total (wet plus dry) deposition was correlated with rainfall depth where dry deposition was correlated with the amount of vehicle wear.

Huber and Helmreich (2016) investigated seven different traffic related sources of constituents in German roadway runoff (tires, brakes, roadway abrasion, tire balance weights, guardrails, lampposts and signs, and deicing salts). Zinc was found to mostly originate from tires and galvanized items, copper and lead mostly originated from brakes, and deicing salts were the major source of cadmium.

Huber et al. (2016) investigated data from 294 sites on six continents and noted that bridge deck runoff can contain high levels of zinc due to safety fences and other galvanized items. Such sources can also cause great variations in zinc concentrations at roadway locations other than bridge decks. The study found that roads with ADT values greater than 5,000 are often more polluted due to site factors such as traffic lights, which cause braking and acceleration. Overall, the study found that runoff constituent loads depend on many factors such as surrounding land use, traffic, climate, and operational characteristics.

Road runoff often contains hydrocarbons, including polycyclic aromatic hydrocarbons (PAH), and several studies have investigated potential sources and important variables. For example, Hwang and Foster (2006) investigated the source, fate, and transport of PAHs in the Anacostia River in Washington, DC. In all water samples collected, PAHs related to traffic and vehicles were more important than those related to wood burning, coal burning, and oil spills. Sample collection, however, was not during a seasonal cold period when wood and coal burning would typically be prevalent.

Li et al. (2016) found that the main sources of street dust in Beijing, China were gasoline emissions, diesel emissions, coal burning, and unburned petroleum. Surrounding human activity also impacted concentrations as the main road had higher PAH levels compared to residential streets. Mummulage et al. (2016) identified sources of hydrocarbons in roadway runoff in the Gold Coast of Austrailia and found the three most important urban sources were non-combusted lubrication oils, non-combusted diesel fuels, and asphalt and tire wear. Contributions from each source varied from site to site due to differences in traffic, road geometry and conditions, and surrounding land use. Others (Saddler et al. 1999, Brandt and de Groot 2001) have noted that PAHs can leach from asphalt roadways. Other sources of PAHs have been identified as diesel vehicle emissions, industrial activity, oil combustion, gas vehicle emissions, coal burning, wood burning, traffic density, and accumulation of road dust (Dong and Lee 2009, Hussain et al. 2015). Hussain et al. (2015) found that PAH concentrations decreased according to the following order of land use: industrial, commercial, institutional, residential, and forest while Herngren et al. (2010) found that PAH concentrations decreased with increasing rainfall duration.

Particle size is also an important variable regarding PAH levels. Herngren et al. (2010) found that the highest PAH concentrations were associated with particles between 0.45 to 150 μm, regardless of land use. Dong and Lee (2009) found that PAH concentration on road dust (mass PAH per mass of dust) increased with decreasing particle size. Variables impacting PAH build-up on urban roads, listed from highest to lowest impact, were found to be traffic volume, land use, and road surface roughness, with traffic congestion being a more significant factor than traffic volume for PAHs with more than four rings (Liu et al. 2016b, Liu et al. 2017). Based on these results, Liu et al. (2016b) concluded that stormwater treatment may need to be different for runoff from highly congested roads.

2.2 STUDIES INVESTIGATING TRAFFIC VOLUME AND OTHER VARIABLES

While several studies have investigated the impact of daily traffic (ADT or AADT) on roadway stormwater runoff constituent concentrations and/or loads, a Washington State Department of Transportation (DOT) literature review (Barber et al. 2006) determined that using AADT alone as a method to suggest or select appropriate stormwater control measures (SCM) is not feasible. The other important variables included antecedent dry period (ADP), land use, vegetation, percent impervious area, rainfall intensity, total event rainfall, and seasonal cumulative precipitation. Although the values of AADT investigated for all reviewed studies were not listed, the values reported ranged from 1,800 to 259,000. Barber et al. (2006) noted that although some studies have successfully used AADT to estimate runoff constituent concentrations, they did so with a large degree of uncertainty.

Many studies on road runoff constituent concentrations were performed before the above mentioned Washington State DOT review and many have been performed since, although most have been on sites with an ADT above 1500. An early published study that investigated the possibility of predicting highway runoff constituent loads based on independent variables was by Kerri et al. (1985). This study investigated the development of regression equations for predicting runoff loads for boron, total lead (Pb), total zinc (Zn), nitrate, ammonia, total Kjeldahl Nitrogen (TKN), total phosphorus (TP), dissolved phosphorus, oil & grease, non-filterable residue, filterable residue, total cadmium (Cd), and chemical oxygen demand (COD) by analyzing data from three urban paved highway sites in California with ADT values of at least 50,000. Information was also collected from one rural site but no ADT value was reported and this site was not used in the development of the regression equations. The number of vehicles during a storm event was determined to be a satisfactory (i.e. statistically significant to the 5% level) independent variable for estimating loads of total Pb, total Zn, filterable residue, TKN, and COD. The equations, however, were deemed only applicable to highways with ADT values greater than 30,000.

In another study, Ellis et al. (1986) performed linear regression on data from two collection locations on the same roadway (ADT of 500) with five hydrologic variables and found that total rainfall volume and rainfall duration explained over 90% of the variability in Pb, Cd, manganese (Mn), and sediment loads between runoff events. Rainfall intensity and ADP were deemed to be unimportant regarding the removal of particle associated constituents from highway surfaces. No attempt was made, however, to investigate the importance of traffic volume.

Driscoll et al. (1990a, b) analyzed runoff data from 31 sites in 11 states (ADT values from 4,000 to 200,000) to develop predictive models for event mean concentrations (EMCs). It was determined that total rain or rainfall intensities were weakly negatively correlated with concentrations and that there were weak positive correlations between copper concentrations and ADT. Sites with ADT values greater than 30,000 had runoff constituent concentrations two to five times higher than sites with ADT values less than 30,000. Driscoll et al. (1990b) also noted that atmospheric contributions can significantly impact highway runoff concentrations. All sites were urban and the authors noted that their analysis procedure was not suitable for rural sites.

Wu et al. (1998) monitored three sites in Charlotte, NC. Site I was an asphalt and concrete bridge deck with ADT = 25,000. Site II was an asphalt highway with a pervious shoulder and ADT = 21,500. Site III was a non-urban, 4-lane, asphalt divided highway with ADT = 5000. It was determined that, of all the runoff constituents associated with vehicle traffic (i.e. total dissolved solids, total suspended solids, total P, nitrate), only total suspended solids (TSS) was linearly correlated with the volume of traffic during the storm event. Also, precipitation data at Site I (the bridge deck) indicated that 20% of the TSS, 70-90% of the nitrogen, and 10-50% of the other runoff constituents may have originated from wet atmospheric deposition.

Barrett et al. (1998) investigated the water quality of stormwater runoff from roads that had different ADT values. Three sites, each with a different ADT, in Austin, TX were monitored. Site information is given in Table 2.1. It is important to note that the runoff from Site 3 was collected after it had traversed a large, grassy median and passed through a drop structure. Thus, reported water quality values for this site did not represent water quality of road runoff as it left the road surface. Rather, the data represented the quality of road runoff after it had been treated and likely improved by the grassy median. The EMCs of TSS, volatile suspended solids (VSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate, total P, copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) were measured at the three sites. Site 1, which had the highest ADT, had the highest EMC values. Site 3, which had the mid-range ADT value of 47,000, had the lowest EMCs. This was attributed to the fact that the runoff from site 3 had been treated by the grassy median before it was collected. The authors stated that the EMCs of TSS and other runoff constituents appeared to be impacted by changes in ADT, rainfall intensity, and other variables.

Table 2.1 Sampled roadway site information from Barrett et al. (1998).

Site	ADT	Watershed area (m^2)	Surface	Comments
1	60,000	5,341	100% asphalt	Adjacent land use: Mixed residential and Commercial
2	8,780	526	100% asphalt bridge deck	Two total lanes and two wide shoulders
3	47,000	104,600	37% paved highway asphalt	Highway had a grassy shoulder and median. Land use: high density residential and commercial

Thiem et al. (1993) investigated stormwater runoff quality from three sampling locations along Rhode Island highways for six storms (two winter and four non-winter events). It was concluded that, over the range of ADT values investigated (2,000 – 15,000), ADT did not impact the loads of the runoff constituents investigated (TSS, metals, nutrients, organics, and inorganics). Rather, land use and seasonal characteristics such as leaves in the fall and winter road salt application had the most impact.

Irish et al. (1998) sought to develop regression models to estimate highway stormwater runoff quality. Although traffic volumes were not reported, the investigation determined that TSS loads were dependent on the current storm, the ADP, and the preceding storm. Oil and grease loads, however, were only dependent on conditions during the storm such as runoff volume and number of vehicles. Other important variables were the duration of the rainfall event, volume of runoff per watershed area, intensity of the runoff per watershed area, average traffic volume per lane during the rainfall event, antecedent dry period (ADP), and average vehicles per lane during the dry period. Characteristics of the previous storm such as duration, volume of runoff per watershed area, and intensity of runoff per watershed area were also found to be important.

Drapper et al. (2000) monitored stormwater runoff quality from 21 sites in Australia and investigated concentrations of metals, nitrogen, phosphorus, hydrocarbons, pesticides, and physical characteristics such as TSS. ADT values ranged from 6,000 to 50,000 with all sites having asphalt surfaces except for the two with the highest ADT values, which had concrete pavement. Antecedent dry period was a statistically significant factor in determining EMCs while ADT explained 30% of the variation in TSS and zinc EMCs and about 20% for all other constituents. Overall, 70% of the correlation was unexplained for lead while the other runoff constituents had 80% of the correlation unexplained. The study also noted that sites near exit lanes had higher concentrations of zinc and copper, likely due to vehicle brake wear, and that rainfall contributed significantly to nitrogen and phosphorus concentrations.

Stormwater runoff quality from two highway sites in China, one urban (ADT = 22,170) and one rural (ADT = 31,000), was monitored and compared by Gan et al. (2008) who also investigated the impact of different variables on EMCs of ortho-phosphate, total nitrogen, nitrate, chemical oxygen demand, biochemical oxygen demand, copper, cadmium, lead, nickel, zinc, and others. Except for total organic carbon and organic phosphorus, all EMCs at the urban site were 6 to 73% higher than at the rural site. The difference between sites was attributed mostly to differences in surrounding land use. Investigation into variables affecting runoff quality revealed that rainfall depth and ADP were the main factors influencing runoff quality. These two variables explained approximately 30 to 70% of the variability of all EMCs except for total organic carbon, TSS, total phosphorus, and chromium.

Highway runoff at 12 Massachusetts locations with ADT values ranging from 3,000 to 190,000 was monitored and characterized by Smith and Granato (2010). Median concentrations of metals at the 12 sites increased with ADT as did the frequency of detection of organic compounds.

Zhao and Li (2013) also investigated differences in road stormwater quality between urban and non-urban areas using simulated rainfall. ADT in vehicles per day per meter of lane width were reported (values ranged from 105 to 8,900 veh/d-m) but no information on lane widths was given. At a typical lane width of 4 m, the ADTs varied between 420 and 35,600. This study examined solids deposited on the road, the portion of deposited solids that were washed off during a rainfall event, and metals adsorbed to the solids in three different land use areas: 1) urban, 2) suburban, and 3) rural. All areas were either in or around Beijing, China. Metal concentrations associated with solids decreased from urban to suburban to rural, however, the amount of road deposited solids and the solids washed off per unit area of road surface increased along this gradient. Overall, the rural village and rural town had the largest metal load per area in both road deposited solids and washoff particles. The urban village and central suburban county areas, however, had the largest proportion of potential washoff metal load.

Klimaszewska et al. (2007) investigated the concentrations of cadmium, lead, and anions (chloride, nitrate, sulfate, and ammonium) in road runoff in Poland and compared daytime concentrations (from 7 AM to 6 PM) to nighttime concentrations (1 AM to 6 AM) when traffic volumes were less. For all runoff constituents, concentrations during the day time (when traffic volumes were 2,100 vehicles/hour or larger) were substantially higher than the corresponding nighttime concentration (1,000 vehicles per hour or larger). The concentration differences were likely due to the difference in traffic.

Kayhanian et al. (2003, 2007) investigated data from 43 California highway sites to determine the impact of several variables on runoff constituent EMCs. In the study, average annual daily traffic (AADT) values ranged from 2,000 to 328,000. The runoff constituents that were investigated included TSS, TDS, COD, turbidity, total and dissolved metals (As, Cd, Cr, Cu, Pb, Ni, Zn), nutrients, and others. No direct linear correlation was found between EMC and AADT for the full range of AADT investigated. Other factors such as wind, vehicle turbulence, volatilization, and oxidation were noted as potentially having impact on EMC values. When only including highways with AADT > 60,000, however, the average concentrations of approximately half of the runoff constituents correlated well with AADT. It was determined, that ADT did influence EMCs in conjunction with other variables such as watershed characteristics, antecedent dry period (ADP), seasonal cumulative rainfall, total event rainfall, rainfall maximum intensity, and land use. The impact of total event rainfall, seasonal cumulative rainfall, and ADP on EMCs were, in fact, significant for more than 70% of the runoff constituents. The impact of watershed size and maximum rainfall intensity were less important and significant less often. It was also noted that most EMCs were higher on urban highways (i.e. ADT > 30,000) but that COD, TSS, TDS, turbidity, ammonia, and diazinon (a pesticide) were higher on non-urban highways (i.e. ADT<30,000). The authors concluded that ADT and other factors can be used to plan stormwater management efforts in highly urbanized areas and that land uses in these areas was less important than ADT and other variables.

Davis and Birch (2010) compared metal export between two sites, one with and ADT of 84,500 and one with an ADT equal to 2,000. No consistent relationship between traffic volume and heavy metal load export was found. In fact, the higher ADT road was not more loaded than the lower ADT road. This observation was attributed to passing vehicles cleaning the road surface. It was noted that local factors are important to the development of a road or highway stormwater management plan and that the proximity of the traffic to a curb, if present, may be a major factor impacting the mass of runoff constituent that remains on the road surface per vehicle. Other important factors regarding lead build-up included atmospheric deposition and dislodged wheel weights.

MacKay et al. (2011) monitored roadway stormwater runoff quality from six sites in rural Connecticut whose ADT values ranged from 2,000 to 8,000. Because the TSS, total copper, total zinc, and total lead EMCs from the rural roads fell within the range of reported values for urban roads (32 – 10,000 mg/L TSS, 14 – 740 µg/L copper, 80 – 30,000 µg/L zinc, and 6 – 2,300 µg/L lead), MacKay et al. (2011) stated that there were no findings of differences between EMCs of total suspended solids and heavy metals between urban and rural locations.

Finney et al. (2010) investigated stormwater runoff quality from an urban highway site with an AADT of approximately 100,000 and noted that traffic volume and ADP were key factors that influenced the build-up of runoff constituent on the road surface. The build-up plateaued, however, after about a seven-day dry period so that the EMCs in the runoff had no further increase even if the ADP continued beyond seven days. Regarding runoff constituent wash-off, important factors included total precipitation depth and precipitation intensity. The study also determined that roads with ADT values of more than 20,000 may potentially have high copper concentrations (i.e. greater than 5 mg/L).

Miguntanna et al. (2010) investigated the build-up of solids and nutrients on road surfaces in the Gold Coast, Queensland State, Australia and found that solid build-up was influenced by land use, ADP, and ADT (although ADT values were not listed). Nutrient build-up was independent of land use and solely dependent on the size of the built-up solids. Overall, most nutrients were associated with particles ranging from 75 to 150 µm in size but for phosphorus the important particles ranged from 1 to 150 µm. Nitrogen build-up was primarily due to organics while phosphorus build-up was mostly inorganic. Vaze and Chow (2002) also investigated the impact of particle size and found that most nutrients were attached to finer sediment. For example, in their study more than half of the sediment was larger than 300 µm but less than 15% of the total phosphorus and total nitrogen were associated with particles of this size.

Another study that investigated the build-up of runoff constituents on urban roads, this time semi-volatile and non-volatile organic compounds, was Mahbub et al. (2011). ADT values over the course of the study ranged from 581 to 24,506. The two most important factors impacting build-up were traffic congestion in commercial areas and the use of motor oils and lubricants in industrial areas. Traffic with an ADT ranging from 2,300 to 5,900 with a congestion factor of 0.47 (volume to capacity ratio) dominated build-up of semi- and non-volatile organic compounds when traffic patterns varied.

Rodriguez-Hernandez et al. (2013) statistically analyzed results of 37 papers to determine the impact of ADT along with watershed size, location, and land use on the quality of roadway stormwater runoff. Values of ADT were not reported, however, results showed that TSS EMC values in watersheds less than 20 ha did not depend on watershed size, land use, or ADT. Also, in America and Europe, watershed size and ADT did not influence zinc EMCs, while land use influence was inconclusive. In general, ADT influenced copper EMCs while land use influenced COD values. Watershed size did not influence copper or COD EMCs. When comparing data between continents, TSS, copper, and COD from America, Asia, and Europe were not statistically different but zinc EMCs were higher in Asia.

Gunawardena et al. (2014) investigated how land use and traffic characteristics such as AADT and traffic congestion impacted metal build-up on roads in the Gold Coast area of Queensland, Australia. Eleven sites were included and AADT values ranged from 30 to 25,571. Land use did not show a clear relationship to metal build-up while traffic characteristics did influence the build-up process. The sources of runoff constituents were also investigated. Nickel and chromium were found to originate from vehicle exhaust, while lead, copper, and zinc came from vehicle wear and the source of cadmium was found to be both exhaust and wear. Finally, manganese was found to originate from natural sources.

Liu et al. (2015) found that, in Shenzhen, a Chinese mega-city, traffic congestion and road surface roughness impacted the build-up of heavy metals on road surfaces more than traffic volume (not reported). Also, zinc, cadmium, copper, nickel, and lead associated with particles smaller than 75 µm originated from human activity such as traffic, whereas lead associated with particles larger than 75 µm and chromium (regardless of size) originated from the soil. In a later study, Liu et al. (2016a) found traffic volume to be the most influential factor impacting metal build-up on roads in Australia while ADP, road surface, and road location relative to arterial roads had low importance.

Moffet (2017) found that AADT and land use had an impact on the runoff constituent levels in three highway sites in Tennessee, USA. Copper and zinc were higher at the urban site (AADT = 159,837), while TSS and nutrients were higher at the rural site surrounded by farmland (AADT = 5217).

2.3 STUDIES INVESTIGATING OTHER VARIABLES BUT NOT TRAFFIC VOLUME

Ball et al. (1998) took the concept of antecedent dry period (ADP) and expanded it to be days between cleaning events to incorporate the fact that all rainstorms might not wash the accumulated constituents from the road surface (i.e., a light rainstorm might not or might not do so as effectively as a more intense storm) and that other events such as wind, street sweeping, or vehicle induced turbulence might remove the accumulated constituents from the road surface. By examining data from a suburban road in eastern Sidney, Ball et al. (1998) found that true cleaning events included rainfall with an intensity greater than 7 mm/hr, street sweeping, and wind events with an average velocity greater than 21 km/hr. This finding aligns well with Vaze and Chow (2002) who noted that runoff constituent wash off depends on the rainfall and runoff characteristics and that the "every day" storm only washes off a small fraction of the constituents that have built up. Vaze and Chow (2002) also concluded that street sweeping may release but not remove fine particles from the road surface. The released fine particles would then be more available to be washed off during subsequent rainfall events.

Kim et al. (2004) investigated variables that impacted total captured gross constituents, defined as larger than 0.5 cm, on six southern California roadside sites with ADT values between 122,000 and 328,000. The gross runoff constituents were almost 90% vegetation and about 10% litter, with 50% of the litter being biodegradable. The EMC of total gross constituents showed an increasing trend with ADP and a decreasing trend with total rainfall/runoff volume but the trends were not statistically significant.

Li and Barrett (2008) and Li et al. (2008) investigated the build-up of TSS, TKN, nitrate, total phosphorus, dissolved phosphorus, total copper, dissolved copper, total and dissolved lead and zinc, and COD on highway surfaces at two sites with high ADT in Texas in order to determine the impact of ADP. One site showed that all measured EMCs significantly decreased with increasing ADP but concentrations from the other site were not significantly correlated with the ADP. An explanation given by the authors was that build-up of runoff constituents may occur relatively quickly during wet weather when splashing from the road surface washes material off of vehicles. Then, during dry times, the road surface is cleaned by natural and/or vehicle induced winds. Although not present at the study sites, the potential of curbs keeping constituents on the highway was also discussed.

Egodawatta et al. (2013) investigated the source of roadway runoff constituents and developed empirical models for predicting metal build-up rates on road surfaces based on ADP. The models had relative prediction errors of 12 to 50%. The build-up rate was initially high but became asymptopic to a near constant value after 14 days. Metals that originated from human activity (copper and zinc) had different build-up rates than those from natural sources (aluminum, calcium, iron, manganese). Lead was from natural sources such as soils (which still have lead in them from the legacy of lead-based gasoline) and also from traffic activity such as tire wear.

The impact of ADP on copper, cadmium, and zinc build-up on road dust in Germany was investigated by Zhang et al. (2015). In general, the amount of copper and zinc on road sediment increased with ADP but this trend, however, was not as evident with cadmium. Zhang et al. (2015) also investigated the metal build-up as a function of particle size. Again, in general, for most size ranges copper and zinc build-up increased with increasing ADP but cadmium build-up did not exhibit as strong of relationship with ADP.

Chow et al. (2015) investigated build-up characteristics on roads in residential, commercial, and industrial areas by collecting dust and dirt from the road surfaces and also found build-up was asymptopic as dry days increased. Dry days before dust collection varied from 1 to 10 days with the particles size distribution, BOD, COD, and total phosphorus concentrations being determined. Build-up typically reached a maximum after five days but characteristics of the road particles, such as constituent to solid ratio, were very site specific. For example, industrial areas had the highest COD to solid ratio while commercial areas had the highest total phosphorus to solid ratio. Trenouth and Gharabaghi (2016) also noted that ADP impacts runoff constituent loads but that the relationship is complex, non-linear, and highly variable.

2.4 IMPACT OF PARTICLE SIZE DISTRIBUTION

At all sites the proportion of fine particles increased with ADP, which may have been due to larger particles being crushed into smaller pieces or, the authors suggest, that smaller particles would be more likely to be transported to the road surface by wind. Also, there was a decrease in the amount of large solids with time, a trend that supports the possibility of large particles being crushed. Vaze and Chow (2002) also found that surface particles became finer as the number of dry days progressed and they also attributed this to the disintegration of larger particles into finer particles.

Chow et al. (2015) found that the particle size distribution was highly influenced by the road surface condition in that rough surfaces collected runoff constituents more efficiently. The build-up for total dust and dirt (DD), fine DD, and total phosphorus all reached asymptotes as ADP increased up to five days. Also the build-up rates for all constituents were impacted by human activities, ADT, and road surface conditions. Selbig (2015) found that collector streets (ADT = 6,600) had the lowest median particle size of about 8 µm. In order of increasing median particle size, the next largest were found on parking lots (32 µm), arterial streets (43 µm, ADT = 40,000 and 49,450), feeder streets (50 µm, ADT = 1,500 and 1,700), and residential streets (80 µm, no ADT reported), and mixed land use (95 µm, no ADT reported). No formal statistical analysis, however, between the median particle size and ADT or the roadway classification was performed. Winston and Hunt (2017) also investigated particles size and particles size distribution of TSS in runoff from eight asphalt roadway sites with ADT values ranging from 520 to 34,000 and, after statistical analysis, concluded that ADT has little effect on particle size. The site with the lowest ADT value had the largest d10 and d50 values but the site with the second lowest ADT (3,400) had relatively fine particles and the site with the highest ADT had mid-range size particles.

2.5 IMPACT OF PAVEMENT TYPE

The type of pavement can impact stormwater quality of road runoff either due to constituents essentially being removed by the road surface, the leaching of constituents from the road surface, or by the impact of road surface roughness. For example, as previously discussed, Brandt and de Groot (2001) found that PAHs could leach from bitumen or asphalt pavement. Their leachate equilibrium tests found that, although PAHs did leach into the water, equilibrium concentrations were well below surface water limits that exist in several European Economic Community (EEC) countries and are more than ten times lower than current EEC limits for potable water. In general, only PAHs with four rings or less were found in water at concentrations above 0.1 ng/L. Murphy et al. (2015) found that zinc can leach from asphalt pavements and this can result in higher zinc loads.

Murphy et al. (2015) also found that TSS and lead loads were higher from concrete pavements as compared to asphalt, a finding they attributed to concrete having a smoother surface which would tend to allow particulates to move more easily across the surface. In the study, zinc and copper loads from concrete were less than from asphalt, however, because carbonates and hydroxides within the concrete can bind with these metals. Wicke et al. (2012) also found higher zinc loads from asphalt and higher TSS loads from concrete and attributed these differences to zinc leaching from asphalt and concretes smoother surface, respectfully. Haselbach et al. (2014) found that concrete was effective in removing zinc and copper via sorption and/or complexation. At typical stormwater concentrations (100 g/L for zinc and 20 g/L for copper), retention rates by the concrete pavement were over 80%. Bahar et al. (2008) also found that concrete pavement can retain copper due to its ability to form a copper rich surface but removal rates were lower than those observed by Haselbach et al. (2014). Bahar et al. (2008) found that retention varied between 5 and 20% in laboratory studies (synthetic stormwater copper concentration was 3 mg/L, pH = 6.2) and 10 and 40% in the field (six of eight runoff events had copper concentrations from 2-3 mg/L and two had near zero concentration, pH typically ranged from 6.6 to 7.3). Bahar et al. (2018) also found that a small fraction of the copper previously retained became mobile during subsequent runoff events.

Although the above studies document leaching from pavements can occur, Kayhanian et al. (2009) concluded that leaching from the pavement itself is not a significant source of highway runoff constituents. Under controlled laboratory studies, metal leaching from concrete and asphalt pavements was investigated. In general, the concentrations of all metals were below reporting limits for both asphalt and concrete pavements. The exception was chromium, which leached from concrete but not asphalt. This leaching, however, decreased over time and it was concluded that leaching was not a significant source of chromium in runoff from hardened concrete pavements.

2.6 SEASONAL EFFECTS AND WINTER LOADS

Sansalone and Glenn (2002) and Glenn and Sansalone (2002) investigated the build-up of constituents in snow along the side of an interstate highway (average ADT = 110,251) in Cincinnati, OH. The study found that constituents did build-up in the snow as time (and the number of passing vehicles) increased. For example, TSS values in the snow increased gradually with time and approached 100,000 mg/L. Also, during the study, 220,000 kg of deicing salt that contained cyanide as an anticaking agent was applied to the 27 km section of highway. As a result, 6 kg of cyanide was discharged from the study site.

In the study by Smith and Granato (2010), EMCs of almost all runoff constituents increased substantially during winter months with snowfall. For example, average concentrations of total phosphorus, total metals, and TSS were three to 11 times higher during this months than non-winter months. Most of the difference was attributed to sand applied to roads to increase traction. Deicing compounds accounted for only a small fraction of the difference in total phosphorus, total metals and TSS, as expected.

To investigate what impact winter variables might have on road runoff quality, some researchers have investigated the impact of snow cover. For example, Abaza et al. (2012) investigated the relationship between ADT, ranging from 120 to 37,854, and the quantity of organics, inorganics, and particulates present in samples of “road snow” collected from the shoulders of Anchorage, AK streets. As traffic volumes increased, so did the concentrations of organics, inorganics, and solids in the snow. The variability in the data, which the authors attributed to storm cycles and maintenance activities, was high and, according to the authors, unavoidable in a study of this nature.

Moghadas et al. (2015) also investigated the quality of snow and found the amount of TSS and metals in snow was impacted by snow age, ADT (which ranged from 1,500 to 20,000), and cumulative traffic volume (i.e. the product of snow age and ADT). Only chloride and sodium originating from winter road salt applications did not follow this relationship. A linear regression model using cumulative traffic volume was developed to estimate TSS loads but it was determined to be less accurate than a multiple linear regression model with a polynomial equation based on snow residence time, ADT, and snow water equivalent. Finally, Helmreich et al. (2010) found that copper, total organic carbon, TSS, zinc, and pH all increased multiple times during the cold season. The increase in metals was attributed to increased tire wear from winter gravel that was applied to the road surface, presumably to increase friction.

2.7 SUMMARY

Most of the literature has focused on sites with ADT values in the tens of thousands or greater. Very little has been reported on the stormwater runoff quality from roads with ADT values ranging from 200 to 1,500, which is the focus of this study. For high ADT studies, important variables have been found to be ADT, antecedent dry period, road surface texture, rainfall intensity, rainfall duration, number of vehicles passing during the rainfall event, similar characteristics of the previous storm, and others. Results of different studies have not always been in agreement. What is clear, however, is that the process of build-up and wash-off of runoff constituents involves many variables and is poorly understood. Other important variables, according to some studies, are the surrounding area land use and atmospheric deposition, two variables that may be linked. With low-volume roads and high-volume roads having vast differences in ADT values and surrounding land use, there may be significant, yet unknown, differences in stormwater runoff quality between these two road classifications.

CHAPTER 3: METHODS AND MATERIALS

3.1 SITE SELECTION

A site selection questionnaire was emailed to nine MN county engineers in the Technical Advisory Panel (TAP) to collect a list of potential sampling locations along paved rural roads with low traffic volumes. The criteria considered for site selection were roads with ADT less than 1500, surrounding land uses and soil types, proximity of weather stations with rainfall monitoring (e.g., airports), site accessibility, and feasibility of installing runoff samplers at the edge of the road. Site reconnaissance visits were conducted by the University of Minnesota (UMN) personnel along with the project team members in May and June 2018. A total of 10 sites were selected for runoff monitoring after the site visits (Table 3.1). In addition to the 10 low-volume road sites, the Mississippi river water, just upstream of the CSAH 37 monitoring site in Clearwater County, was also sampled for comparison with roadway runoff.

Table 3.1 Characteristics of the low-volume road monitoring sites selected for this study.

County	Location	ADT	Surrounding land use	Nearest rain gauge[a]	Primary Contact
Aitkin	CSAH 39 (46.448,-93.667)	660	Wooded	iweathernet.com and private gauge 5 miles away	John Welle
Aitkin	CSAH 4 (46.504,-93.521)	600	Wooded		John Welle
Cass	CSAH 31 (46.325,-94.530)	740	Agriculture	14 miles, Baxter KMNBAXTE8	Darrick Anderson
Chisago	CSAH 21 (45.361,-92.748)	560	Agricultural	KMNSHAFE2[a]	John Gulliver Poornima Natarajan
Chisago	CSAH 86 (45.310,-92.767)	1150	Agricultural	KMNSCAND2[a]	
Chisago	CSAH 1 (45.724,-93.050)	1400	Agricultural	KMNNESSE2[a]	
Clearwater	CSAH 37 (47.3111, -95.243)	195	Wooded	10 ft, DNR Cooperative Stream Gage at Mississippi river nr Vern 07052003[b]	Dan Sauve
Fairbault	CSAH 1 (43.610, -94.227)	530	Agricultural	3270 ft E of Mooreville KMNBLUEE4[a]	Mark Daly
Polk	CSAH 13	271	Agricultural	KMNMENTO3	Rich Sanders
St. Louis	CSAH 133 (47.069,-92.514)	1450	Wooded	15 miles, Leisure Lake KMNMAKIN4[a]	Carol Andrews

[a]Airport or personal weather stations accessible at www.wunderground.com
[b]<www.dnr.state.mn.us/waters/csg/site_report.html?mode=getsitereport&site=07052003>

3.2 RUNOFF SAMPLING METHOD

3.2.1 Runoff sampler design and installation

The road runoff samplers (Figure 3.1) were fabricated at the St. Anthony Falls Laboratory (SAFL). The runoff sampler consists of polyvinyl chloride (PVC) housing (~14 in height; ~5 in diameter) that is sealed at the bottom. The top of the sampler is closed with a removable PVC grate cap. A 1-L HDPE bottle (Nalgene™ single use stormwater sampler bottle) placed inside the PVC sampler housing collects the runoff. The bottle top is equipped with a floating ball valve that automatically seals off the bottle's sample collection port when full and prevents additional water from entering the sampler bottle (Figure 3.1). A rubber mat was attached at the top of the sampler housing to facilitate installation at the edge of the pavement. A U-shaped silicone beading was applied on the rubber mat to help channel runoff into the sampler.

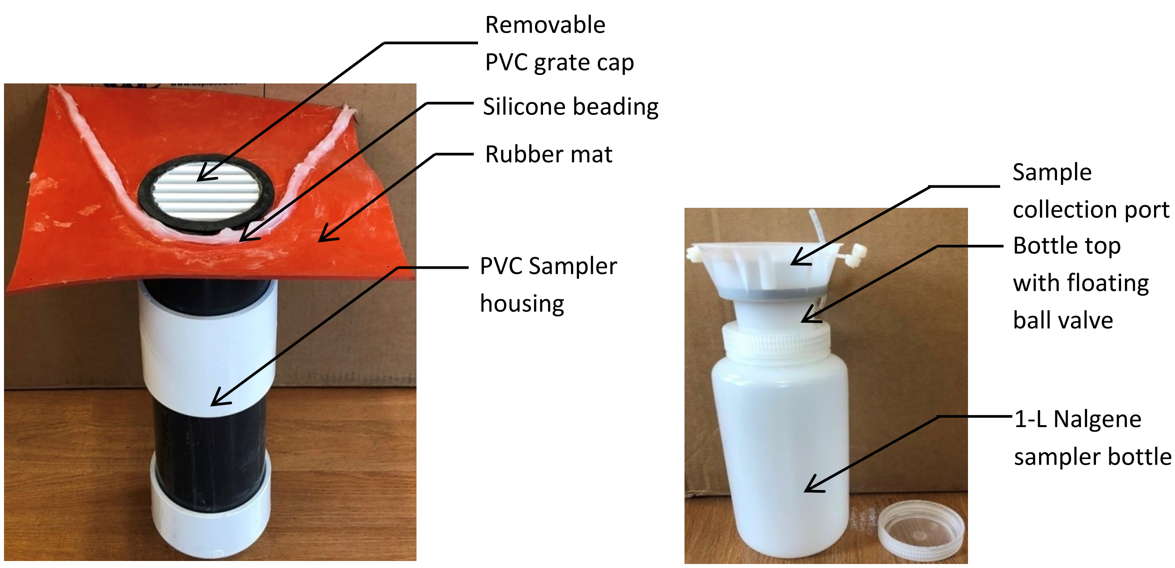


Figure 3.1. Photographs of the runoff sampler (left) and the Nalgene sampler bottle (right) used to collect runoff samples at at the low-volume road sampling sites.

The roadside runoff samplers were installed at the selected monitoring sites during the site reconnaissance visits in May and June 2018. The installations were performed by the UMN personnel and the project subcontractor (Prof. Peter Weiss) with the help of the local project team member. At each site, the runoff sampler was installed at the edge of the paved shoulder such that the sampler's surface was flush with the road (Figure 3.2). A silicone seal was applied to seal the rubber mat against the pavement edge. The sampler was further secured to the ground by nailing the rubber mat to the ground. The sampler operation was demonstrated to the project team members at the time of sampler installation.

Figure 3.2. Photographs showing runoff samplers installed along the selected monitoring locations along low-volume roads.

During the early phase of monitoring in 2018, it was observed that soil particles were accumulating on the sampler's surface after a rainfall event at some sites (Figure 3.3). The soil particles appeared to be locally-eroded material being splashed onto the sampler's surface, especially during high-intensity precipitation events. Sometimes, the accumulated soil particles clogged the grate cap assembly covering the sampler which prevented runoff sample collection. Also, the preliminary chemical analysis results indicated that the high concentrations of suspended solids (TSS) measured in some water samples could be erroneous due to the presence of eroded debris. Therefore, a barrier that would minimize erosion around the sampler was considered necessary. Lawn edging was installed around the sampler at some sites (Aitkin, Chisago, St. Louis, Polk) (Figure 3.4). Geotextile fabric was placed around the sampler (sites in Cass, Clearwater, Chisago, Fairbault) when the proximity of lawn edging to roadway was a concern or when the lawn edging was repeatedly found to be damaged due to vehicles running over it. Because the geotextile fabric held up well during the 2018 monitoring period, the geotextile fabric was installed around the samplers at all sites before 2019 monitoring began.

Figure 3.3 Photograph showing debris collected on runoff sampler surface that caused sampling issues (Photo courtesy: Mark Daly, Fairbault County).

Figure 3.4 Photographs showing the installation of lawn edging (CSAH 1, Fairbault County; photo courtesy: William Goo), and geotextile fabric (CSAH 37, Clearwater County; photo courtesy: Dan Sauve) installed around the runoff sampler during 2018 monitoring. All sites were switched to geotextile fabric cover in 2019.

Routine minor maintenance, including re-sealing the sampler's rubber mat edge to the pavement or to the sampler housing, was required during the course of the two-year monitoring period. After the first-year monitoring ended in October 2018, the samplers at the three sites in Chisago County were uninstalled and then reinstalled before the second-year monitoring. At the remaining seven monitoring sites, the samplers were left on site from October 2018 through the winter. The samplers were assessed for damage before monitoring began in June 2019. The sampler at the Fairbault County site was replaced due to minor damages to the old sampler that could not be repaired on site. The sampler at the Polk County site could not be located and was not replaced. The samplers at other sites required minor repairs to attach the rubber mat to the sampler and the edge of road using silicone sealant. Members of the local county engineer's office were essential in adhering to the protocol for sample collection and performing maintenance tasks to keep the program running.

3.2.2 Runoff sample collection and handling

Sample collection at the 10 monitoring sites was performed by the local team members following the same protocols established for this study. A manual containing the sampling protocol and guidelines on the operation of the sampler, the identification, retrieval, storage and processing of water samples collected, and preparation of the site for the next rain event was distributed and explained to all team members before monitoring began in 2018.

The runoff sampler was designed to collect approximately the first liter of runoff generated from the road surface during a rainfall event. When possible, the runoff sampling frequency was spaced out by a few days to allow build-up of constituents on the road surface. Before a target rainfall event, a clean 1 L Nalgene sample bottle was placed inside the sampler housing and the housing was closed with the grate cap. The sample bottle was retrieved typically within 1-3 days after the rainfall event ended, but samples were not picked up for 6 days on some occasions. After the sample bottle was removed and capped, any debris (gravel, road dust, etc.) accumulated on the sampler's rubber surface was brushed off. Water pooled inside the sampler housing was siphoned out. Then, a clean sample bottle was placed inside the sampler housing for the next sampling event.

The sample bottle retrieved from the site was shaken to mix the water, and as quickly as possible, the water was poured into three separate pre-labeled plastic bottles (~500 mL for TSS analysis, ~250 mL for metals analysis, and ~250 mL for analysis of phosphorus and nitrogen species). Acid preservative (concentrated sulfuric acid) was added to the sample assigned for nutrient species analysis. The three plastic bottles were packed with freezer packs in a cooler and sent for chemical analysis. The water samples were mailed within 7 days of the rainfall event. The 7-day limit (which includes the up to 6 days before sample collection occurred) was based on the maximum holding time allowed for TSS analysis per the laboratory chemical analysis protocol.

After each use, the Nalgene sample bottles were cleaned with phosphorus-free detergent and distilled water or deionized water, and once again triple-rinsed with distilled water or deionized water and dried before next use. A log of the sample volume collected and rainfall depth recorded at the nearest rain gauge was maintained by the team members for all sampling events.

3.2.2.1 Issues with sample collection

Some issues with sample collection were encountered during 2018 monitoring. The grate cap was found to be dislodged from the sampler housing which resulted in an empty or a partially-filled bottle (Figure 3.5). This issue was observed frequently at some sites (CSAH 4 and 39 in Aitkin and CSAH 21 in Chisago County), and only occasionally at other sites (Cass, Clearwater and Fairbault). The water volume collected was not sufficient for chemical analysis and had to be discarded. Two possible reasons were identified. First, the sampler housing was found to be full of water after an event, which could have caused the bottle and grate cap to displace from the housing. The float mechanism in the Nalgene bottle seals the bottle when it is full and prevents additional water from entering the bottle. New runoff flow towards the sampler is then expected to drain through the hole in the bottom of the housing. However, it was reported that the in situ soil conditions (such as clayey or compacted soil) prevented water from draining into the surrounding soil at some sites. It is likely that a faster flow of runoff, especially during intense rainfall, caused water to fill the sampler housing instead of the bottle. Second, the cap's slightly loose fit in the housing could have caused it to be easily displaced. However, this design was intentional to prevent the cap from getting jammed if debris lodges in the fine gap between the cap and housing.

Figure 3.5 Photographs showing the sample bottle displaced from the runoff sampler after a rainfall event (photos taken at a Chisago County site by Poornima Natarajan (left) and at the Clearwater county site by Dan Sauve (right)).

To solve this, the grate cap edge was taped to the sampler housing to hold it in place. Layers of tape were also applied around the cap to improve its fit inside the sampler housing. Also, grease was applied to the sides of the cap to minimize seepage of water through the very small gap between the cap and the housing. These measures prevented the grate cap from being displaced on most occasions and helped collect water samples in the sample bottle. At Aitkin County sites, packing material was placed around the sample bottle inside the sampler housing to prevent the bottle from popping out during flow periods. At one Chisago County site (CSAH 21), water from the ground was found to be seeping into the sampler housing and the drain holes in the sampler's bottom were plugged with Vulkem, which kept the bottle intact on most occasions.

3.2.3 **Chemical analysis**

The water samples collected at the 10 monitoring sites were analyzed at RMB Environmental Laboratories, Detroit Lakes, MN. The concentrations of total suspended solids (TSS) (Standard Methods 2540 D-2011), metals (cadmium, chromium, copper, lead, nickel, zinc) (EPA 200.7), total phosphorus (TP) (EPA 365.3), and nitrate and nitrite (NO3-NO2 or NOx) (EPA 353.2 Rev 2.0) were determined in the samples collected. The laboratory reporting limits are 10 mg/L for TSS, 0.003 mg/L for TP, 0.03 mg/L for NOx, 3 µg/L for cadmium, 10 µg/L for chromium, 10 µg/L for copper, 20 µg/L for lead, 20 µg/L for nickel, and 20 µg/L for zinc.

3.2.4 Data handling

If the concentration detected in the water sample was less than the laboratory reporting limit (RL) for a given analyte, half the RL value was assigned as the concentration for that sample for data analysis purpose (US EPA 2000, Kayhanian et al. 2007). However, if a large proportion of the samples (>50%) contain below detection concentrations, the concentrations were expressed as below the laboratory RL (i.e., < RL) for the runoff constituents that mostly fell below the laboratory RL (US EPA 2000). For such instances, mean and median concentrations were deemed to be meaningless, and were therefore not calculated.

CHAPTER 4: MONITORING RESULTS

4.1 YEAR 1 AND YEAR 2 MONITORING RESULTS

Runoff quality was monitored at 10 monitoring sites in 2018 (year 1 of this study) and at 9 sites in 2019 (year 2 of this study). The sampling site in Polk County was excluded in 2019 since the sampler could not be located after 2018 monitoring ended. In 2018, 79 rainfall events were sampled across 10 sites from June through November 2018. In 2019, 95 rainfall events were sampled across nine sites from June through October 2019. Thus, initial runoff were sampled for 174 rainfall events total during the two-year monitoring period. During a majority of the events, approximately the first liter of runoff from the road surface was collected in the runoff samplers at the monitoring sites. On some occasions (10 out of 174 events), the sample bottles contained less than 1 L volume (2/3 full) at some sites; these samples were analyzed only for nutrients species and metals. Four samples of the Mississippi river, upstream of the CSAH 37 monitoring site in Clearwater County, were collected during the study. A summary of the runoff quality at the 10 monitoring sites during the 2018 and 2019 sampling events, including the Mississippi river water, is provided in Appendix A.

4.1.1 Overall water quality

Figure 4.1 shows the variability in runoff constituent concentrations at each monitoring site and across the ten sites during the 174 sampled rainfall events. The TSS concentrations varied from 3.1 to 1900 mg/L across the sites (mean = 164 mg/L ± 234 SD) during 166 events (TSS was not analyzed during 8 out of the 174 events). The very high TSS of 1700 mg/L (in 2018) and 1900 mg/L (in 2019) were measured at CSAH 1 in Fairbault County. The 1700 mg/L TSS was measured before the lawn edging was installed at the site and thus could be due to particles transported by local erosion, but the reason for the 1900 mg/L TSS is not clear. However, it must be noted that the runoff sampler at this site was located near a farm field entrance, which increased the likelihood of sediment tracking from the field on to the road surface by tractors driving out of the fields. Relatively high TSS concentrations were also measured during some events at CSAH 4 (Aitkin County), CSAH 1 and 21 (Chisago County), and CSAH 13 (Polk County). TSS concentrations were largely low at CSAH 133 (St. Louis County) and CSAH 86 (Chisago County). The TSS concentrations in the Mississippi river samples were always below 5 mg/L.

Total phosphorus (TP) concentrations ranging between 0.01 and 2.5 mg/L were measured (mean = 0.34 mg/L ± 0.37 SD). Relatively high concentrations were recorded at CSAH 1 (Fairbault County), CSAH 31 (Cass County) and CSAH 13 (Polk County). The initial concentrations of nitrite and nitrate in runoff ranged from 0.015 to 2.7 mg/L (mean = 0.43 ± 0.41 mg/L), with runoff from two Aitkin County sites and CSAH 133 (St. Louis County) with wooded land cover containing high concentrations during most events. In the Mississippi river samples, TP levels were 0.020 – 0.055 mg/ L, and nitrite and nitrate were always below the laboratory reporting limit (<0.03 mg/L).

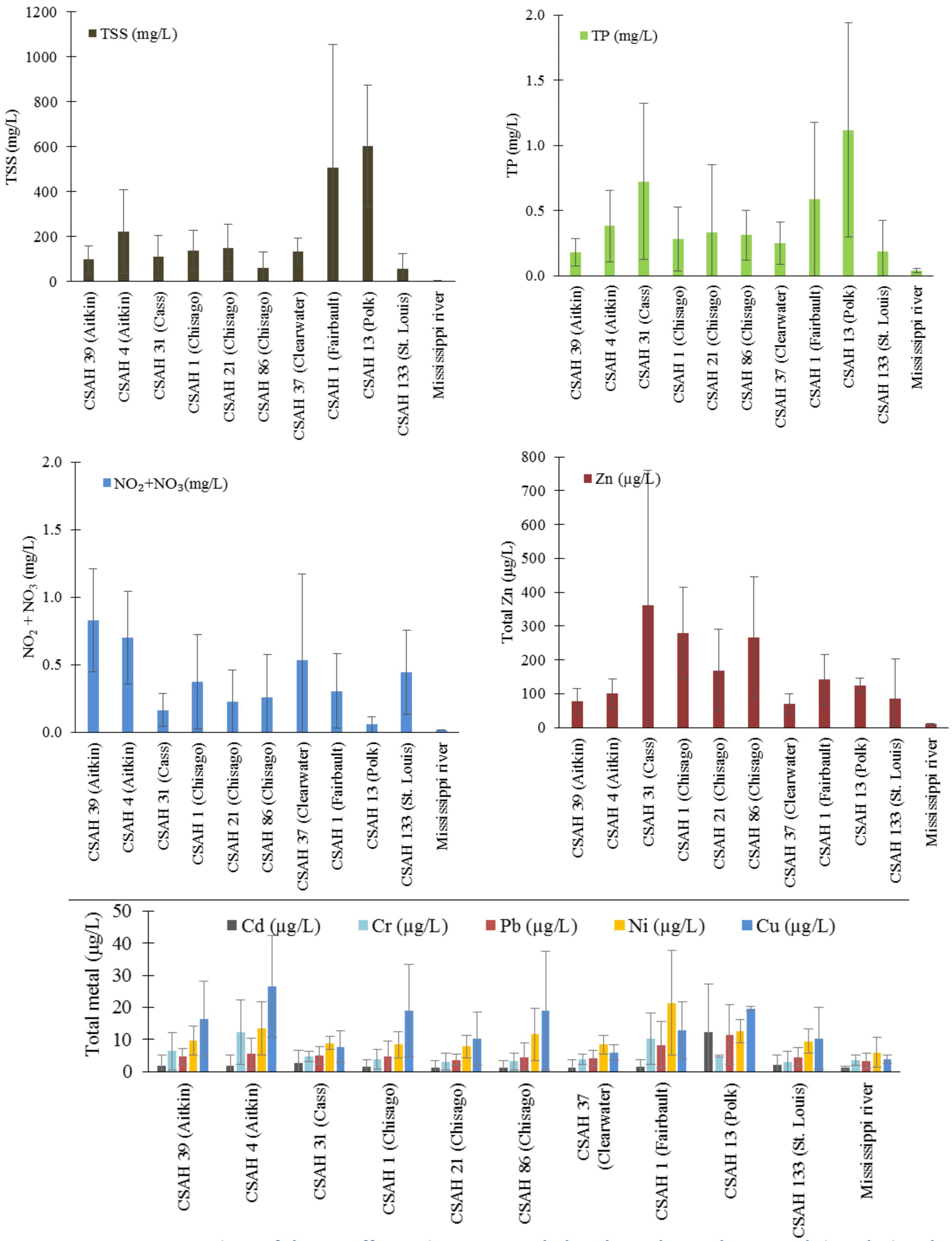


Figure 4.1. Mean concentrations of the runoff constituents sampled at the 10 low-volume road sites during the rainfall events sampled in 2018 and 2019. Error bars show standard deviations. Concentrations measured in the Mississippi headwater samples (4 total) are included in the plots for comparison.

Zinc and copper, which typically originate from vehicle wear, were always present at measurable levels in the runoff sampled at all sites. Zinc concentrations ranged between 10 and 1174 µg/L (mean = 168 ± 167 µg/L), with high concentrations recorded mostly at CSAH 1 and 86 (Chisago County) and at CSAH 31 (Cass County). Copper concentrations were between 2.5 and 92 µg/L (mean = 15 ± 14 µg/L). Other metals that originate from vehicle exhaust (cadmium, chromium and nickel) and vehicle wear (cadmium and lead) were present at levels below the laboratory reporting limit (RL) in a majority of the samples collected; i.e., 98% of the samples for cadmium, 61% of the samples for chromium, 89% of the samples for lead and 81% of the samples for nickel were below the respective metal RL. Because of the relatively large amount of non-detect sample concentrations, the concentrations of these metals were simply considered to be below the laboratory reporting limit (US EPA 2000). A mean or median concentration was therefore not calculated for cadmium, chromium, lead, and nickel in this study.

The overall and site-based median concentrations of the analyzed constituents are summarized in Table 4.1. The coefficient of variation was high for all analyzed constituents indicating large variability in the measured concentrations. The impacts of site-specific characteristics including surrounding land use and soil type on the concentrations of runoff constituents sampled are discussed in sections 4.1.5 and 4.1.6. The presence of routine sources of sediment such as farm field entrances, off-road trails or logging roads at some sites (for example, farm field entrance near CSAH 1 in Fairbault County) could increase the runoff constituent concentrations at those sites, and contribute to the variability observed in the overall results. In the Mississippi river samples, nitrite + nitrate and all metal constituents were always below the laboratory detection limits.

Table 4.1. Overall and site-based median concentrations in the initial runoff sampled at the low-volume road sites. Values given in parentheses for the overall median all sites are coefficient of variation (ratio of standard deviation to the mean). *n* is the number of rainfall events sampled at each site.

		Median Concentration in Initial Runoff					
Site	**Land use**	***n***	**TSS mg/L**	**TP mg/L**	**NO_2+NO_3 mg/L**	**Cu µg/L**	**Zn µg/L**
All sites (2018 and 2019)		**174**	**94 (1.4)**	**0.23 (1.1)**	**0.34 (0.94)**	**12 (0.89)**	**108 (1.0)**
Aitkin CSAH 39	Wooded	22	84	0.15	0.90	14	73
Aitkin CSAH 4	Wooded	22	150	0.28	0.67	21	94
Cass CSAH 31	Agricultural	10	65	0.45	0.17	5.0	211
Chisago CSAH 1	Agricultural	23	121	0.17	0.24	15	239
Chisago CSAH 21	Agricultural	19	127	0.18	0.11	10	117
Chisago CSAH 86	Agricultural	27	49	0.27	0.15	14	253
Clearwater CSAH 37	Wooded	16	130	0.24	0.37	5.7	59
Fairbault CSAH 1	Agricultural	16	281	0.38	0.35	10	161
Polk CSAH 13	Agricultural	2	602	1.12	0.06	20	125
St Louis CSAH 133	Wooded	17	32	0.13	0.45	7.7	51
Clearwater Mississippi river headwaters		4	1.5	0.04	<0.03	<10	<20

Correlation analysis between initial TSS concentrations and the initial concentrations of TP and Zn were performed for the sampled events since these constituents are predominantly attached to particles in runoff. A strong relationship was not found between these constituents (Figure 4.2), indicating both particulate and dissolved forms of phosphorus and zinc impacted their respective total levels in runoff and the first-flush behavior. For example, stormwater metal fractions can constitute up to 50% of the dissolved form (Morrison et al. 1984). A first flush phenomenon is more common for dissolved metals than for particulate-bound metals because rainfall intensity influences if dissolved forms (which is flow-driven) or particulate forms (which is transport-driven) are washed off during the storm (Sansalone et al. 1998). However, zinc, copper, and chromium EMCs have correlated well with TSS concentrations in other studies (Kearfott et al. 2005, Kayhanian et al. 2003).

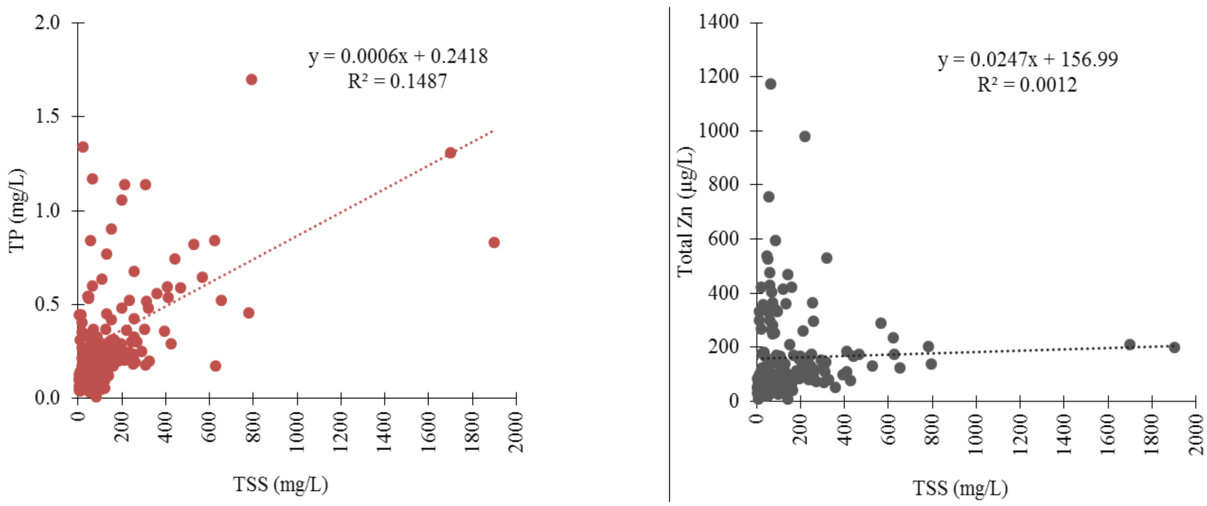


Figure 4.2. Correlations of total suspended solids (TSS) concentrations with total phosphorus (TP) and total zinc (Zn) concentrations in the initial runoff from 166 events sampled at the low-volume road monitoring sites in 2018 and 2019. The exclusion of the two high TSS values of 1700 and 1900 mg/L TSS did not improve the correlations with TP and zinc.

4.1.2 Relationship with rainfall depth

The impact of total rainfall depth on runoff quality has been observed in some studies (Gan et al. 2008), although other studies have noted the lack of direct relationship between total rainfall and event mean concentrations (EMCs) in road runoff (Driscoll et al. 1990a, b). Han et al. (2006) found negative relationship between total rainfall depth and EMCs, likely due to dilution effects of high rainfall amounts. At the low-volume road sites sampled, the initial runoff quality did not appear to be directly influenced by the estimated total rainfall depth for the 174 events that ranged between 0.07 and 5 inches; the linear correlation coefficient, R^2, was 0 to 0.022 for the analyzed constituents (scatter plots are not shown). The rainfall amount that generated the initial runoff volume was not measured or simulated in this study, but the estimated rainfall depth from nearby gauging stations indicates that the initial runoff constituent concentrations could not be explained by the total rainfall depth.

4.1.3 **Relationship with antecedent dry period**

Antecedent dry period (ADP) is one of the main factors that influences the EMC in runoff since the dry period between rainfall events allows the build-up of constituents on the road surface (Drapper et al. 2000, Gan et al. 2008). The ADP varied between 1 and 23 days for the 174 rainfall events sampled (mean = 6 days, median = 5 days). The scatter plots in Figure 4.3 illustrate the generally weak relationship between antecedent dry period and the initial concentrations of the runoff constituents during 166 sampled events. The low linear R^2 values indicate that ADP does not explain the variability in the measured concentrations in the initial runoff from low-volume roads.

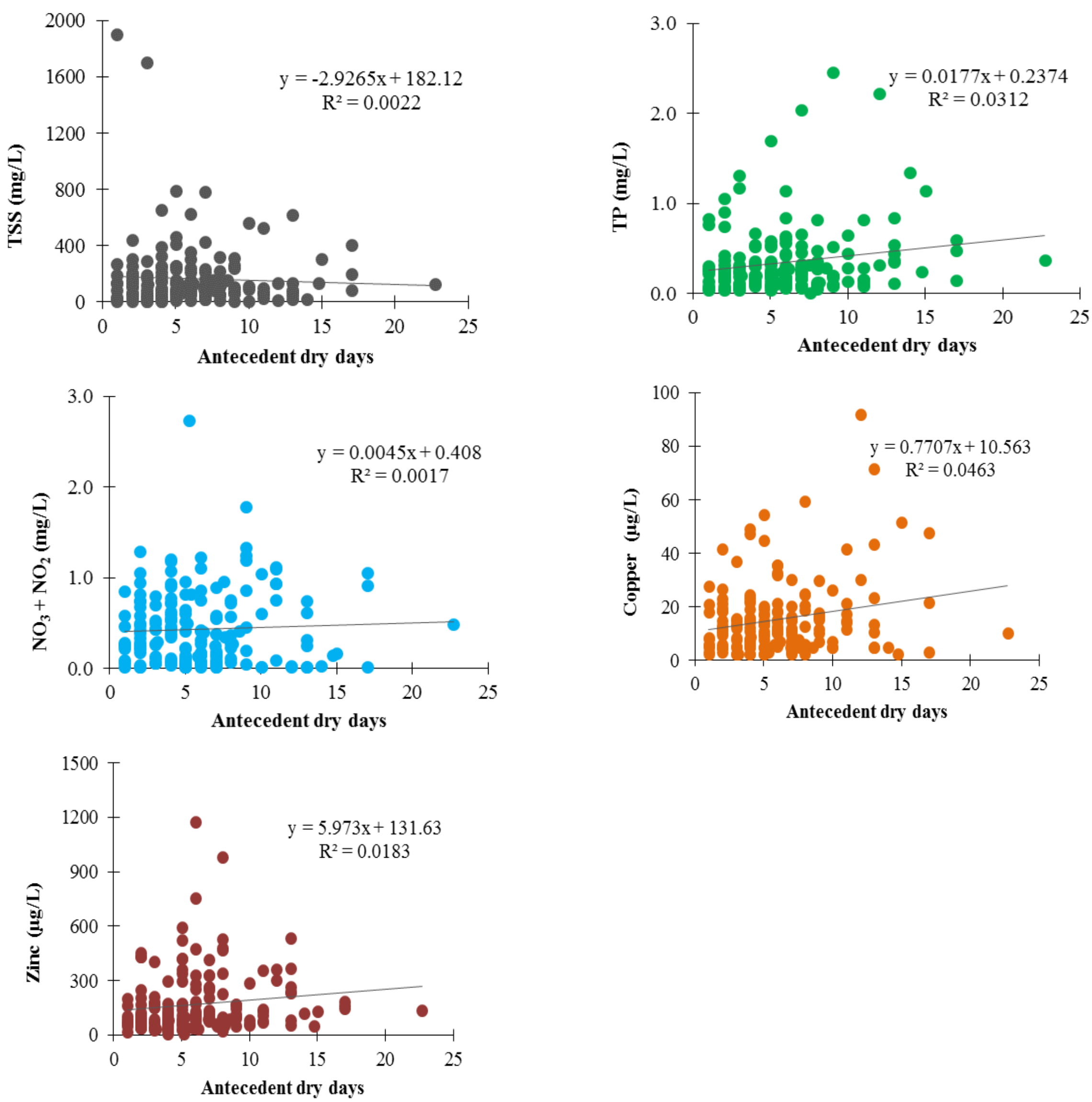


Figure 4.3. Scatter plots showing the relationship between antecedent dry period and concentrations of TSS, total phosphorus (TP), nitrate + nitrite, zinc, and copper in the initial runoff samples collected at the 10 sampling sites along low-volume roads.

Transport away from the road due to wind and vehicle turbulence can decrease the accretion of particles and associated constituents on the road surface and the EMCs (Kerri et al. 1985, Ball et al. 1998, Kayhanian et al. 2003, 2007, Li and Barrett 2008, Li et al. 2008). Another study (AADT~ 100,000) found that the build-up of runoff constituents on the road surface plateaued after about a seven-day dry period so that the runoff EMCs had no further increase even if the ADP continued beyond seven days (Finney et al. 2010).

4.1.4 Relationship with Average Daily Traffic (ADT)

For the 10 low-volume road sites sampled, none of the runoff constituent concentrations exhibited a noticeable linear correlation with the ADT at the sites (scatter plots are not shown). The range of ADT of 195 to 1450, however, is small and is the possible reason for the lack of a direct relationship between ADT and runoff concentrations. Even in high-volume roads, ADT alone could not explain the runoff concentrations but was found to be significant only in conjunction with other variables such as drainage area, antecedent dry period, seasonal cumulative rainfall, total event rainfall, rainfall maximum intensity, and land use (Kayhanian et al. 2003). Factors such as wind, vehicle turbulence, volatilization, and oxidation can limit the accretion of runoff constituents on road surfaces and thereby decrease the importance of ADT (Irish et al. 1995, Kayhanian et al. 2003). Instead, the number of vehicles passing during the rainfall event may have a greater impact on the runoff loads for certain constituents (Kerri et al. 1985). The number was vehicles passing the monitoring sites was, however, not quantified during the sampled events in this study.

4.1.5 Relationship with surrounding land cover

Of the 10 monitored sites, four sites have wooded land cover (Aitkin, Clearwater and St. Louis counties) and six sites have agricultural land cover (Cass, Chisago, Fairbault and Polk counties). Sampling in the Mississippi river headwaters showed that the roadway runoff concentrations were affected by surrounding land use (Table 4.1). Comparison between the 10 sites based on surrounding land cover showed that differences greater than 50% were present for TSS (mean values), TP (mean values), nitrite + nitrate, cadmium (median value) and zinc concentrations in the initial runoff from the adjacent roadways (Table 4.2).

Runoff from sites surrounded by agricultural land contained higher mean TP but significantly lower mean nitrite + nitrate concentrations than the wooded sites (Table 4.2). One reason could be that phosphorus is more persistent in farm soils when compared to dissolved nitrogen forms (i.e. nitrate and nitrite). Farm equipment such as tractors can transport soil particles on to the roadway or shoulder surface, which would wash off with runoff. This could also be the reason for the somewhat higher mean TSS at sites along farms. Agricultural fertilizer applications and atmospheric deposition can be a large source of nutrients in highway runoff (Driscoll et al. 1990b). Other studies have also noted high TSS and phosphorus concentrations in runoff from rural roads (ADT ~6000) with largely agricultural lands (Zhao and Li 2013, Mofett 2017).

The mean zinc level at the sites with agricultural land cover was more than twice the mean concentration at the wooded sites. The main sources of zinc in roadway runoff are tires, brake pads and galvanized items (Davis et al. 2001, Huber and Helmreich 2016). The predominant use of galvanized farm equipment likely explains the higher zinc in the runoff from sites located along agricultural fields. The mean concentrations of copper did not appear to be influenced by land use. Lead, copper, cadmium, chromium and nickel were very low (mostly below lab reporting limit) at all sites irrespective of the surrounding land cover.

Table 4.2. Median concentrations in the initial runoff sampled at the low-volume road sites surrounded by agricultural land cover (6 sites) and wooded land cover (4 sites) in 2018 and 2019. Values given in parentheses are mean ± standard deviation. n is the number of rainfall events sampled.

Runoff constituent	Low-volume road sites with wooded land cover		Low-volume road sites with agricultural land cover	
	n	Median (Mean ± SD)	*n*	Median (Mean ± SD)
TSS (mg/L)	77	93 (132 ± 128)	88	100 (176 ± 247)
TP (mg/L)	76	0.20 (0.25 ± 0.22)	97	0.27 (0.41 ± 0.45)
$NO_2 + NO_3$ (mg/L)	76	0.59 (0.64 ± 0.44)	97	0.16 (0.27 ± 0.29)
Total cadmium (µg/L)	77	0.38 (1.9 ± 3.1)	96	1.2 (1.8 ± 3.2)
Total chromium (µg/L)	77	5.0 (6.9 ± 7.3)	96	4.2 (4.7 ± 4.7)
Total copper (µg/L)	77	12 (16 ± 14)	96	12 (15 ± 14)
Total lead (µg/L)	77	3.1 (4.8 ± 3.4)	96	3.4 (5.3 ± 4.9)
Total nickel (µg/L)	77	9.9 (10 ± 5.7)	96	9.9 (12 ± 9.5)
Total zinc (µg/L)	77	75 (84 ± 65)	96	173 (236 ± 192)

The crop types in the agricultural fields during the 2018 and 2019 growing seasons were hay (CSAH 21), corn (CSAH 31), soybean (CSAH 1 and 86 in Chisago County), corn and soybean (CSAH 1 Fairbault County), and alfalfa and wheat (CSAH 133 in Polk County). Since there are only 1 or 2 sites per crop type, it is not clear if differences in runoff quality at the sites were caused by the crop type or other site-specific factors.

4.1.6 Relationship with soil type

Soil maps for the areas surrounding the runoff samplers were obtained using the Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS) tool. The soil types were fine sandy loam (CSAH 39 in Aitkin), loamy sand (CSAH 31 in Cass), sandy loam (CSAH 31 in Clearwater), silt loam (CSAH 4 in Aitkin and CSAH 21 in Chisago), silty clay loam (CSAH 1 in Fairbault), loam (CSAH 1 and 86 in Chisago), and mucky peat (CSAH 133 in St. Louis). Based on the USDA Soil Survey Manual (Soil Science Division Staff 2017), two broad soil texture classes were established by combining the subclasses of sandy loam (i.e., fine sandy loam, loamy sand, sandy loam) and loam (i.e., silt loam, loam, silty clay loam, sandy clay). Accordingly, data for the sandy loam sites (4 sites, 49 samples), loam sites (5 sites, 108 samples) and organic soil site (1 site, 17 samples) were analyzed (Figure 4.4).

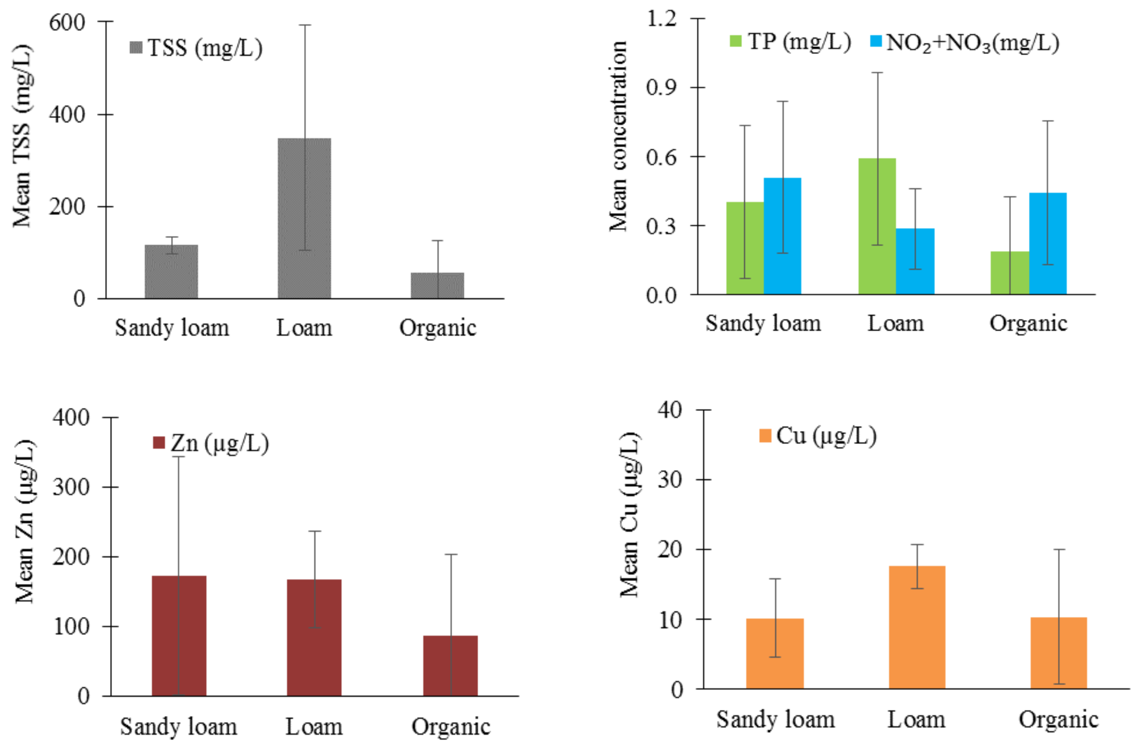


Figure 4.4. Mean concentrations in the initial runoff sampled at the low-volume road sites surrounded by sandy loam (4 sites), loam (5 sites), and organic soil (1 site) during the 2018 and 2019 rainfall events. The number of samples collected were 49 samples at sandy loam sites, 108 samples at loam sites and 17 samples at organic soil site. Error bars represent the standard deviation.

Sandy loam soil, which is moderately-coarse textured, typically contains a higher fraction of sand and a lower fraction of silt plus clay. Loam soil type, which is medium-textured, contains a higher composition of fines (silt and clay). The overall mean TSS and TP and metal levels in the initial runoff were higher at sites surrounded by loam soil, which can be explained by the possibilities that smaller particles are more likely to be transported to the road surface by wind, silt and clay fraction tend to stick to vehicle tires, and runoff constituents, especially metals, have a greater adherence per particle mass to finer soil particles due to a higher surface area per unit mass. The particle size of the solids accumulated on road surface is thus important, especially for metals (Lancaster 2005, Sansalone et al. 1998).

It must be noted that the sites with agricultural land use also had loam soil (5 out of 6 sites), and the wooded sites were covered by sandy loam (2 out of 4 sites). It is likely that the surrounding soil type and land use had a combined effect on the observed runoff constituent concentrations at the low-volume road sites. Although the individual impacts of land use and soil type on the runoff quality may not be obvious at the monitored sites, the importance of these two factors has been observed in urban and rural road runoff studies (Thiem et al. 1993, Gan et al. 2008, Zhao and Li 2013).

4.2 COMPARISON TO HIGH-VOLUME ROAD RUNOFF QUALITY

One overall challenge of this study was to determine if there is a significant difference between runoff water quality of roads with an AADT (or ADT) below 1500 versus those with an AADT in the tens of thousands. The initial concentrations of the runoff constituents sampled at the low-volume road sites were converted to the expected event mean concentrations (EMCs) using the EMC:first flush concentration ratio reported in Stenstrom and Kayhanian (2005). The Stenstrom and Kayhanian (2005) study quantified the impact of first flush on a series of constituents in stormwater runoff from high ADT highways, and their results were used to calculate a ratio of the EMC to the first flush concentration for the first 20% of the runoff (Table 4.3). Then, the ratio was multiplied by the median initial concentrations for the low-volume road runoff samples collected during the 174 events, to estimate a median EMC for each constituent. The estimated EMCs for the low-volume road runoff constituents were then compared to the median EMCs measured in high-volume highways in the US with ADT ranging from 2000 to 328,000 (Table 4.4).

Table 4.3. Ratio of EMC:first flush concentration reported in Stenstrom and Kayhanian (2005) (the ratio was calculated based on concentrations measured in the initial 20% of the storm).

	EMC:First flush concentration ratio Stenstrom and Kayhanian (2005)
TSS	0.58
TP	0.58
Nitrite + Nitrate	0.74
Cadmium	0.79
Chromium	0.82
Copper	0.61
Lead	0.81
Nickel	0.60
Zinc	0.60

Table 4.4. Median concentrations of TSS, TP, nitrite + nitrate (NO2 + NO3), total copper (Cu), and total zinc (Zn) in the runoff samples collected at the low-volume road sampling sites (EMC was calculated by adjusting the initial concentrations using ratios in Table 4.3).

Constituent	This study Median Initial concentration	This study Estimated Median EMC[1]	Median EMCs for high ADT highways			
			Kayhanian et al. (2007)[3]	Maestre and Pitt (2005)[2]	FHWA (1990)[4]	NURP (1983)[5]
Events sampled	174	174	635	185	n/a	n/a
TSS (mg/L)	94	55	59	99	93	180
TP (mg/L)	0.23	0.13	0.18	0.25	n/a	0.42
NO_2+NO_3 (mg/L)	0.34	0.25	0.60	0.28	0.66	0.60
Copper (µg/L)	12	7.3	21	35	39	43
Zinc (µg/L)	108	65	111	200	217	202

[1]Calculated by multiplying values in Table 4.3 with the initial concentration measured at the 10 low-volume road sites with 195–1450 vehicles/day.
[2]34 urban and non-urban highway sites with AADT in the range of 2000–328,000 vehicles/day monitored in CA, US.
[3]Freeway runoff concentrations from Maestre and Pitt (2005) (ADT not provided). The study characterized stormwater runoff quality for 3765 storm events at 360 monitoring sites with different land use types across the US.
[4]FHWA (Federal Highway Administration), 31 highway sites with AADT in the range of 4000–200,000 vehicles/day were monitored throughout the US.
[5]NURP (USEPA Nationwide Urban Runoff Program), 28 highway sites with AADT in the range of 5000–120,000 vehicles/day were monitored throughout the US.
n/a: data not available or data not known

The estimated EMCs for the low-volume road runoff were substantially lower in the median levels of nitrite + nitrate, copper and zinc when compared to CA highways (Kayhanian et al. 2007). When compared to the median freeway concentrations in the US (Maestre and Pitt 2005), the low-volume roads generated runoff containing much lower TSS, TP, copper, and zinc concentrations. The low-volume road runoff EMCs were much lower for all runoff constituents when compared to median levels in other highways across the US (NURP 1983, FHWA 1990). Overall, copper and zinc were the runoff constituents that had substantially lower median levels when compared to other urban highways. As discussed earlier, cadmium, lead, nickel and chromium were mostly (>50%) present at below detection limits and hence their median values were not calculated and not compared to other highway studies. This non-detect level is also below other highway studies.

The TSS concentrations can be higher in rural areas due to the impact of erosion and lower in urban areas that have more paved surfaces (Kayhanian et al. 2012, Zhao and Li 2013). However, in this study, the estimated TSS EMC for low-volume roads was generally lower than that of high ADT roads used for comparison. At the low-volume roads monitored, the surrounding agricultural or wooded lands were potential sources of soil and organic matter rich in nutrients. Nitrogen and phosphorus loads from traffic-related sources can be less than that from natural sources, such as soil and vegetation (Kayhanian et al. 2012), highlighting the importance of adjoining land use on nutrient concentrations in roadway runoff. This could be a possible explanation for similar TSS and TP EMC medians in the current study and CA highways (Kayhanian et al. 2007). Metal levels tend to be higher in urbanized areas with much higher vehicular sources (Kayhanian et al. 2007), which explains the substantially lower metal concentrations in the low-volume road runoff.

CHAPTER 5: RECOMMENDATIONS ON STORMWATER RUNOFF TREATMENT FOR PAVED RURAL ROADS

One of the objectives of this study is to use the results of runoff quality monitoring, along with existing knowledge of stormwater BMP cost, design, and performance, to develop recommendations to optimize the cost-effectiveness of stormwater management and treatment of runoff from low-volume, rural, paved roads. Data obtained from the county engineers in the Technical Advisory Panel (TAP) for this project indicated that roadside drainage ditches or swales (with or without check dams) are among the stormwater treatment practices implemented when stormwater treatment is required, typically due to the addition of 1 or more acres of new impervious surface for low-volume rural roadway projects (also see Chapter 7, Table 7.1).

Roadside drainage ditches/swales have the capability to reduce runoff volume and improve water quality. Volume reduction occurs primarily through infiltration into the soil, either as the water flows over the side slope perpendicular to the roadway into the swale or down the length of the swale parallel to the roadway. Swales have been shown to infiltrate a large fraction of stormwater runoff from the road surface (Barrett et al. 1998, Garcia-Serrana et al. 2017a, 2017b, 2017c). Infiltration measurements in five representative Minnesota swales have shown roadside swales as an effective means of infiltrating stormwater runoff (Ahmed et al. 2014). Up to 100% runoff volume reduction can be achieved by swales including infiltration in the side slope areas (Yousef et al. 1987, Lancaster 2005). In a review of data compiled in the International Stormwater BMP Database, Barrett (2008) found that, if the soil is permeable and the initial moisture content is low, the infiltration achieved by swales can approach 50% of the runoff volume in semiarid regions. Infiltration measured along a roadside embankment in Pullman, WA, showed that roadway runoff had infiltrated within the first 2 m from the edge of pavement (EOP) (Lancaster 2005), while another study recorded runoff volume reductions of 71% to 89% at 2 m from EOP and 66% to 94% at 4 m from EOP (Ahearn and Tveten 2008). In tight soils, however, runoff reduction has been as low as 9% (Yousef et al. 1987). Factors such as soil permeability, initial moisture content, compaction of soil, and presence of vegetation (plant or tree roots) affect the extent of volume reduction.

Runoff treatment in swales occurs by sedimentation of solid particles onto the soil surface, filtration of solid particles by vegetation, or infiltration of dissolved constituents in stormwater into the soil (Backstrom 2002, Abida and Sabourin 2006). Swales have been found to be very effective in reducing large particles in several field studies, resulting in 60 to 90% removal of TSS, as long as sediment erosion and resuspension does not occur. Removal of metals also occurs in swales; 18 to 87% for zinc, copper and lead, although mixed results have been observed for dissolved metals in some studies (Barrett 2008; Caltrans 2003). Variable treatment of nutrient species (total phosphorus, nitrate, total nitrogen) has been observed with > 60% reduction or export from the swales (Barrett 2008; Yonge 2000; Caltrans 2003; Ahearn and Tveten 2008; Stagge et al. 2012). Treatment of dissolved constituents is largely dependent on volume reduction by infiltration in the swales (Caltrans 2003; Barrett 2008). An extensive literature review on performance of swales for pollution prevention is presented by Ahmed et al. (2014).

Based on the infiltration capacity, roadside ditches/swales will reduce runoff volume and treat the runoff constituents. If concentrations in the runoff are low, such as for the low-volume roads, drainage ditches/swales will be effective stormwater treatment practices and more expensive treatment options likely will not be necessary. Runoff infiltrated by a swale can be assumed to have 100% of the constituents removed in the process (MPCA 2018), which increases its overall effectiveness in reducing runoff constituent loads. Several case studies on road widening projects have been modeled in Chapter 6 to show how roadside drainage ditches/swales can be used to satisfy the runoff volume capture requirements in existing roads and new road projects. As will be shown in Chapter 7 on detailed cost benefit analysis, drainage swales alone are less expensive to install and maintain, especially when the swale is in the right-of-way and purchase of additional land for stormwater treatment is not necessary. Swales will thus have a lower overall total project cost compared to other treatment practices. In fact, swales are considerably less expensive and remove more runoff constituents than wet ponds, which are widely used due to their low cost and relatively high removal effectiveness.

CHAPTER 6: CASE STUDIES ON MEETING STORMWATER MANAGEMENT REQUIREMENTS FOR PAVED RURAL ROADS USING ROADSIDE SWALES

Because this study seeks to make recommendations for the optimization of stormwater treatment practices for paved rural roads, this section investigates sample road widening projects, (case studies), and how corresponding stormwater management requirements can best be achieved by roadside swales. The key requirement for each case study is the Minnesota Pollution Control Agency's (MPCA's) Minimal Impact Design Standards (MIDS) requirement for linear projects (without restrictions and of one acre or more) that 1.1 inches of runoff from the net increase in impervious area be captured and retained (MPCA 2020). The requirement for road reconstruction projects is based on 1.0 inch of runoff from the increase in impervious area but, for the sake of the case studies, the MIDS requirement of 1.1 inches is used and is a conservative assumption. Thus, the requirement for each case study is that the newly constructed road, as compared to the existing road, has an increase in volume reduction credit of 1.1 inch multiplied by the increase in impervious area. For example, a road project that increases the impervious area by 10,000 ft^2 would have to provide an additional 917 ft^3 (i.e., 10,000 x 1.1/12) of volume reduction credit. To investigate how this requirement can best be achieved, the MIDS calculator (MPCA 2020) was used. In a separate analysis for confirmation and comparison, Minnesota's Roadside Swale Calculator (RSC) (SAFL 2019) was also used in these case studies.

One difference between the MIDS calculator and the RSC is the amount of infiltration that occurs in the swale side slope within each model. In MIDS calculator models, swale side slopes account for a small fraction of the overall infiltration and, therefore, the side slopes account for a small fraction of the volume reduction credit that occurs in combined swale side slopes and swale main channels. In research studies, however, swale side slopes have been found to account for a significant fraction of the infiltration that occurs in roadside swales. For example, Lancaster (2005), who investigated infiltration along roadside swales in the State of Washington, reported 100% infiltration of runoff within the first two meters from the edge of pavement at one site (36 precipitation events). At a different site, 67% of the 18 monitored rainfall events produced no observed runoff. Ahearn and Tveten (2008) investigated the performance of four, 41 year old, unimproved roadside swales. Volume reduction four meters from the edge of pavement ranged from 66% to 94%. Finally, Garcia-Serrana et al. (2016, 2017) performed experiments on the side slopes of roadside swales to determine their infiltration capability. For flows that corresponded to the two-year storm event, the average percent of water infiltrated ranged from 70% (in the fall) to 84.7% (in the spring). For ten-year storm event tests, the average percent of water infiltrated was 47.1% and for the one-year storm event tests, the average amount of water infiltrated on the side slope of roadside swales was 68.7%. The work by Garcia-Serrana et al. (2016, 2017) was part of the development of the RSC (Garcia-Serrana et al. 2018).

The case studies that were investigated are as follows:

<u>Case Study 1</u>

Location: Rochester, MN, zip code = 55902, annual MIDS rainfall = 32.2”
Existing Road: 12’ lane, 2’ shoulder, 5:1 side slope, 3’ swale depth, 3’ bottom width
New Road: 12’ lane, 5’ shoulder, 4:1 side slope, 3’ swale depth, 3’ bottom width

Case Study 2

Location: Grand Marais, MN, zip code = 55604, annual MIDS rainfall = 29.5”
Existing Road: 12’ lane, 2’ shoulder, 3:1 side slope, 4’ swale depth, 2’ bottom width
New Road: 12’ lane, 5’ shoulder, 4:1 side slope, 4’ swale depth, 8’ bottom width

Case Study 3

Location: Thief River Falls, MN, zip code = 56701, annual MIDS rainfall = 22.2”
Existing Road: 12’ lane, no shoulder, 3:1 side slope, 3’ swale depth, 2’ bottom width
New Road: 12’ lane, 5’ shoulder, 4:1 side slope, 4’ swale depth, 8’ bottom width

Case Study 4

Location: Itasca, MN, zip code = 56458, annual MIDS rainfall = 26.4”
Existing Road: 12’ lane, 2’ shoulder, 3:1 side slope, 4’ swale depth, 8.5’ bottom width
New Road: 12’ lane, 5’ shoulder, 5:1 side slope, 4’, swale depth, 10’ bottom width

Case Study 5

Location: St. Cloud, MN, zip code = 56395, annual MIDS rainfall = 26.7”
Existing Road: 12’ lane, 2’ shoulder, 3:1 side slope, 4’ swale depth, 8.5’ bottom width
New Road: 12’ lane, 5’ shoulder, 5:1 side slope, 4’, swale depth, 10’ bottom width.

6.1 CASE STUDY 1

This case study involves the following scenario in Rochester, MN that, according to the MIDS calculator, has an average annual rainfall depth of 32.2 inches:

Existing Road: 12 ft lane, 2 ft shoulder, 5:1 (h:v) swale side slope, 3 ft swale depth, and 3 ft swale bottom width,

New Road: 12 ft lane, 5 ft shoulder, 4:1 swale side slope, 3 ft swale depth, and 3 ft swale bottom width.

As will be done with the other case studies, a one mile long section of road was investigated. Based on the conditions stated above, the new road had an additional 3 ft of impervious area across its width. When multiplied by 5280 ft/mile, the increase in impervious area is 15,840 ft^2. With 1.1 inches of runoff from this increase in impervious area, the new road must capture and retain an additional 1,450 ft^3 (within rounding error) of runoff when compared to the existing road. First, the MIDS calculator was used to investigate if, or how, the new road can meet this requirement. Later, the RSC was used to answer the same question.

6.1.1 **MIDS Calculator – Case Study 1**

Initially, this scenario was modeled in one road segment with a road, shoulder, side slope, and swale main bottom length of 5,280 ft. Two stormwater best management practices (BMPs) were used, a swale side slope and a swale main channel that receives runoff from the swale side slope. The scenario was run for all hydrologic soil groups (HSG). Values of saturated hydraulic conductivity associated with each HSG are provided in the *Minnesota Stormwater Manual* (MPCA 2020) as follows: HSG A: 1.63 in/hr, HSG B: 0.45 in/hr, HSG C: 0.2 in/hr, and HSG D: 0.06 in/hr. These values cover the range of K_{sat} available in the MIDS calculator. The main channel slope was 3% and the swale side was assumed to be mowed turf while the swale main channel was assumed to be native grass.

Based on the impervious area increase when comparing the existing road to the new road, an additional 1,450 ft^3 needs to be retained on the new road. This value can also be obtained from the MIDS calculator, by taking the difference between the "Retention Volume Requirement" (RVR) for both scenarios. The MIDS RVR for the existing and new roads were 6,776 ft^3 and 8,226 ft^3, respectively. For each K_{sat} modeled, the MIDS "Volume Removed by BMPs" (VR-BMP) was also 6,776 ft^3 and 8,226 ft^3, respectively. This means that, according to this MIDS calculator model, the new road will satisfy the requirement that 1.1 inch of runoff from the increase in impervious area be captured and retained for the range of K_{sat} values available in the MIDS calculator. Complete MIDS calculator summary reports for all scenarios are available in Appendix B.

A discrepancy in the MIDS calculator results, however, was observed when the same 5,280 ft long sections of road were each (existing and new cases) modeled as five, 1,056 ft long separate but connected segments. In this model, the upstream-most swale side slope discharged into the upstream most swale main channel, the next downstream swale side slope discharged into the next downstream main channel, and so on for all five segments. In addition to each swale side slope discharging into its corresponding swale main channel, the upstream most swale main channel discharged into the next downstream swale main channel, that swale main channel discharged into the next downstream main channel, and so on all the way down the channel. The areas of each swale side slope and swale main channel were reduced by a factor of five so that the total area remained constant and corresponded to a one mile long road. All other variables such as swale main channel slope, the slope of the swale side, etc., were not changed from the corresponding one-segment model. Figure 6.1 shows the MIDS calculator BMP schematic for the five-segment modeling scenario.

In the five-segment models, the RVR for the existing and new roads were again 6,776 ft^3 and 8,226 ft^3, respectively. Results for VR-BMP for each of the four HSGs and the additional volume that must be captured by the new road to meet requirements are shown in Potential BMPs to provide the required additional capture volume that are available within the MIDS calculator and that would not require the purchase of additional right-of-way include non-permeable check dams and a bioretention base, both of which would be input as part of the swale main channel BMP. Because drawdown times would likely be prohibitive in poorly draining soils (i.e., HSG C and D), a bioretention base was investigated as a method to meet volume capture requirements. In the HSG D scenario, the additional required capture volume of 1,373 ft^3 was achieved by making a 1,556 ft long section of the swale bottom at the downstream end of the swale (i.e., 4,668 ft^2 of surface area of the swale bottom) a bioretention base with a depth of one foot and a porosity of 0.30. With this bioretention provided, the total capture volume determined by the MIDS calculator for the new road was 2,972 ft^3, which now provides enough volume to meet requirements. Of course, other bioretention depths, bioretention porosities, and bioretention areas could be used to meet requirements. Other BMPs such as an infiltration basin, permeable pavement, or underground infiltration may also provide the additional required capture volume but may not be practical for some road projects due to required additional land purchases or other expenses and complications. It must be noted that the MPCA stormwater permit “prohibits permittees from constructing infiltration systems in areas of predominately Hydrologic Soil Group type D soils (clay)” (per Section 16.7), and that the “permit does not consider wet sedimentation basins and filtration systems to be volume reduction practices” (per Section 15.5). BMPs outside of the right-of-way, such as wet or dry ponds, could also be used to meet stormwater runoff requirements as long as the soil is not HSG D.

Table 6.1. As shown in Potential BMPs to provide the required additional capture volume that are available within the MIDS calculator and that would not require the purchase of additional right-of-way include non-permeable check dams and a bioretention base, both of which would be input as part of the swale main channel BMP. Because drawdown times would likely be prohibitive in poorly draining soils (i.e., HSG C and D), a bioretention base was investigated as a method to meet volume capture requirements. In the HSG D scenario, the additional required capture volume of 1,373 ft^3 was achieved by making a 1,556 ft long section of the swale bottom at the downstream end of the swale (i.e., 4,668 ft^2 of surface area of the swale bottom) a bioretention base with a depth of one foot and a porosity of 0.30. With this bioretention provided, the total capture volume determined by the MIDS calculator for the new road was 2,972 ft^3, which now provides enough volume to meet requirements. Of course, other bioretention depths, bioretention porosities, and bioretention areas could be used to meet requirements. Other BMPs such as an infiltration basin, permeable pavement, or underground infiltration may also provide the additional required capture volume but may not be practical for some road projects due to required additional land purchases or other expenses and complications. It must be noted that the MPCA stormwater permit “prohibits permittees from constructing infiltration systems in areas of predominately Hydrologic Soil Group type D soils (clay)” (per Section 16.7), and that the “permit does not consider wet sedimentation basins and filtration systems to be volume reduction practices” (per Section 15.5). BMPs outside of the right-of-way, such as wet or dry ponds, could also be used to meet stormwater runoff requirements as long as the soil is not HSG D.

Table 6.1, the new road alone does not meet volume capture requirements for any of the scenarios modeled. Based on these results, additional capture volume must be provided for all HSGs.

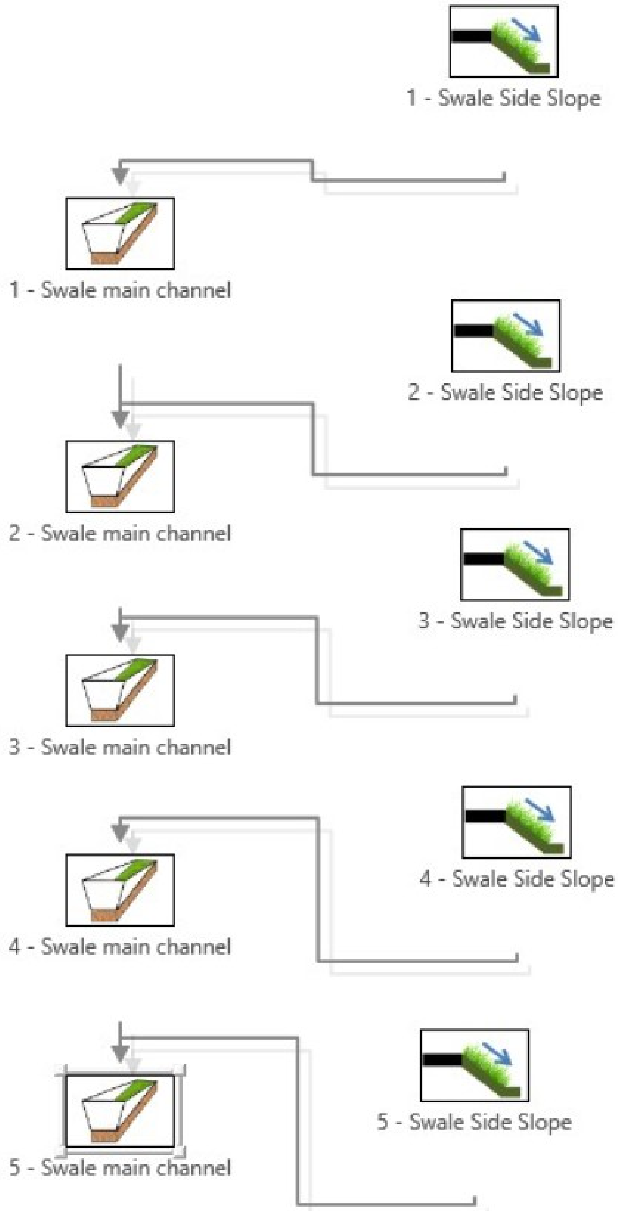


Figure 6.1 MIDS calculator swale BMP schematic for five-segment model.

Potential BMPs to provide the required additional capture volume that are available within the MIDS calculator and that would not require the purchase of additional right-of-way include non-permeable check dams and a bioretention base, both of which would be input as part of the swale main channel BMP. Because drawdown times would likely be prohibitive in poorly draining soils (i.e., HSG C and D), a bioretention base was investigated as a method to meet volume capture requirements. In the HSG D scenario, the additional required capture volume of 1,373 ft^3 was achieved by making a 1,556 ft long section of the swale bottom at the downstream end of the swale (i.e., 4,668 ft^2 of surface area of the swale bottom) a bioretention base with a depth of one foot and a porosity of 0.30. With this bioretention provided, the total capture volume determined by the MIDS calculator for the new road was 2,972 ft^3, which now provides enough volume to meet requirements. Of course, other bioretention depths, bioretention porosities, and bioretention areas could be used to meet requirements. Other BMPs such as an infiltration basin, permeable pavement, or underground infiltration may also provide the additional required capture volume but may not be practical for some road projects due to required additional land purchases or other expenses and complications. It must be noted that the MPCA stormwater permit “prohibits permittees from constructing infiltration systems in areas of predominately Hydrologic Soil Group type D soils (clay)” (per Section 16.7), and that the “permit does not consider wet sedimentation basins and filtration systems to be volume reduction practices” (per Section 15.5). BMPs outside of the right-of-way, such as wet or dry ponds, could also be used to meet stormwater runoff requirements as long as the soil is not HSG D.

Table 6.1.Summary of 5-segment swale model MIDS calculator results for Case Study 1.

HSG (K_{sat} in/hr)	Value	Existing Road RVR = 6,776 ft^3	New Road RVR = 8,226 ft^3	Additional Capture Volume Required
A (1.63)	VR-BMP	2702	3295	857
	Volume Remaining	4074	4931	
B (0.45)	VR-BMP	2403	2728	1125
	Volume Remaining	4373	5498	
C (0.20)	VR-BMP	1763	1970	1243
	Volume Remaining	5013	6256	
D (0.06)	VR-BMP	1465	1542	1373
	Volume Remaining	5311	6684	

RVR = Reduction Volume Required
VR-BMP = Volume Reduction Credited to BMPs

6.1.2 Roadside Swale Calculator – Case Study 1

Due to the discrepancy in the MIDS calculator results previously discussed, the Roadside Swale Calculator (RSC) was used to estimate capture volumes for the same 5,280 ft long existing and new road sections previously described in Case Study 1.

The RSC uses historical rainfall records based on location, the width of the swale to width of the road ratio, and the saturated hydraulic conductivity (K_{sat}) of the soil to estimate the fraction of annual runoff infiltrated (i.e. captured) by the swale side slope and a swale bottom width of 1.64 ft. The swale bottom width is a constant in the RSC and cannot be adjusted by the user. None of the five case studies, however, had a swale bottom width of 1.64 ft. Thus, in order to apply the RSC to the case studies, the cross-section of both the new and existing roads was approximated by extending the swale side slope from the edge of the road shoulder to the location on the swale bottom that corresponded to a swale bottom width equal to 1.64 ft. Figure 6.2 shows a schematic of this approximation for the existing road in Case Study 1.

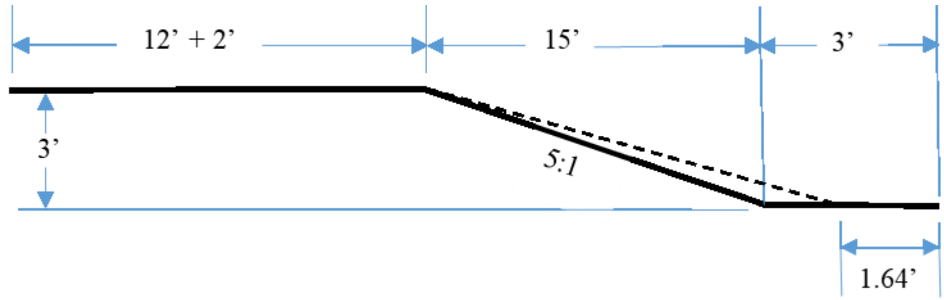


Figure 6.2.Schematic of approximated cross-section used for the existing road in the Roadside Swale Calculator for Case Study 1 (not to scale).

In Figure 6.2, the thick, solid black lines show the actual cross-section of the case study. The dashed black line shows the side slope of the swale used in the RSC approximated cross-section. The value of swale width used in the RSC was based on the side slope shown by the dashed line. Because the approximated cross-section had slightly less length of swale side slope and swale bottom than the actual cross-section, the road corresponding to the approximated cross-section had slightly less area available for infiltration than the actual cross-section. This made the approximated cross-section slightly conservative. The difference in available area, however, in all case studies was 1% or less. The approximated cross-sections were used in the RSC to calculate the fraction of annual rainfall infiltrated by the swale side slope and swale bottom.

The adjustment of the swale side slope to accommodate the constant swale bottom width in the RSC also affected the infiltration in another manner. The side slopes infiltrate a percentage of what the swale bottom would because Garcia-Serrana et al. (2017) found that the side slope was only partially covered with water, i.e., water coming off the road forms "fingers" as it flows down the slope towards the swale bottom, and the smaller area available for infiltration was incorporated that into the swale calculator. The difference is a more conservative (lower) infiltration rate in the RSC, and the difference becomes larger with an increase in the true case study bottom width above 1.64 ft.

To determine a corresponding capture volume (VR-BMP) from the percent of annual rainfall infiltrated, the same method used by the MIDS calculator was used in the RSC analysis. In that method, a MIDS "performance curve" corresponding to the given K_{sat} value (and available as part of the MIDS calculator instructions, MPCA 2020) was used. Figure 6.3 shows the performance curve for a K_{sat} value of 1.63 in/hr.

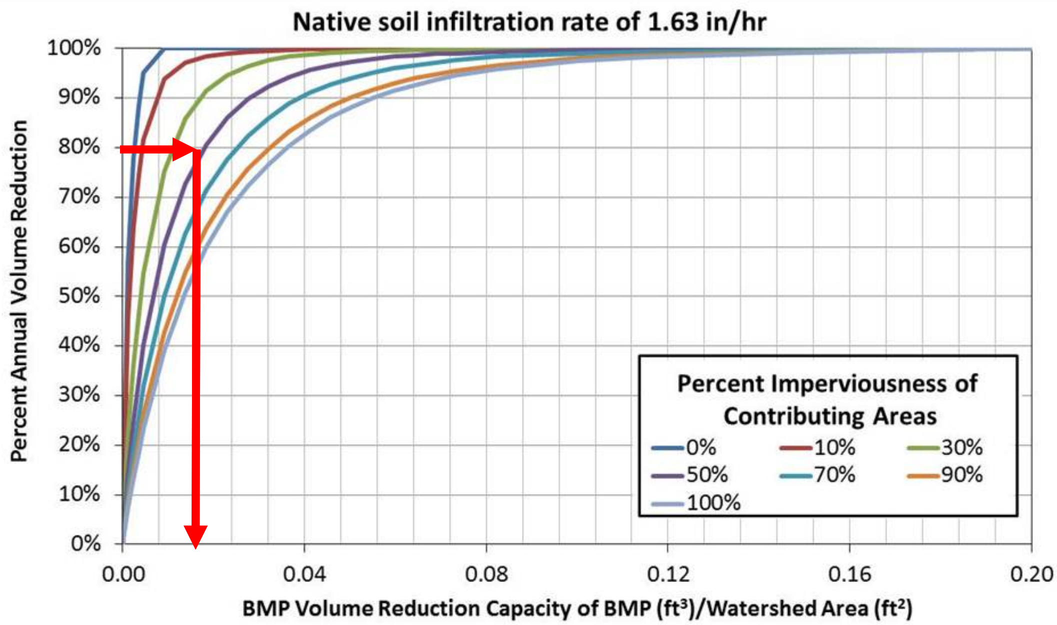


Figure 6.3. Performance Curve for Ksat equal to 1.63 in/hr (MPCA 2020).

The method involves entering the corresponding performance curve on the vertical axis at the percent annual runoff infiltrated (i.e., percent annual volume reduction on Figure 6.3), moving horizontally to the right to the corresponding "Percent Impervious of Contributing Area" curve, which was 43.7% for the existing road and 53.1% for the new road. The percent impervious for each case was based on the horizontal distances of road width, shoulder width, side slope width, and the swale bottom, with the road and shoulder being impervious. For example, the percent impervious of the existing road in this case study was calculated be taking the total impervious width of 14 ft (12 ft of road plus 2 ft of shoulder) and dividing it by the total cross-section horizontal width of 32 ft (14 ft of impervious plus 15 ft of swale side slope plus 3 ft of swale bottom). Once at the appropriate curve or, by linear interpolation, at the appropriate location between curves, one then drops vertically to the horizontal axis to read the corresponding value of "BMP Volume Reduction Capacity (ft^3)/Watershed Area (ft^2)." The value read from the horizontal axis is then multiplied by the total watershed area (ft^2) to determine the Volume Reduction Capacity (ft^3) of the BMP (i.e., VR-BMP). For example (as shown by the red arrows on Figure 6.3), if the percent annual volume reduction calculated by the RSC was 80% and the watershed was 40% impervious, the value read from the horizontal axis would be approximately 0.0152 (ft^3/ft^2).

Values for K_{sat} of 0.45 in/hr were linearly interpolated between values from performance curves corresponding to K_{sat} of 0.6 in/hr and 0.3 in/hr because no performance curve was available in the MIDS calculator for K_{sat} of 0.45 in/hr. Similarly, for HSG D soils with K_{sat} of 0.06 in/hr, values were linearly interpolated between values corresponding to the performance curve for K_{sat} of 0.2 in/hr and zero. The value obtained from the performance curve(s) was then multiplied by the total watershed area to determine the volume reduction capacity, or VR-BMP, of the roadside swale. The total watershed area used for this calculation was determined by multiplying the total horizontal width (i.e., the sum of the road, shoulder, side slope, and swale bottom) by a length of 5,280 ft.

Table 6.2 shows RSC results for Case Study 1. As with the MIDS calculator, the RSC shows that additional capture volume is required for all soil types.

Table 6.2. Roadside swale calculator results for volume reduction capacity (VR-BMP) of existing and new roads for Case Study 1.

HSG	K_{sat} (in/hr)	Rochester, MN		Additional Capture Volume Required (ft^3)
		Existing	New	
HSG A	1.63	4190	4866	776
HSG B	0.45	3176	3143	1486
HSG C	0.20	2433	2298	1587
HSG D	0.06	385	385	1452

6.2 CASE STUDY 2

This case study involves the following scenario in Grand Marais, MN, that, according to the MIDS calculator, has an average annual rainfall depth of 29.5 inches:

Existing Road: 12 ft lane, 2 ft shoulder, 3:1 (h:v) swale side slope, 4 ft swale depth, and 2 ft swale bottom width,

New Road: 12 ft lane, 5 ft shoulder, 4:1 swale side slope, 4 ft swale depth, and 8 ft swale bottom width.

As with the other case studies, a one mile long section of road was investigated. Based on the conditions stated above, the new road had an additional 3 ft of impervious area across its width. When multiplied by 5280 ft/mile, the increase in impervious area is 15,840 ft^2. With 1.1 inches of runoff from this increase in impervious area, the new road must capture and retain an additional 1,458 ft^3 (within rounding error) of runoff when compared to the existing road. In comparison to Case Study 1, slight differences were observed due to rounding. In comparison to Case Study 1, slight differences were observed due to rounding. First, the MIDS calculator was used to investigate if, or how, the new road can meet this requirement. Later, the RSC was used to answer the same question.

6.2.1 MIDS Calculator – Case Study 2

Initially, this scenario was modeled in one road segment with a road, shoulder, side slope, and swale main bottom length of 5,280 ft. Two stormwater best management practices (BMPs) were used, a swale side slope and a swale main channel that receives runoff from the swale side slope. The scenario was run for all hydrologic soil groups (HSG). Values of saturated hydraulic conductivity associated with each HSG were as follows: HSG A: 1.63 in/hr, HSG B: 0.45 in/hr, HSG C: 0.2 in/hr, and HSG D: 0.06 in/hr. These values cover the range of K_{sat} available in the MIDS calculator. Also, the main channel slope was 3% and the swale side slide was assumed to be mowed turf while the swale main channel was assumed to be native grass.

Based on the impervious area increase when comparing the existing road to the new road, an additional 1,458 ft^3 (within rounding error) needs to be retained by the new road. This value can also be obtained from the MIDS calculator by taking the difference between the MIDS "Retention Volume Requirement" (RVR) for both scenarios. The MIDS RVR values for the existing and new roads were 6,768 ft^3 and 8,226 ft^3, respectively. For each K_{sat} modeled, the MIDS "Volume Removed by BMPs" (VR-BMP) for the existing and new roads were also 6,768 ft^3 and 8,226 ft^3, respectively. This means that, according to the MIDS calculator, the new road will satisfy the requirement that 1.1 inch of runoff from the increase in impervious area be captured and retained for the range of K_{sat} values available in the MIDS calculator. Complete MIDS calculator summary reports for all scenarios are available in Appendix B.

The discrepancy in MIDS calculator results, described in Case Study 1, resulted in the 5,280 ft long sections of road being modeled as five, 1,056 ft long separate but connected segments. In the five-segment models, the RVR for the existing and new roads were 6,768 ft^3 and 8,226 ft^3, respectively. Results for VR-BMP for each of the HSGs are shown in Table 6.3. In this case, only the new road in HSG A had a VR-BMP value equal to its RVR value. In the one-segment model, however, this occurred for all HSGs for both the new and existing road.

As shown in Table 6.3, in all scenarios, even though the new road increased the RVR, the increase in the capture volume associated with the new road is greater than the increase in RVR (i.e., greater than 1458 ft^3). Thus, based on these results, the new road alone satisfies the requirement of retaining an additional 1.1 inch of runoff from the increase in impervious surface area. This is true for all HSGs. The increase in capture volume for the new road is due to an increased swale side slope length and an increase in the channel bottom width, both of which allow for more infiltration to occur. In the MIDS calculator, the swale main channel is given much more infiltration capacity than the swale side slope, so most of the benefit of the new road is due to the increase in the swale bottom width in this case study when using the MIDS calculator.

Table 6.3.Summary of 5-segment swale model MIDS calculator results for Case Study 2.

HSG (K_{sat} in/hr)	Value	**Existing Road** RVR = 6,768 ft^3	**New Road** RVR = 8,226 ft^3	Additional Capture Volume Required
A (1.63)	VR-BMP	2490	8226	0
	Volume Remaining	4278	0	
B (0.45)	VR-BMP	2056	4453	0
	Volume Remaining	4712	3773	
C (0.20)	VR-BMP	1447	3503	0
	Volume Remaining	5321	4723	
D (0.06)	VR-BMP	1113	3263	0
	Volume Remaining	5655	4963	

RVR = Reduction Volume Required
VR-BMP = Volume Reduction Credited to BMPs

6.2.2 Roadside Swale Calculator – Case Study 2

Due to the discrepancy in the MIDS calculator results previously discussed, the Roadside Swale Calculator (RSC) was used to estimate capture volumes for the same 5,280 ft long existing and new road sections previously described in Case Study 2.

The RSC uses historical rainfall records based on location, the width of the swale to width of the road ratio, and the saturated hydraulic conductivity (K_{sat}) of the soil to estimate the fraction of annual runoff infiltrated (i.e., captured) by the swale side slope and a swale bottom width of 1.64 ft. The swale bottom width is a constant in the RSC and cannot be adjusted by the user. None of the five case studies, however, had a swale bottom width of 1.64 ft. Thus, in order to apply the RSC to the case studies, the cross-section of both the new and existing roads was approximated by extending the swale side slope from the edge of the road shoulder to the location on the swale bottom that corresponded to a swale bottom width equal to 1.64 ft. Figure 6.4 shows a schematic of this approximation for the existing road in Case Study 2.

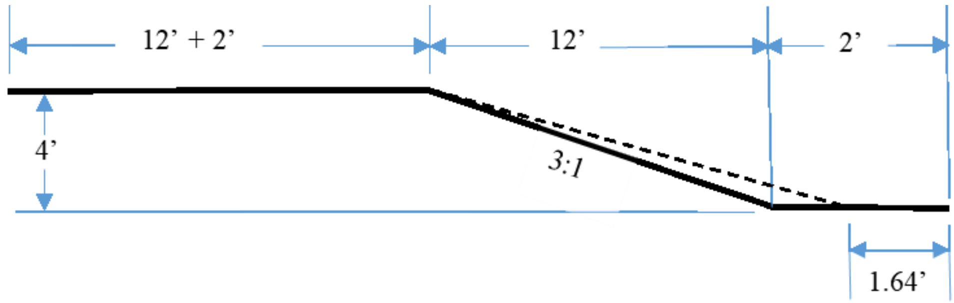


Figure 6.4. Schematic of approximated cross-section used for the existing road in the Roadside Swale Calculator for Case Study 2 (not to scale).

In Figure 6.4, the thick, solid black lines show the actual cross-section of the case study. The dashed black line shows the side slope of the swale used in the RSC approximated cross-section. The value of swale width used in the RSC was based on the side slope shown by the dashed line. Because the approximated cross-section had slightly less length of swale side slope and swale bottom than the actual cross-section, the road corresponding to the approximated cross-section had slightly less area available for infiltration than the actual cross-section. This made the approximated cross-section slightly conservative. The difference, however, in all case studies was 1% or less. The approximated cross-sections were used in the RSC to calculate the fraction of annual rainfall infiltrated by the swale side slope and swale bottom.

To determine a corresponding capture volume (VR-BMP) from the percent of annual rainfall infiltrated, the same method used by the MIDS calculator was used in the RSC analysis. In that method, a MIDS "performance curve" corresponding to the given K_{sat} value (and available as part of the MIDS calculator instructions, MPCA 2020) was used. Figure 6.3 shows the performance curve for a K_{sat} value of 1.63 in/hr.

The method involves entering the corresponding performance curve on the vertical axis at the percent annual runoff infiltrated (i.e. percent annual volume reduction on Figure 6.3), moving horizontally to the right to the corresponding "Percent Impervious of Contributing Area" curve, which was 50.0% for the existing road and 41.5% for the new road. The percent impervious for each case was based on the horizontal distances of road width, shoulder width, side slope width, and the swale bottom, with the road and shoulder being impervious. For example, the percent impervious of the existing road in this case study was calculated be taking the total impervious width of 14 ft (12 ft of road plus 2 ft of shoulder) and dividing it by the total cross-section horizontal width of 28 ft (14 ft of impervious plus 12 ft of swale side slope plus 2 ft of swale bottom). Once at the appropriate curve or, by linear interpolation, at the appropriate location between curves, one then drops vertically to the horizontal axis to read the corresponding value of "BMP Volume Reduction Capacity (ft^3)/Watershed Area (ft^2)." The value read from the horizontal axis is then multiplied by the total watershed area (ft^2) to determine the Volume Reduction Capacity (ft^3) of the BMP (i.e. VR-BMP). For example and as shown by the red arrows on Figure 6.3, if the percent annual volume reduction as calculated by the RSC was 80% and the watershed was 40% impervious, the value read from the horizontal axis would be approximately 0.0152 (ft^3/ft^2).

Values for K_{sat} of 0.45 in/hr were linearly interpolated between values from performance curves corresponding to K_{sat} of 0.6 in/hr and 0.3 in/hr because no performance curve was available for K_{sat} of 0.45 in/hr. Similarly, for HSG D soils with K_{sat} of 0.06 in/hr, values were linearly interpolated between values corresponding to the performance curve for K_{sat} of 0.2 in/hr and zero. The value obtained from the performance curve(s) was then multiplied by the total watershed area to determine the volume reduction capacity, or VR-BMP, of the roadside swale. The total watershed area used for this calculation was determined by multiplying the total horizontal width (i.e., the sum of the road, shoulder, side slope, and swale bottom) by a length of 5,280 ft.

Table 6.4 shows RSC results for Case Study 2. As with the MIDS calculator, the RSC determined that no additional capture volume was required for HSG A, B, and C. For HSG D, however, the MIDS calculator found that no additional capture volume was required but the RSC determined that an additional 1,183 ft^3 of capture volume was required. Thus, there is a large difference between the MIDS calculator and the RSC for HSG D.

Table 6.4. Roadside swale calculator results for volume reduction capacity (VR-BMP) of existing and new roads for Case Study 2.

HSG	Ksat (in/hr)	Rochester, MN		Additional Capture Volume Required (ft^3)
		Existing	New	
HSG A	1.63	4613	6927	0
HSG B	0.45	3134	5109	0
HSG C	0.20	2306	3983	0
HSG D	0.06	355	623	1183

6.3 CASE STUDY 3

This case study involves the following scenario in Thief River Falls, MN, that, according to the MIDS calculator, has an average annual rainfall depth of 22.2 inches:

Existing Road: 12 ft lane, no shoulder, 3:1 swale side slope, 3 ft swale depth, and 2 ft swale bottom width,

New Road: 12 ft lane, 5 ft shoulder, 4:1 swale side slope, 4 ft swale depth, and 8 ft swale bottom width.

As with the other case studies, a one mile long section of road was investigated. Based on the conditions stated above, the new road had an additional 5 ft of impervious area across its width. When multiplied by 5280 ft/mile, the increase in impervious area is 26,400 ft^2. With 1.1 inches of runoff from this increase in impervious area, the new road must capture and retain an additional 2,416 ft^3 (within rounding error) when compared to the existing road. First, the MIDS calculator was used to investigate if, or how, the new road can meet this requirement. Later, the RSC was used to answer the same question.

6.3.1 MIDS Calculator – Case Study 3

Initially, this scenario was modeled in one road segment with a road, shoulder, side slope, and swale main bottom length of 5,280 ft. Two stormwater best management practices (BMPs) were used, a swale side slope and a swale main channel that receives runoff from the swale side slope. The scenario was run for all hydrologic soil groups (HSG). Values of saturated hydraulic conductivity associated with each HSG were as follows: HSG A: 1.63 in/hr, HSG B: 0.45 in/hr, HSG C: 0.2 in/hr, and HSG D: 0.06 in/hr. These values cover the range of K_{sat} available in the MIDS calculator. Also, the main channel slope was 3% and the swale side slide was assumed to be mowed turf while the swale main channel was assumed to be native grass.

Based on the impervious area increase when comparing the existing road to the new road, an additional 1,458 ft^3 (within rounding error) needs to be retained by the new road. This value can also be obtained from the MIDS calculator by taking the difference between the MIDS "Retention Volume Requirement" (RVR) for both scenarios. The MIDS RVR values for the existing and new roads were 5,810 ft^3 and 8,226 ft^3, respectively. For each K_{sat} modeled, the MIDS "Volume Removed by BMPs" (VR-BMP) for the existing and new roads were also 5,810 ft^3 and 8,226 ft^3, respectively. This means that, according to the MIDS calculator, the new road will satisfy the requirement that 1.1 inch of runoff from the increase in impervious area be captured and retained for the range of K_{sat} values available in the MIDS calculator. Complete MIDS calculator summary reports for all scenarios are available in Appendix B.

The discrepancy in MIDS calculator results, described in Case Study 1, resulted in the 5,280 ft long sections of road being modeled as five, 1,056 ft long separate but connected segments. In the five-segment models, the RVR for the existing and new roads were again 5,810 ft^3 and 8,226 ft^3, respectively. Results for VR-BMP for each of the HSGs are shown in Table 6.5. For HSGs A, B, and D, even though the new road increased the RVR, the increase in the capture volume associated with the new road is greater than the increase in RVR (i.e., greater than 2,420 ft^3). Thus, based on these results, the new road alone satisfies the requirement of retaining an additional 1.1 inch of runoff from the increase in impervious surface area for HSGs A, B, and D. The increase in capture volume for the new road is due to an increased swale side slope length and an increase in the channel bottom width, both of which allow for more infiltration to occur. In the MIDS calculator, the swale main channel is given much more infiltration capacity than the swale side slope, so most of the benefit of the new road (according to the MIDS calculator) is due to the increase in the swale bottom width. The additional capture volume required for the new road in the HSG C scenarios is 66 ft^3, which is relatively small. As with Case Study 1, this requirement could be met by placing bioretention soil in the bottom of the swale. Because the additional required capture volume is relatively small in this case, a bioretention area in a small portion of the swale bottom would satisfy capture volume requirements.

Table 6.5. Summary of 5-segment swale model MIDS calculator results for Case Study 3.

HSG (K_{sat} in/hr)	Value	Existing Road RVR = 5,810 ft^3	New Road RVR = 8,226 ft^3	Additional Capture Volume Required
A (1.63)	VR-BMP	2656	8226	0
	Volume Remaining	3154	0	
B (0.45)	VR-BMP	2246	5097	0
	Volume Remaining	3564	3129	
C (0.20)	VR-BMP	1699	4049	66
	Volume Remaining	4111	4177	
D (0.06)	VR-BMP	1406	3842	0
	Volume Remaining	4404	4384	

RVR = Reduction Volume Required
VR-BMP = Volume Reduction Credited to BMPs

6.3.2 Roadside Swale Calculator – Case Study 3

Due to the discrepancy in the MIDS calculator results previously discussed, the Roadside Swale Calculator (RSC) was used to estimate capture volumes for the same 5,280 ft long existing and new road sections previously described in Case Study 3.

The RSC uses historical rainfall records based on location, the width of the swale to width of the road ratio, and the saturated hydraulic conductivity (K_{sat}) of the soil to estimate the fraction of annual runoff infiltrated (i.e., captured) by the swale side slope and a swale bottom width of 1.64 ft. The swale bottom width is a constant in the RSC and cannot be adjusted by the user. None of the five case studies, however, had a swale bottom width of 1.64 ft. Thus, in order to apply the RSC to the case studies, the cross-section of both the new and existing roads was approximated by extending the swale side slope from the edge of the road shoulder to the location on the swale bottom that corresponded to a swale bottom width equal to 1.64 ft. Figure 6.5 shows a schematic of this approximation for the existing road in Case Study 3.

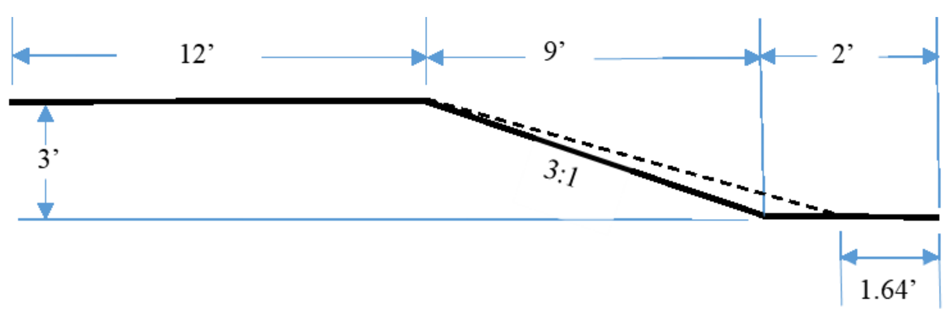


Figure 6.5. Schematic of approximated cross-section used for the existing road in the Roadside Swale Calculator for Case Study 3 (not to scale).

In Figure 6.5, the thick, solid black lines show the actual cross-section of the case study. The dashed black line shows the side slope of the swale used in the RSC approximated cross-section. The value of swale width used in the RSC was based on the side slope shown by the dashed line. Because the approximated cross-section had slightly less length of swale side slope and swale bottom than the actual cross-section, the road corresponding to the approximated cross-section had slightly less area available for infiltration than the actual cross-section. This made the approximated cross-section slightly conservative. The difference, however, in all case studies was 1% or less. The approximated cross-sections were used in the RSC to calculate the fraction of annual rainfall infiltrated by the swale side slope and swale bottom.

To determine a corresponding capture volume (VR-BMP) from the percent of annual rainfall infiltrated, the same method used by the MIDS calculator was used in the RSC analysis. In that method, a MIDS "performance curve" corresponding to the given K_{sat} value (and available as part of the MIDS calculator instructions, MPCA 2020) was used. Figure 6.3 shows the performance curve for a K_{sat} value of 1.63 in/hr.

The method involves entering the corresponding performance curve on the vertical axis at the percent annual runoff infiltrated (i.e. percent annual volume reduction on Figure 6.3), moving horizontally to the right to the corresponding "Percent Impervious of Contributing Area" curve, which was 52.2% for the existing road and 41.5% for the new road. The percent impervious for each case was based on the horizontal distances of road width, shoulder width, side slope width, and the swale bottom, with the road and shoulder being impervious. For example, the percent impervious of the existing road in this case study was calculated be taking the total impervious width of 12 ft (12 ft of road with no shoulder) and dividing it by the total cross-section horizontal width of 23 ft (12 ft of impervious plus 9 ft of swale side slope plus 2 ft of swale bottom). Once at the appropriate curve or, by linear interpolation, at the appropriate location between curves, one then drops vertically to the horizontal axis to read the corresponding value of "BMP Volume Reduction Capacity (ft^3)/Watershed Area (ft^2)." The value read from the horizontal axis is then multiplied by the total watershed area (ft^2) to determine the Volume Reduction Capacity (ft^3) of the BMP (i.e., VR-BMP). For example and as shown by the red arrows on Figure 6.3, if the percent annual volume reduction as calculated by the RSC was 80% and the watershed was 40% impervious, the value read from the horizontal axis would be approximately 0.0152 (ft^3/ft^2).

Values for K_{sat} of 0.45 in/hr were linearly interpolated between values from performance curves corresponding to K_{sat} of 0.6 in/hr and 0.3 in/hr because no performance curve was available for K_{sat} of 0.45 in/hr. Similarly, for HSG D soils with K_{sat} of 0.06 in/hr, values were linearly interpolated between values corresponding to the performance curve for K_{sat} of 0.2 in/hr and zero. The value obtained from the performance curve(s) was then multiplied by the total watershed area to determine the volume reduction capacity, or VR-BMP, of the roadside swale. The total watershed area used for this calculation was determined by multiplying the total horizontal width (i.e., the sum of the road, shoulder, side slope, and swale bottom) by a length of 5,280 ft.

Table 6.6 shows RSC results for Case Study 3. The RSC shows more additional capture volume requirements than the MIDS calculator for all HSGs. In fact, the additional capture volume requirement for the MIDS calculator was zero for all HSGs except for HSG C, which had only 66 ft^3 of additional capture volume required. The RSC was slightly more than zero for HSG A but increased with decreasing saturated hydraulic conductivity to 2,137 ft^3 for HSG D. It is believed that the primary reason for this difference is the extension of the side slope that is required to make up for the 1.64' swale bottom width, which is a constant in the RSC.

Table 6.6. Roadside swale calculator results for volume reduction capacity (VR-BMP) of existing and new roads for Case Study 3.

HSG	Ksat (in/hr)	Thief River Falls, MN		Additional Capture Volume Required (ft^3)
		Existing	New	
HSG A	1.63	3012	5369	63
HSG B	0.45	2089	4243	266
HSG C	0.20	1700	3290	830
HSG D	0.06	262	546	2137

6.4 CASE STUDY 4

This case study involves the following scenario in Itasca, MN, that, according to the MIDS calculator, has an average annual rainfall depth of 26.4 inches:

Existing Road: 12 ft lane, 2 ft shoulder, 3:1 swale side slope, 4 ft swale depth, and 8.5 ft swale bottom width,

New Road: 12 ft lane, 5 ft shoulder, 5:1 swale side slope, 4 ft swale depth, and 10 ft swale bottom width.

As with the other case studies, a one mile long section of road was investigated. Based on the conditions stated above, the new road had an additional 3 ft of impervious area across its width. When multiplied by 5280 ft/mile, the increase in impervious area is 15,840 ft^2. With 1.1 inches of runoff from this increase in impervious area, the new road must capture and retain an additional 1,458 ft^3 (within rounding error) when compared to the existing road. First, the MIDS calculator was used to investigate if, or how, the new road can meet this requirement. Later, the RSC was used to answer the same question.

6.4.1 MIDS Calculator – Case Study 4

Initially, this scenario was modeled in one road segment with a road, shoulder, side slope, and swale main bottom length of 5,280 ft. Two stormwater best management practices (BMPs) were used, a swale side slope and a swale main channel that receives runoff from the swale side slope. The scenario was run for all hydrologic soil groups (HSG). Values of saturated hydraulic conductivity associated with each HSG were as follows: HSG A: 1.63 in/hr, HSG B: 0.45 in/hr, HSG C: 0.2 in/hr, and HSG D: 0.06 in/hr. These values cover the range of K_{sat} available in the MIDS calculator. The main channel slope was set to 3% and the swale side slide was assumed to be mowed turf while the swale main channel was assumed to be native grass.

Based on the impervious area increase when comparing the existing road to the new road, an additional 1,458 ft^3 (within rounding error) needs to be retained by the new road. This value can also be obtained from the MIDS calculator by taking the difference between the MIDS "Retention Volume Requirement" (RVR) for both scenarios. The MIDS RVR values for the existing and new roads were 6,768 ft^3 and 8,226 ft^3, respectively. For each K_{sat} modeled, the MIDS "Volume Removed by BMPs" (VR-BMP) for the existing and new roads were also 6,768 ft^3 and 8,226 ft^3, respectively. This means that, according to the MIDS calculator, the new road will satisfy the requirement that 1.1 inch of runoff from the increase in impervious area be captured and retained for the range of K_{sat} values available in the MIDS calculator. Complete MIDS calculator summary reports for all scenarios are available in Appendix B.

The discrepancy in MIDS calculator results, described in Case Study 1, resulted in the 5,280 ft long sections of road being modeled as five, 1,056 ft long separate but connected segments. In the five-segment models, the RVR for the existing and new roads were 6,768 ft^3 and 8,226 ft^3, respectively. Results for VR-BMP for each of the HSGs are shown in Table 6.7. The only scenario in which the new road meets the requirement with the five-segment simulation is when the soil is HSG A. For all other HSGs, additional capture volume is required. Also, of note is that the additional capture volume of HSG D is less than that of HSG C. Thus, based on these results, additional capture volume must be provided for HSGs B, C, and D.

Table 6.7 Summary of 5-segment swale model MIDS calculator results for Case Study 4.

HSG (K_{sat} in/hr)	Value	Existing Road RVR = 6,768 ft^3	New Road RVR = 8,226 ft^3	Additional Capture Volume Required
A (1.63)	VR-BMP	6768	8226	0
	Volume Remaining	0	0	
B (0.45)	VR-BMP	4363	5371	450
	Volume Remaining	2405	2855	
C (0.20)	VR-BMP	3456	4194	720
	Volume Remaining	3312	4032	
D (0.06)	VR-BMP	3321	4132	647
	Volume Remaining	3447	4094	

RVR = Reduction Volume Required
VR-BMP = Volume Reduction Credited to BMPs

Potential BMPs to provide the required additional capture volume that are available within the MIDS calculator and that would not require the purchase of additional right-of-way include non-permeable check dams and a bioretention base, both of which would be input as part of the swale main channel BMP. Because drawdown times would likely be prohibitive in poorly draining soils (i.e., HSG C and D), a bioretention base was investigated as a method to meet volume capture requirements. The additional capture volume can be achieved by making a 240 foot long section of the swale bottom (with a 10 ft wide swale, this is 2,400 ft^2 of area) a bioretention base with a depth of one foot and a soil porosity of 0.30. In the MIDS calculator this must be placed in the most downstream swale bottom so that enough of the road runoff flows into the bioretention area. Of course, other bioretention depths, bioretention porosities, and bioretention areas could be selected to meet requirements. Other BMPs such as an infiltration basin, permeable pavement, or underground infiltration may also provide the additional required capture volume but may not be practical for some road projects due to required additional land purchases or other expenses and complications. It must be noted that the MPCA stormwater permit "prohibits permittees from constructing infiltration systems in areas of predominately Hydrologic Soil Group type D soils (clay)" (per Section 16.7), and that the "permit does not consider wet sedimentation basins and filtration systems to be volume reduction practices" (per Section 15.5). BMPs outside of the right-of-way, such as wet or dry ponds, could also be used to meet stormwater runoff requirements as long as the soil is not HSG D.

6.4.2 Roadside Swale Calculator – Case Study 4

Due to the discrepancy in the MIDS calculator results previously discussed, the Roadside Swale Calculator (RSC) was used to estimate capture volumes for the same 5,280 ft long existing and new road sections previously described in Case Study 4.

The RSC uses historical rainfall records based on location, the width of the swale to width of the road ratio, and the saturated hydraulic conductivity (K_{sat}) of the soil to estimate the fraction of annual runoff infiltrated (i.e. captured) by the swale side slope and a swale bottom width of 1.64 ft. The swale bottom width is a constant in the RSC and cannot be adjusted by the user. None of the five case studies, however, had a swale bottom width of 1.64 ft. Thus, in order to apply the RSC to the case studies, the cross-section of both the new and existing roads was approximated by extending the swale side slope from the edge of the road shoulder to the location on the swale bottom that corresponded to a swale bottom width equal to 1.64 ft. Figure 6.6 shows a schematic of this approximation for the existing road in Case Study 4.

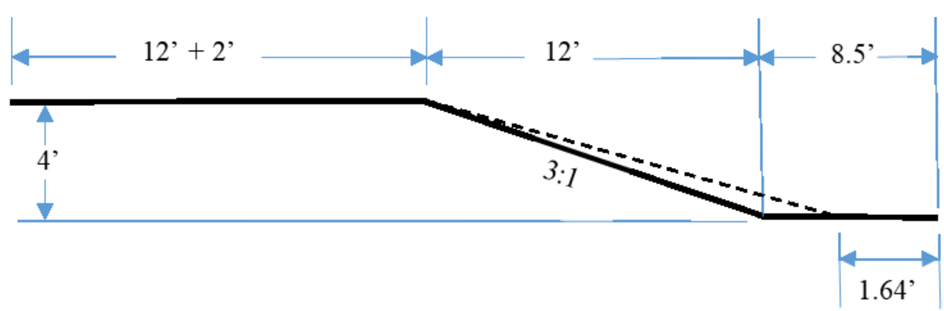


Figure 6.6. Schematic of approximated cross-section used for the existing road in the Roadside Swale Calculator for Case Study 4 (not to scale).

In Figure 6.6, the thick, solid black lines show the actual cross-section of the case study. The dashed black line shows the side slope of the swale used in the RSC approximated cross-section. The value of swale width used in the RSC was based on the side slope shown by the dashed line. Because the approximated cross-section had slightly less length of swale side slope and swale bottom than the actual cross-section, the road corresponding to the approximated cross-section had slightly less area available for infiltration than the actual cross-section. This made the approximated cross-section slightly conservative. The difference, however, in all case studies was 1% or less. The approximated cross-sections were used in the RSC to calculate the fraction of annual rainfall infiltrated by the swale side slope and swale bottom. Also, for the new road in Case Study 4, the width of swale divided by the width of road was 1.69, which exceeds the maximum value of 1.4 that can be entered in the RSC. Thus, the percent annual rainfall volume infiltrated for the new road was obtained through extrapolation from 1.4 to 1.69.

To determine a corresponding capture volume (VR-BMP) from the percent of annual rainfall infiltrated, the same method used by the MIDS calculator was used in the RSC analysis. In that method, a MIDS "performance curve" corresponding to the given K_{sat} value (and available as part of the MIDS calculator instructions, MPCA 2020) was used. Figure 6.3 shows the performance curve for a K_{sat} value of 1.63 in/hr.

The method involves entering the corresponding performance curve on the vertical axis at the percent annual runoff infiltrated (i.e. percent annual volume reduction on Figure 6.3), moving horizontally to the right to the corresponding "Percent Impervious of Contributing Area" curve, which was 40.6% for the existing road and 36.2% for the new road. The percent impervious for each case was based on the horizontal distances of road width, shoulder width, side slope width, and the swale bottom, with the road and shoulder being impervious. For example, the percent impervious of the existing road in this case study was calculated be taking the total impervious width of 14 ft (12 ft of road plus 2 ft of shoulder) and dividing it by the total cross-section horizontal width of 34.5 ft (14 ft of impervious plus 12 ft of swale side slope plus 8.5 ft of swale bottom). Once at the appropriate curve or, by linear interpolation, at the appropriate location between curves, one then drops vertically to the horizontal axis to read the corresponding value of "BMP Volume Reduction Capacity (ft^3)/Watershed Area (ft^2)." The value read from the horizontal axis is then multiplied by the total watershed area (ft^2) to determine the Volume Reduction Capacity (ft^3) of the BMP (i.e. VR-BMP). For example and as shown by the red arrows on Figure 6.3, if the percent annual volume reduction as calculated by the RSC was 80% and the watershed was 40% impervious, the value read from the horizontal axis would be approximately 0.0152 (ft^3/ft^2).

Values for K_{sat} of 0.45 in/hr were linearly interpolated between values from performance curves corresponding to K_{sat} of 0.6 in/hr and 0.3 in/hr because no performance curve was available for K_{sat} of 0.45 in/hr. Similarly, for HSG D soils with K_{sat} of 0.06 in/hr, values were linearly interpolated between values corresponding to the performance curve for K_{sat} of 0.2 in/hr and zero. The value obtained from the performance curve(s) was then multiplied by the total watershed area to determine the volume reduction capacity, or VR-BMP, of the roadside swale. The total watershed area used for this calculation was determined by multiplying the total horizontal width (i.e., the sum of the road, shoulder, side slope, and swale bottom) by a length of 5,280 ft.

Table 6.8 shows RSC results for Case Study 4. The RSC determined that no additional capture volume was required for HSGs A, B, and C. This differs from the MIDS calculator, which found that only HSG A had no additional capture volume required. Thus, the RSC found no additional capture volume requirement for HSG B and C, whereas the MIDS calculator found additional capture volumes of 450 and 720 ft^3 for these HSGs, respectively. The RSC, however, calculated a larger additional capture volume requirement for HSG D (1196 ft^3) than did the MIDS calculator (647 ft^3). Since the swale bottom width was not changed by much in the old to new swale, this did not have as much impact on the results as Case Study 3.

Table 6.8. Roadside swale calculator results for volume reduction capacity (VR-BMP) of existing and new roads for Case Study 4.

HSG	Ksat (in/hr)	Itasca, MN		Additional Capture Volume Required (ft^3)
		Existing	New	
HSG A	1.63	4663	7743	0
HSG B	0.45	3643	5559	0
HSG C	0.20	2915	6452	0
HSG D	0.06	459	715	1196

6.5 CASE STUDY 5

This case study involves the following scenario in St. Cloud, MN that, according to the MIDS calculator, has an average annual rainfall depth of 26.7 inches:

Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width

New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 2' bottom width.

As with the other case studies, a one mile long section of road was investigated. Based on the conditions stated above, the new road had an additional 3 ft of impervious area across its width. When multiplied by 5280 ft/mile, the increase in impervious area is 15,840 ft^2. With 1.1 inches of runoff from this increase in impervious area, the new road must capture and retain an additional 1,458 ft^3 (within rounding error) when compared to the existing road. First, the MIDS calculator was used to investigate if, or how, the new road can meet this requirement. Later, the RSC was used to answer the same question.

6.5.1 MIDS Calculator – Case Study 5

Initially, this scenario was modeled in one road segment with a road, shoulder, side slope, and swale main bottom length of 5,280 ft. Two stormwater best management practices (BMPs) were used, a swale side slope and a swale main channel that receives runoff from the swale side slope. The scenario was run for all hydrologic soil groups (HSG). Values of saturated hydraulic conductivity associated with each HSG were as follows: HSG A: 1.63 in/hr, HSG B: 0.45 in/hr, HSG C: 0.2 in/hr, and HSG D: 0.06 in/hr. These values cover the range of K_{sat} available in the MIDS calculator. The main channel slope was set to 3% and the swale side slide was assumed to be mowed turf while the swale main channel was assumed to be native grass.

Based on the impervious area increase when comparing the existing road to the new road, an additional 1,458 ft^3 (within rounding error) needs to be retained by the new road. This value can also be obtained from the MIDS calculator by taking the difference between the MIDS "Retention Volume Requirement" (RVR) for both scenarios. The MIDS RVR values for the existing and new roads were 6,768 ft^3 and 8,226 ft^3, respectively. For each K_{sat} modeled, the MIDS "Volume Removed by BMPs" (VR-BMP) for the existing and new roads were also 6,768 ft^3 and 8,226 ft^3, respectively. This means that, according to the MIDS calculator, the new road will satisfy the requirement that 1.1 inch of runoff from the increase in impervious area be captured and retained for the range of K_{sat} values available in the MIDS calculator. Complete MIDS calculator summary reports for all scenarios are available in Appendix B.

The discrepancy in MIDS calculator results, described in Case Study 1, resulted in the 5,280 ft long sections of road being modeled as five, 1,056 ft long separate but connected segments. In the five-segment models, the RVR for the existing and new roads were 6,768 ft^3 and 8,226 ft^3, respectively. Results for VR-BMP for each of the HSGs are shown in Table 6.9, where none of the scenarios meet the capture and storage requirement in the five-segment simulation. Additional capture volume is required for all HSGs. Thus, based on these results, the new road will need additional stormwater BMPs to increase capture volume from 1,203 to 1,462 ft^3, depending on the HSG.

Table 6.9. Summary of 5-segment swale model MIDS calculator results for Case Study 5.

HSG (K_{sat} in/hr)	Value	Existing Road	New Road	Additional Capture Volume Required
		RVR = 6,768 ft^3	RVR = 8,226 ft^3	
A (1.63)	VR-BMP	2615	2870	1203
	Volume Remaining	4153	5356	
B (0.45)	VR-BMP	2178	2376	1260
	Volume Remaining	4590	5850	
C (0.20)	VR-BMP	1558	1641	1375
	Volume Remaining	5210	6585	
D (0.06)	VR-BMP	1225	1221	1462
	Volume Remaining	5543	7005	

RVR = Reduction Volume Required
VR-BMP = Volume Reduction Credited to BMPs

Potential BMPs to provide the required additional capture volume that are available within the MIDS calculator and that would not require the purchase of additional right-of-way include non-permeable check dams and a bioretention base, both of which would be input as part of the swale main channel BMP. Because drawdown times would likely be prohibitive in poorly draining soils (i.e., HSG C and D), a bioretention base was investigated as a method to meet volume capture requirements. The additional capture volume can be achieved by making a 1,056 ft long section of the swale bottom (with a 2 ft wide swale, this is 2,112 ft^2 of area) a bioretention base with a depth of 2 1/3 ft and a soil porosity of 0.30. In the MIDS calculator this should be placed in the most downstream swale bottom so that enough of the road runoff flows into the bioretention area. Of course, other bioretention depths, bioretention porosities, and bioretention areas could be selected to meet requirements. Other BMPs such as an infiltration basin, permeable pavement, or underground infiltration may also provide the additional required capture volume but may not be practical for some road projects due to required additional land purchases or other expenses and complications. It must be noted that the MPCA stormwater permit "prohibits permittees from constructing infiltration systems in areas of predominately Hydrologic Soil Group type D soils (clay)" (per Section 16.7), and that the "permit does not consider wet sedimentation basins and filtration systems to be volume reduction practices" (per Section 15.5). Finally, BMPs outside of the right-of-way, such as wet or dry ponds, could also be used to meet stormwater runoff requirements as long as the soil is not HSG D.

6.5.2 Roadside Swale Calculator – Case Study 5

Due to the discrepancy in the MIDS calculator results previously discussed, the Roadside Swale Calculator (RSC) was used to estimate capture volumes for the same 5,280 ft long existing and new road sections previously described in Case Study 5.

The RSC uses historical rainfall records based on location, the width of the swale to width of the road ratio, and the saturated hydraulic conductivity (K_{sat}) of the soil to estimate the fraction of annual runoff infiltrated (i.e. captured) by the swale side slope and a swale bottom width of 1.64 ft. The swale bottom width is a constant in the RSC and cannot be adjusted by the user. None of the five case studies, however, had a swale bottom width of 1.64 ft. Thus, in order to apply the RSC to the case studies, the cross-section of both the new and existing roads was approximated by extending the swale side slope from the edge of the road shoulder to the location on the swale bottom that corresponded to a swale bottom width equal to 1.64 ft. Figure 6.7 shows a schematic of this approximation for the existing road in Case Study 5.

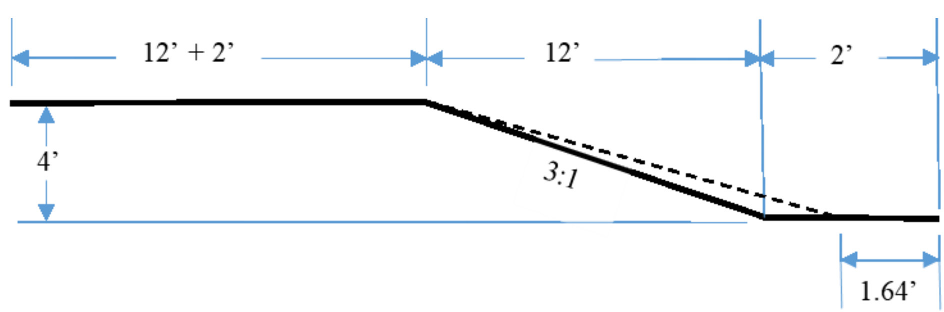


Figure 6.7. Schematic of approximated cross-section used for the existing road in the Roadside Swale Calculator for Case Study 5 (not to scale).

In Figure 6.7, the thick, solid black lines show the actual cross-section of the case study. The dashed black line shows the side slope of the swale used in the RSC approximated cross-section. The value of swale width used in the RSC was based on the side slope shown by the dashed line. Because the approximated cross-section had slightly less length of swale side slope and swale bottom than the actual cross-section, the road corresponding to the approximated cross-section had slightly less area available for infiltration than the actual cross-section. This made the approximated cross-section slightly conservative. The difference, however, in all case studies was 1% or less. The approximated cross-sections were used in the RSC to calculate the fraction of annual rainfall infiltrated by the swale side slope and swale bottom.

To determine a corresponding capture volume (VR-BMP) from the percent of annual rainfall infiltrated, the same method used by the MIDS calculator was used in the RSC analysis. In that method, a MIDS "performance curve" corresponding to the given K_{sat} value (and available as part of the MIDS calculator instructions, MPCA 2020) was used. Figure 6.3 shows the performance curve for a K_{sat} value of 1.63 in/hr.

The method involves entering the corresponding performance curve on the vertical axis at the percent annual runoff infiltrated (i.e., percent annual volume reduction on Figure 6.3), moving horizontally to the right to the corresponding "Percent Impervious of Contributing Area" curve, which was 50.0% for the existing road and 48.6% for the new road. The percent impervious for each case was based on the horizontal distances of road width, shoulder width, side slope width, and the swale bottom, with the road and shoulder being impervious. For example, the percent impervious of the existing road in this case study was calculated be taking the total impervious width of 14 ft (12 ft of road plus 2 ft of shoulder) and dividing it by the total cross-section horizontal width of 28 ft (14 ft of impervious plus 12 ft of swale side slope plus 2 ft of swale bottom). Once at the appropriate curve or, by linear interpolation, at the appropriate location between curves, one then drops vertically to the horizontal axis to read the corresponding value of "BMP Volume Reduction Capacity (ft^3)/Watershed Area (ft^2)." The value read from the horizontal axis is then multiplied by the total watershed area (ft^2) to determine the Volume Reduction Capacity (ft^3) of the BMP (i.e. VR-BMP). For example and as shown by the red arrows on Figure 6.3, if the percent annual volume reduction as calculated by the RSC was 80% and the watershed was 40% impervious, the value read from the horizontal axis would be approximately 0.0152 (ft^3/ft^2).

Values for K_{sat} of 0.45 in/hr were linearly interpolated between values from performance curves corresponding to K_{sat} of 0.6 in/hr and 0.3 in/hr because no performance curve was available for K_{sat} of 0.45 in/hr. Similarly, for HSG D soils with K_{sat} of 0.06 in/hr, values were linearly interpolated between values corresponding to the performance curve for K_{sat} of 0.2 in/hr and zero. The value obtained from the performance curve(s) was then multiplied by the total watershed area to determine the volume reduction capacity, or VR-BMP, of the roadside swale. The total watershed area used for this calculation was determined by multiplying the total horizontal width (i.e., the sum of the road, shoulder, side slope, and swale bottom) by a length of 5,280 ft.

Table 6.10 shows RSC results for Case Study 5. Like the MIDS calculator results, the RSC determined additional capture volume is required for all HSGs. The RSC determined lower additional capture volumes for all HSGs were required, however, as compared to the MIDS calculator results. The amount that RSC required additional capture volumes are lower than the MIDS calculator results decreases with decreasing saturated hydraulic conductivity (i.e., from HSG A to HSG D). At HSG A, the RSC additional capture volume of 343 ft^3 is 72% lower than the MIDS value of 1203 ft^3. At HSG D, however, the two models give values are within 6% of each other.

Table 6.10. Roadside swale calculator results for volume reduction capacity (VR-BMP) of existing and new roads for Case Study 5.

HSG	Ksat (in/hr)	St. Cloud, MN		Additional Capture Volume Required (ft^3)
		Existing	New	
HSG A	1.63	4435	5544	343
HSG B	0.45	2839	3548	742
HSG C	0.20	2070	2587	935
HSG D	0.06	319	399	1372

6.6 CASE STUDIES SUMMARY

Five sample road widening projects, or case studies, were investigated to determine how stormwater management requirements of the road widening projects can be achieved using roadside swales. Each case study was performed at four different saturated hydraulic conductivity, K_{sat}, values. The K_{sat} values were chosen to represent hydrologic soil groups (HSG) A, B, C, and D. The stormwater management requirement in all cases was the MPCA's MIDS requirement for linear projects (without restrictions and of one acre or more) that 1.1 inches of runoff from the net increase in impervious area be captured and retained (MPCA 2020). To investigate if the new road in each case study will meet the requirement, the Minimal Impact Design Standards (MIDS) calculator (MPCA 2020) was used. In a separate analysis for confirmation and comparison, the Minnesota's Roadside Swale Calculator (RSC) (SAFL 2019) was used in combination with MIDS calculator results to determine if the requirement will be met by the new road. If it were determined by the MIDS calculator that the new road would not meet the capture requirement using swales alone, stormwater BMPs that could help meet requirements were investigated and proposed. A summary of each case study along with MIDS calculator five-segment model and RSC results are shown in Table 6.11.

In Table 6.11, "permit retention volume required" is the additional volume that needs to be retained for the new road due to the net increase in the impervious area of the new road (which is the difference between the MIDS "retention volume requirement" (RVR) for the new and old roads). The "new road additional capture volume" is the difference between the MIDS "Volume Removed by BMPs" for the new road and existing road. The remaining volume (permit retention volume required - new road additional capture volume) is the "additional capture volume required" that needs to be met with other BMPs in addition to swales. For example, for Case Study 1, both the MIDS calculator and the RSC calculator modeling results indicate that the new road alone does not meet volume capture requirements for any of the HSGs and additional capture volume must be provided with other BMPs. In Case Study 2, a zero "additional capture volume required" means the swales alone satisfies the volume capture requirements for all HSGs and no other BMPs need to be implemented.

In all cases where additional capture volume is required, that requirement can be met by making a portion of the swale bottom (in the MIDS calculator) a bioretention base. Many different combinations of bioretention area, depth, and porosity are available to meet the requirements because credit is given based on the additional void space in the bioretention soil, not any one variable. Other BMP types may also be used to satisfy requirements. For example, impermeable check dams in the drainage swale increase volume retention credit in the MIDS calculator. In poorly draining soils, however, draw down times may preclude the use of check dams. In fact, it must be noted that the MPCA permit requirement for road reconstruction projects states that the "permit prohibits permittees from constructing infiltration systems in areas of predominately Hydrologic Soil Group type D soils (clay)" (per Section 16.7), and that the "permit does not consider wet sedimentation basins and filtration systems to be volume reduction practices" (per Section 15.5). Finally, BMPs outside of the right-of-way, such as wet or dry ponds, could also be used to meet stormwater runoff requirements as long as the soil is not HSG D.

Table 6.11. Summary of case studies and modeling results of the MIDS calculator 5-segment models and the Roadside Swale Calculator (RSC).

		MIDS Calculator		Roadside Swale Calculator	
Case Studies	**HSG**	**New Road Additional Capture Volume (ft^3)**	**Additional Capture Volume Required (ft^3)**	**New Road Additional Capture Volume (ft^3)**	**Additional Capture Volume Required (ft^3)**
Case 1 - Rochester, MN Increase Impervious area: 15,840 ft^2/lane mile Permit Retention Volume Required: 1450 ft^3 **Existing Road:** 12' lane, 2' shoulder, 5:1 side slope, 3' swale depth, 3' bottom width **New Road:** 12' lane, 5' shoulder, 4:1 side slope, 3' swale depth, 3' bottom width	A	593	857	676	774
	B	325	1125	-34	1484
	C	207	1243	-135	1585
	D	77	1373	0	1450
Case 2 - Grand Marais, MN Increase Impervious area: 15,840 ft^2/lane mile Permit Retention Volume Required: 1458 ft^3 **Existing Road:** 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width **New Road:** 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width	A	5736	0	2315	0
	B	2397	0	1975	0
	C	2056	0	1677	0
	D	2150	0	269	1189
Case 3 - Thief River Falls, MN Increase Impervious area: 26,400 ft^2/lane mile Permit Retention Volume Required: 2416 ft^3 **Existing Road:** 12' lane, no shoulder, 3:1 side slope, 3' swale depth, 2' bottom width **New Road:** 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width	A	5570	0	2357	59
	B	2851	0	2154	262
	C	2350	66	1590	826
	D	2436	0	283	2133
Case 4 - Itasca, MN Increase Impervious area: 15,840 ft^2/lane mile Permit Retention Volume Required: 1458 ft^3 **Existing Road:** 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 8.5' bottom width **New Road:** 12' lane, 5' shoulder, 5:1 side slope, 4', swale depth, 10' bottom width.	A	1458	0	3079	0
	B	1008	450	1916	0
	C	738	720	3538	0
	D	811	647	256	1202
Case 5 - St. Cloud, MN Increase Impervious area: 15,840 ft^2/lane mile Permit Retention Volume Required: 1458 ft^3 **Existing Road:** 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width **New Road:** 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 2' bottom width	A	255	1203	1109	349
	B	198	1260	710	748
	C	83	1375	517	941
	D	-4	1462	80	1378

Permit Retention Volume Required: MIDS requirement to infiltrate 1.1 inch of runoff from the net increase of impervious surface created by the new road project

Additional Capture Volume Required: A value of zero means the new road alone satisfies volume retention requirements using swales; a value greater than zero means BMPs in addition to swales are needed to meet the requirements.

6.6.1 Discrepancy between MIDS calculator and RSC simulations

In all five case studies a one mile long stretch of road was modeled. In each case, a discrepancy in MIDS calculator results was observed when comparing the results of the roads modeled as a single, one mile long (i.e., 5280 ft) segment and the results of the roads modeled as five separate but connected segments totaling one mile in length (i.e., five, 1056 ft long segments). In all five case studies, when the roads were modeled as a single, one mile long segment in the MIDS calculator, the new road alone (i.e., without additional stormwater BMPs) achieved the stormwater capture and retention requirement for all HSGs. Modeling the roads as five separate but connected segments reduced MIDS calculator estimates for capture and retention, which resulted in only the new road of Case Study 2 meeting requirements for all HSGs. In Case Study 1, all HSGs required additional BMPs to meet requirements, in Case Study 3, HSG C required additional BMPs, and in Case Study 4, HSGs B, C, and D required additional BMPs to meet capture and retention requirements. In Case Study 5, all HSGs required additional capture volume. The MPCA was contacted about this discrepancy and, at the time of publication of this report, had not yet provided an explanation or a solution.

For comparison, the RSC was also used in all five case studies to investigate the ability of the new road to meet stormwater capture and retention requirements. For each case study, the RSC was used to model the scenario at the same location as was used in the MIDS calculator. In Case Studies 1 and 5, like the MIDS calculator, the RSC determined that additional capture volume was required for all HSGs. Also, like the MIDS calculator, the RSC determined no additional capture volume as required in HSGs A, B, and C for Case Study 2. For HSG D, however, the RSC determined additional capture volume was required whereas the MIDS calculator did not. For Case Study 3, the RSC determined additional capture volume was required for all HSGs whereas the MIDS calculator found that additional capture volume was required for only HSG C and that value was only 66 ft^3. Finally, for Case Study 4, the RSC determined that no additional capture volume was required for HSGs A, B, and C whereas the MIDS calculator determined only HSG A required no additional capture volume. For HSG D, however, the RSC calculator determined more additional capture volume was required when compared to the MIDS calculator results.

There are advantages and disadvantages to using the RSC over the MIDS calculator. The MIDS calculator does not give adequate credit for infiltration on the side slopes of swales, which we believe is insufficient. The RSC, however, has only a 1.64 ft swale bottom width and requires that the side slope be extended to account for a larger bottom width. The side slope only has partial infiltration because it is not fully covered by water. This will reduce the amount of infiltration that occurs in the RSC model because the actual swale bottom is fully covered with water but a portion of the swale bottom is modeled as the side slope, which is not fully covered with water. Because permit requirements are set by the MPCA, however, volume reduction credit must be calculated by an MPCA approved method. Currently, only the MIDS calculator meets this criterion. However, we recommend that calculations should be done using both the MIDS calculator and RSC calculator since both methods have their own limitations.

CHAPTER 7: COST-BENEFIT ANALYSIS

Three key benefits were identified from the results and conclusions of this research project. First, cost savings benefit is possible because roads with lower runoff constituent concentrations and/or loads will require smaller and/or fewer treatment practices which will result in lower initial construction costs and lower annual operation and maintenance (O&M) costs. Second benefit is from land savings due to the need for smaller treatment devices that have a smaller footprint and require less land. Third, more cost-effective treatment strategies and allocation of resources will allow these limited resources to be applied in other areas, thereby creating additional environmental benefits that may otherwise be unattainable. The three benefits identified are quantified on a large, state-wide scale through a series of estimations and calculations in this section.

7.1 COST SAVINGS

The cost savings that will be realized as a result of this project will be due to the optimization of stormwater treatment practice selection for low traffic volume roads. In the Minnesota Pollution Control Agency's (MPCA) stormwater permit for road projects, infiltration systems (infiltration basins, infiltration trenches, rainwater gardens, bioretention areas without underdrains, swales with impermeable check dams and natural depressions) and filtration systems (sand filters with underdrains, biofiltration areas, swales using underdrains with impermeable check dams and underground sand filters) are recommended for meeting the permanent stormwater treatment requirements (i.e., capture and retention of 1.0 inches of runoff from the net increase in impervious area) for projects that create one acre or more impervious surface (per Sections 15.3, 16.2, 16.7, and 17.2 of the MPCA permit). Data in Table 7.1, obtained from the county engineers in the Technical Advisory Panel (TAP) for this project, show the stormwater infiltration and filtration treatment practices currently being implemented to meet the runoff treatment requirements for rural road projects.

Table 7.1 Low-volume road projects and stormwater treatment practices implemented in select MN counties.

County	Types and frequency (if known) of rural road projects that may exceed MPCA threshold of > 1 ac net impervious	Stormwater treatment practices typically implemented for runoff treatment requirement
Aitkin	• Conversion of gravel road to paved road • Widening of existing paved road • Addition of paved shoulder during pavement rehabilitation (mill and overlay) • ~1 project per year adds >1 ac impervious surface	• Filtration beds with underdrain pipes
Cass	• Pavement preservation projects • Conversion of gravel roads to paved roads • Rarely add >1 ac impervious surface	• Drainage swales (ditches) with check dams

County	Types and frequency (if known) of rural road projects that may exceed MPCA threshold of > 1 ac net impervious	Stormwater treatment practices typically implemented for runoff treatment requirement
Chisago	• Pavement reconstruction and rehabilitation • Addition or expansion of paved shoulder	• Drainage swales (ditches) with check dams
Clearwater	• Grading projects; most projects add >1 ac impervious surface	• Drainage swales (ditches) with drain tiles
Fairbault	• Pavement rehabilitation projects (0-10% projects add >1 ac impervious surface) • Grading projects (100% projects add >1 ac impervious surface)	• Drainage swales (ditches) with check dams
St. Louis	• ~1 project every 7 years adds >1 ac impervious surface	• Drainage swales (ditches)

Based on project results of typical runoff constituent concentrations found in stormwater runoff from low-volume roads, roadside drainage swales/ditches can be effective stormwater treatment practices for such roads and other, more expensive treatment options are not necessary. Drainage swales alone are less expensive to install and maintain than ditches with check dams, sand filters, and filtration beds. This is especially true when the swale is in the road right-of-way, and the purchase of additional land for stormwater treatment is not necessary. Thus, swales will have a lower overall total project cost as compared to these other treatment practices. They are also effective at reducing runoff constituent loads. Both aspects (i.e., cost and effectiveness) will be investigated in this document, with cost savings being investigated in this section.

An estimate of the cost savings that would result from using drainage swales as opposed to other stormwater treatment practices will be based on a half-mile (2640 ft) section of paved road with typical rural road specifications: a 10 foot wide pavement section (i.e., one lane), no paved shoulder, and a 3:1 (horizontal:vertical) side slope down to the bottom of a 3-ft deep drainage swale with a two foot bottom width, and the same (but upward) slope on the far bank. As shown in Figure 7.1, the resulting cross-section has a top width of 20 ft. For a two-lane road it is assumed that the other half of the road/swale will be symmetric, draining to the other side of the road, and will not impact this analysis.

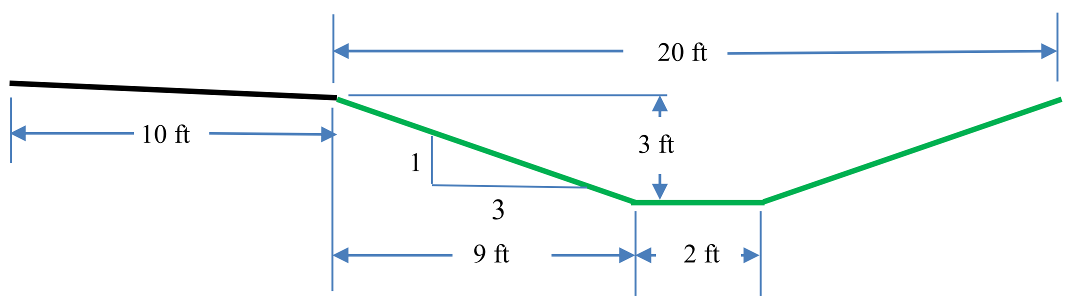


Figure 7.1. Cross-section schematic of 10 foot wide travel lane with drainage swale.

The average total present cost (TPC) of a 1000-ft long drainage swale (including construction and 20 years of operating and maintenance) was found to be a function of the top width of the swale by Weiss et al. (2005). A function fit to the corresponding data presented in Weiss et al. (2005) yielded Equation 1, which enables the average TPC to be estimated:

$$C_S = 3172.2 \times (T) - 13350 \quad (1)$$

where, C_S = TPC of a 1000-ft long swale in 2005 dollars, and T = top width of the swale (ft). With a top width of 20 ft, Equation 1 gives a TPC of $50,094 in 2005 dollars. To adjust to 2019 dollars, the 2005 dollar amount was adjusted by the consumer price index (CPI) for each year up to and including the current average value for 2019 according to values obtained from Inflationdata.com (2019) (Table 7.2). After making this adjustment, the TPC of the swale in 2019 dollars is $87,164. To adjust for a one-half mile length of road, this value is multiplied by 2640/1000, to get the TPC of a half-mile length of swale, which is $230,112.

Table 7.2. Historical Consumer Price Index (Source: Inflationdata.com).

Year	CPI	Year	CPI
2006	3.24	2013	1.47
2007	2.85	2014	1.62
2008	3.85	2015	0.12
2009	-0.34	2016	1.26
2010	1.64	2017	2.13
2011	3.16	2018	2.44
2012	2.07	2019	1.74

Since sand filters and filtration beds have been used as stormwater treatment practices on low-volume roads (Table 7.2), the cost of a sand filter designed to treat stormwater runoff from the same half-mile length of road with the cross-section of that shown in Figure 7.1 will be estimated for comparison. Afterwards, since wet ponds are often used to treat road runoff due to their relatively low cost and high effectiveness, a similar comparison will be made for wet ponds. There is no detailed data available on the cost and performance of swales with check dams so no such comparison will be made. Also, a swale with check dams is very similar to a drainage swale. The difference would be the cost to install and maintain the check dams and a likely increase in performance due to increased infiltration and settling.

The report by Weiss et al. (2005, 2007) on the cost of sand filters and Weiss et al. (2007) gives an equation for the average TPC of a sand filter based on its design water quality volume (WQV), as shown in Equation 2:

$$C_F = 6153 \times (WQV)^{0.594} \quad (2)$$

where, C_F = the TPC of a sand filter in 2005 dollars (including construction and 20 years of operating and maintenance) and WQV is its design water quality volume (ft^3).

The WQV of a half-mile length of road can be estimated from Equation 3:

$$WQV = P \times A \times R_v \qquad (3)$$

where, P is the design rainfall depth (ft), A = watershed area (ft^2), and R_v = runoff coefficient given by Equation 4:

$$Rv = 0.05 + 0.009 \times (I) \qquad (4)$$

where, I = percent of the watershed that is impervious (0 to 100).

The watershed area for a 2640-ft long section of 10-ft wide road is the product of these two values, or 26,400 ft^2. Assuming 100% impervious, R_v = 0.95. Also, as required by the MPCA, a design rainfall depth of 1.0 inch (i.e., 1/12 ft) will be used. With the above values for P, A, and I, Equations 3 and 4 were used to determine a WQV of 2090 ft^3.

With a design WQV of 2090 ft^3, the average TPC for 20 years of a sand filter is, by Equation 2, $577,104 in 2005 dollars. Making the same adjustment based on historical CPI values, the cost is $1,004,160 in 2019 dollars. Thus, the TPC for 20 years of a sand filter is over $774,000 more than the cost of a drainage swale for the same length of road. This does not include land cost, which will be discussed in the next section.

Although wet ponds are not listed as a stormwater treatment practice for low-volume roads in Table 7.1, they are quite numerous throughout the state. Thus, a similar comparison will be made for a wet pond designed to treat stormwater runoff from a half-mile length of 10-ft wide road with a cross-section as shown in Figure 7.1 for a rainfall depth of 1.0 inch. Since the watershed area is the same as that used for the sand filter analysis, the WQV remains unchanged at 2090 ft^3. Weiss et al. (2007) also developed an equation for the TPC of a wet pond based on the WQV, which is shown in Equation 5:

$$C_{WP} = 4398 \times (WQV)^{0.512} \qquad (5)$$

where, CWP = the TPC of a wet pond in 2005 dollars. Equation 5 gives a TPC of $220,379, which, when converted to 2019 dollars using the previously described process, is $383,459. This is over $153,000 more than the cost of a drainage swale and additional land would need to be purchased for the wet pond.

All values presented so far have been for a one-half mile length of road and for one travel lane only. According to MnDOT (2018), there are an estimated 239,772 low volume (ADT < 1000) lane miles in the State of Minnesota. It should be noted that only about one-third of the estimated lane miles were sampled for traffic volume data. Two-thirds of the lane miles were not sampled for traffic counts, instead their traffic volume was estimated. For the purposes of this memo, however, the value of 239,772 low volume lane miles is a reasonable estimate.

With an estimated 239,772 miles of low volume lane miles in Minnesota and 20-year TPC values for each one-half mile of one lane road, the 20-year TPC values presented above ($230,112, $1,004,160, and

$383,459 for swales, sand filters, and wet ponds, respectively) can be multiplied by 2 (to covert to cost per mile) and then by 239,772 to account for all low volume lane miles in the state. The result is a 20-year TPC of $110 billion for swales, $482 billion for sand filters, and $184 billion for wet ponds. This amounts to a 20-year savings of approximately $372 billion when using swales instead of sand filters and $74 billion when using swales instead of wet ponds. On a yearly basis (assuming a 20-year life), the state-wide cost savings of using swales as compared to sand filters and wet ponds is over $18 billion and $3.7 billion, respectively.

Thus, if drainage swales are used instead of sand filters, filtration beds, or wet ponds, significant savings can be achieved. In addition, drainage swales are primarily present to transport large storms away from the road and are necessary for this purpose. It is therefore possible that there is no additional cost for a drainage swale. Also, the above analysis considered only construction and 20 years of maintenance costs. Additional cost savings related to land acquisition can be realized because swales can be contained in the existing road right-of-way whereas sand filters and wet ponds cannot. This topic is discussed in the next section.

7.2 LAND SAVINGS

With the above value for WQV of 2090 ft^3, the required land area (i.e., stormwater treatment practice footprint) of a sand filter or wet pond can be estimated by assuming a maximum depth of one foot. With a 1-ft depth, the corresponding land area required for the WQV is 2090 ft^2. Thus, for every half-mile length of road, 2090 ft^2 would be needed to treat runoff from one 10-ft wide lane and 4180 ft^2 would be needed to treat runoff from one mile of a one-lane road. It will be assumed that drainage swales are within the road right-of-way and do not require any purchase of additional land. Thus, using swales can save 4180 ft^2 of land per lane mile of low-volume road. Again, with an estimated 239,772 lane miles of low-volume road in the state, just over 1 billion ft^2 or over 23,000 acres of land can be saved. With an estimated cost of $4,000 per acre in rural Minnesota (Meersman 2017), this amounts to a cost savings of over $92 million.

Of course, the cost savings alone is not enough. Swales must also provide environmental benefit to make them cost-effective when compared to other options for stormwater treatment. Swales, in fact, will remove more runoff constituents than sand filters or wet ponds. Thus, more environmental benefits will be realized at a lower cost. The next section discusses the increase in environmental benefits.

7.3 INCREASED ENVIRONMENTAL BENEFITS

The environmental benefit of a stormwater treatment practice can be quantified by the amount (or mass) of runoff constituent it is expected to remove on a yearly basis or over its design life. The cost-effectiveness of a stormwater treatment practice can thus be quantified by the cost per mass of constituent it is expected to remove over its design life. In this section both analyses will be performed for a drainage swale, a sand filter, and a wet pond designed for a half-mile length of 10-ft wide road that has a cross-section as shown in Figure 7.1.

Although not initially designed for stormwater treatment, drainage swales have been shown to infiltrate a large fraction of stormwater runoff from the road surface (Barrett et al. 1998). Garcia-Serrana et al. (2016) developed a method to estimate the average annual fraction of road runoff that will be infiltrated by a drainage swale that was used to develop the Roadside Swale Calculator (SAFL 2019). This calculator is in an Excel® spreadsheet that allows the user to select the location, and enter road width, swale width, and the overall effective saturated hydraulic conductivity, Ksat, (cm/hr) of the swale soil in order to estimate the fraction of annual runoff that will be infiltrated by the swale. Also, the *Minnesota Stormwater Manual* (MPCA 2018) states that water infiltrated by a stormwater treatment practice is assumed to have all of its corresponding runoff constituents removed in the process. Thus, for the sake of this analysis, 100% of the constituents in the swale-infiltrated fraction of stormwater runoff will be considered removed and will be attributed to the swale's effectiveness.

The location selected by the user in the Roadside Swale Calculator is used to select the correct relationship between percentile rainfall volume and rainfall depth, which are built-in to the calculator for various locations across Minnesota. For example, the percentile rainfall distribution for Itasca, MN is shown in Figure 7.2. The graph shows the fraction of annual runoff volume (on the horizontal axis) that falls in rainfall events less than or equal to the rainfall depth (vertical axis). Examination of Figure 7.2 shows that 63% of the historical annual rainfall depth fell in events of one inch or less and 80% of the annual rainfall volume has fallen in events of 1.5 inches or less. Thus, if a stormwater treatment practices were to be designed for a one-inch event, it would be expected to treat 63% of the annual runoff. The remaining 37% would exceed the design capacity and would bypass the practice with no treatment.

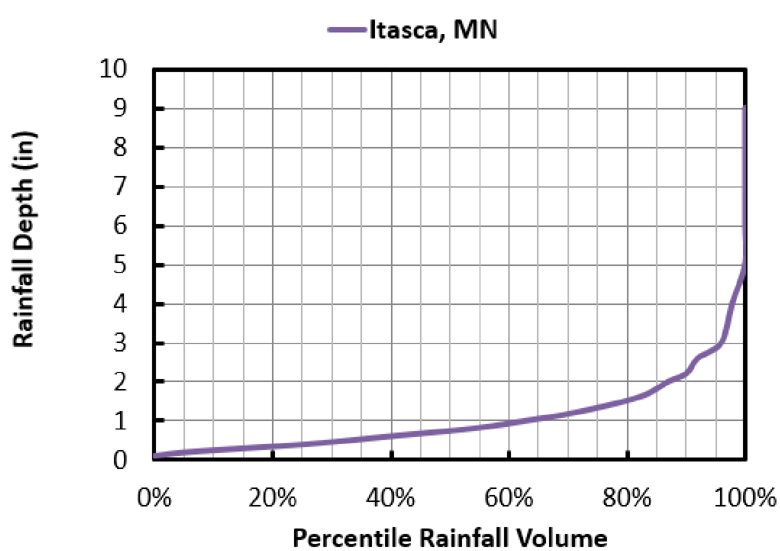


Figure 7.2. Rainfall volume percentile for Itasca, MN (SAFL 2019).

A typical value of K_{sat} for swales in Minnesota can be estimated from Ahmed et al. (2015) who investigated the infiltration capacity of swales and took hundreds of measurements of K_{sat} in the process. Multiple measurements of K_{sat} values were taken at various locations in swales and, upon investigation, the values were found to be log-normally distributed. Thus, Ahmed et al. (2015) reported the geometric mean for each location, which is the mean of a log-normally distributed sample. Those values are shown in Table 7.3. Of the 18 values reported, 12 of them are 2 cm/hr or greater. Thus, as an estimate, and perhaps a slightly conservative one, a value of 2.0 cm/hr will be assumed for K_{sat}.

Table 7.3. Geometric mean values of saturated hydraulic conductivity (K_{sat}) in swales as reported by Ahmed et al. (2015).

	Highway 47	Highway 51	Highway 212
Geometric Mean of K_{sat} (cm/hr)	1.70 3.85 0.85	17.00 11.50 6.50 5.70 2.10 2.80 4.45 1.75 2.00 4.00	0.45 1.05 0.30 6.53 2.03

For the road cross-section of Table 7.1, the width of road is 10 ft and the length of swale down the slope, using Pythagoreans theorem, is 9.4 ft. With a typical K_{sat} value of 2.0 cm/hr and the location of Itasca, MN, the Roadside Swale Calculator estimates that 78% of the annual road runoff will be infiltrated by the swale. To estimate the mass of runoff constituents that will be removed in this process, the results from the current project's roadside sampling efforts were used. The sampling method collects runoff from approximately the first 0.25 inches of rain that runs off the road surface. Thus, the measured concentration is likely a first-flush concentration with subsequent runoff having a lower concentration due to the first-flush phenomenon. The first-flush phenomenon is typically strongest on small watersheds with a high percent of impervious cover (Stenstrom and Kayhanian 2005), and is thus expected for road runoff. Thus, runoff constituent concentrations measured along the low-volume road sites in this study were adjusted to account for first flush. As done in Section 4, the adjustment was performed using values from Stenstrom and Kayhanian (2005) who quantified the impact of first flush on a series of constituents in stormwater runoff from highways. The ratio of the EMC (event mean concentration) to the first flush concentration was calculated for their study. Then, the ratio was multiplied by the concentration measured in the low-volume road runoff samples collected in this study, to estimate an EMC for each constituent. Values used in this process, including the resulting estimated EMC for each runoff constituent, are shown in Table 7.4.

Table 7.4. Measured median first-flush concentrations and estimated EMCs of runoff constituents for the low-volume roads sampled in Minnesota.

Runoff Constituent	Measured Median First Flush Concentration (mg/L)	EMC/First Flush Concentration Ratio (Stenstrom and Kayhanian 2005)	Estimated EMC Concentration (mg/L)
TSS	94	0.58	55
TP	0.23	0.58	0.13
NO_2+NO_3	0.34	0.74	0.25
Cd	0.00038	0.79	0.00030
Cr	0.0050	0.82	0.0041
Cu	0.012	0.61	0.0073
Pb	0.0034	0.81	0.0028
Ni	0.0099	0.60	0.0059
Zn	0.108	0.60	0.065

With Itasca, MN receiving, on average, 27.9 inches of rain annually, and R_v = 0.95, the total annual runoff from a half-mile (2640 ft) length of 10-ft wide road can be obtained by multiplying the length of road by its width and depth of rain in feet (2.32 ft) and, finally, by R_v. The result is 58,311 ft^3 of runoff, 78% of which will be infiltrated by the swale. With the estimated EMC concentrations shown in Table 7.4 and the estimated runoff volume and fraction infiltrated of 78%, the mass of runoff constituents removed by the swale over a 20-year period can be estimated as can the TPC (for a 20-year period) per mass of runoff constituent removed. Results for all runoff constituents are shown in Table 7.5.

Table 7.5. Estimated mass of runoff constituents removed by the swale and cost-effectiveness for one-half mile of two-lane low-volume road.

Runoff Constituent	Annual Load (g)	Annual Mass Removed (g)	Total Mass Removed in 20 years (g)	20-yr TPC per Gram Removed ($/g)
TSS	90344	70468	1409367	0.16
TP	221	173	3450	67
N	413	322	6449	36
Cd	0.496	0.387	7.74	29716
Cr	6.75	5.27	105	2185
Cu	12.1	9.40	188	1224
Pb	4.56	3.56	71.2	3232
Ni	9.73	7.59	152	1516
Zn	107	83.5	1670	138

A different calculation process is necessary to estimate the mass of runoff constituents removed by the sand filter and wet pond. In this process, the total annual volume of runoff is estimated by multiplying the annual depth of precipitation by the watershed area and by R_v. In this case, the watershed area is 26,400 ft^2, which was obtained by multiplying 2640 ft of road by the 10-ft wide lane width. The resulting value of annual runoff is 58,311 ft^3. Then, using Figure 7.2 with the assumption that the sand filter or wet pond is designed for a WQV based on a 1.0 inch rainfall, it can be assumed, as previously discussed, that the treatment practice will treat 63% of the annual runoff with the remaining 37% bypassing the practice. The treated portion will have a fraction of the runoff constituents removed and the bypassed portion will not. The fraction of constituent removed by sand filters and wet ponds from the treated portion was assumed to be equal to values reported in the *Minnesota Stormwater Manual* (MPCA 2018). These values are shown in Table 7.6.

Table 7.6. Assumed fraction of runoff constituents removed by sand filters and wet ponds (MPCA 2018).

Runoff Constituent	Reduction by Sand Filters	Reduction by Wet Ponds
TSS	85%	80%
TP	50%	60%
N	35%	30%
Metals	50%	60%

Multiplying the total annual volume of runoff (58,311 ft^3 or 1,651,181 L) by the average EMC gives the total annual mass of runoff constituent generated from the one-half mile length of 10-ft wide road. Recognizing that 37% of the runoff will bypass the sand filter or wet pond and, using the removal rates shown in Table 7.6 (for the non-bypassed fraction), the annual mass of runoff constituent removed can be estimated. Multiplying that value by 20 gives the total mass of constituent removed over a 20-year period. Dividing the TPC cost of each treatment practice by the mass of runoff constituent removed (in 20 years) gives the cost per gram of runoff constituent removed over a 20-year period. Results are shown in Table 7.7 and Table 7.8. A summary of the above results for drainage swales, sand filters, and wet ponds are given in Table 7.9 and Table 7.10.

Table 7.7. Estimated sand filter loading, performance, and cost-effectiveness for one-half mile of two-lane low-volume road.

Runoff Constituent	Annual Load (g)	Annual Load Treated by Sand Filter	Annual Mass Removed by Sand Filter (g)	Total Mass Removed in 20 years (g)	20-yr Cost per gram removed ($/g)
TSS	90344	56917	48379	967584	1.04
TP	221	139	70	1393	721
N	413	260	91	1823	551
Cd	0.50	0.31	0.16	3	321093
Cr	6.8	4.3	2.13	43	23612
Cu	12.1	7.6	3.80	76	13225
Pb	4.6	2.9	1.44	29	34922

Runoff Constituent	Annual Load (g)	Annual Load Treated by Sand Filter	Annual Mass Removed by Sand Filter (g)	Total Mass Removed in 20 years (g)	20-yr Cost per gram removed ($/g)
Ni	9.7	6.1	3.07	61	16381
Zn	107	67	34	674	1489

Table 7.8. Estimated wet pond loading, performance, and cost-effectiveness for one-half mile of two-lane low volume road.

Runoff Constituent	Annual Load (g)	Annual Load Treated by Wet Pond	Annual Mass Removed by Wet Pond (g)	Total Mass Removed in 20 years (g)	20-yr Cost per gram removed ($/g)
TSS	90344	56917	45533	910668	0.42
TP	221	139	84	1672	229
N	413	260	78	1563	245
Cd	0.50	0.3	0.19	4	102180
Cr	6.8	4.3	2.55	51	7514
Cu	12.1	7.6	4.56	91	4208
Pb	4.6	2.9	1.73	35	11113
Ni	9.7	6.1	3.68	74	5213
Zn	107	67	40	809	474

Table 7.9. Estimated Total Present Cost (TPC) and total mass (g) removed for one-half lane mile of a low-volume road.

	20-yr TPC (2019 $)	TSS (g)	TP (g)	N (g)	Cd (g)	Cr (g)	Cu (g)	Pb (g)	Ni (g)	Zn (g)
Swale	230,112	1,409,367	3,450	6,449	7.7	105	188	71	152	1,670
Sand Filter	1,004,160	967,584	1,393	1,823	3.1	43	76	29	61	674
Wet Pond	383,459	910,668	1,672	1,563	3.8	51	91	35	74	809

Table 7.10. Estimated 20-year Total Present Cost per mass removed for one-half lane mile of a low-volume road (note that the values are in $/g, except for TSS as noted).

	TSS ($/kg)	TP ($/g)	N ($/g)	Cd ($/g)	Cr ($/g)	Cu ($/g)	Pb ($/g)	Ni ($/g)	Zn ($/g)
Swale	163	67	36	29,716	2,185	1,224	3,232	1,516	138
Sand Filter	1038	721	551	321,093	23,612	13,225	34,922	16,381	1,489
Wet Pond	421	170	182	75,634	5,562	3,115	8,226	3,859	351

The values given in Table 7.10 are shown graphically in Figure 7.3 and Figure 7.4. In all cases the swale is much more cost-effective than the sand filter and wet pond. Also, as shown in Table 7.9, swales are less expensive and remove more runoff constituents than sand filters and wet ponds. Thus, swales result in a cost savings and enhanced environmental benefits. One must keep in mind that the values presented in this document are estimated values for a one-half mile length of 10-ft wide road. Thus, the environmental benefits of using swales state-wide can be many times greater than what is represented herein. Also, it must be remembered that the above values were generated for one 10-ft wide travel lane. If two travel lanes were included, the values for cost and mass loads would be double but the values of cost-effectiveness (i.e., $/gram removed) would remain unchanged because the mass of runoff constituent removed would also be doubled.

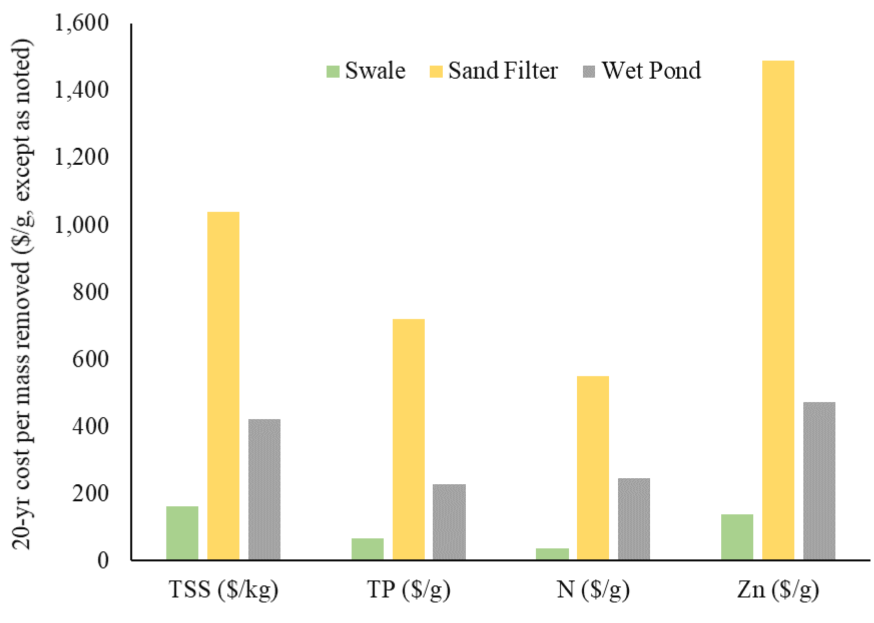


Figure 7.3. Cost-effectiveness comparison for TSS, P, N, and Zn removal by selected stormwater treatment practices.

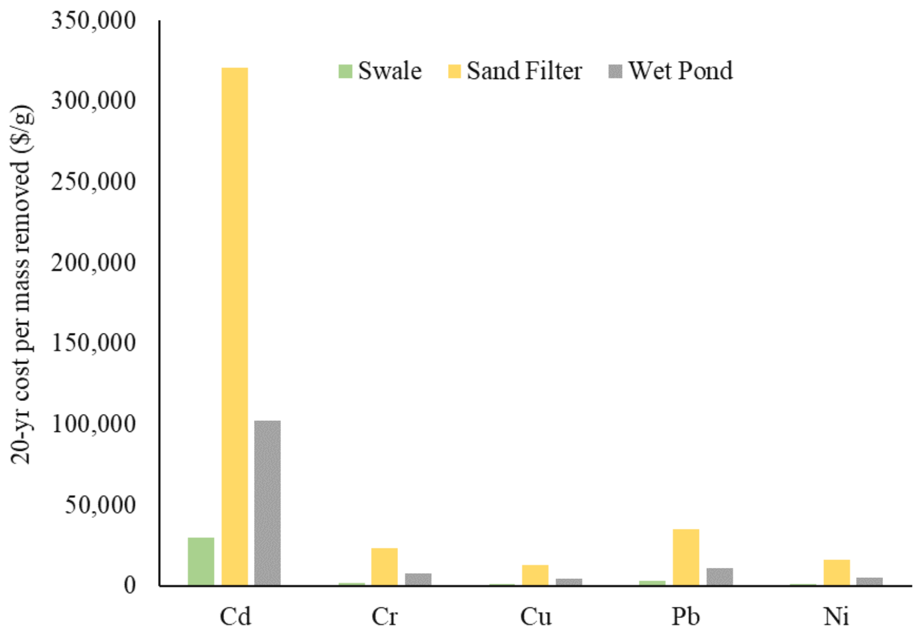


Figure 7.4. Cost-effectiveness comparison for Cd, Cr, Cu, Pb, and Ni removal by selected stormwater treatment practices.

7.4 IMPLEMENTATION AND SUMMARY OF STATE-WIDE COST ANALYSIS

In order to implement this research, it is recommended to select roadside swales as the preferred stormwater treatment practice for low-volume roads throughout the state. Due to their ability to infiltrate a large fraction of the annual rainfall/runoff, swales infiltrate a large fraction of the annual runoff constituent load in that runoff. With the assumption that 100% of the constituents in the infiltrated portion are removed (as stated in the *Minnesota Stormwater Manual*), swales can remove more runoff constituents than other treatment practices such as sand filters and wet ponds. Furthermore, because roadside swales are relatively inexpensive to construct and require no additional land acquisition outside of the right-of-way, they are also cheaper than other stormwater treatment practices. In fact, swales are considerably less expensive and remove more runoff constituents than wet ponds, which are widely used due to their low cost and relatively high runoff constituent removal effectiveness.

CHAPTER 8: SUMMARY AND CONCLUSIONS

In this study, the stormwater runoff quality from along paved, rural, low-volume roads in Minnesota with ADT less than 1500 was characterized. Ten sites along low-volume roads were sampled to collect the initial runoff (first 1 L) from rainfall events using an edge-of-the road sampler over a two-year monitoring period.

1) The initial runoff constituent concentrations were variable at each monitoring site and across the ten sites over the 174 sampled events. The concentrations varied from 3.1 to 1900 mg/L for TSS (mean = 164 mg/L ± 234 SD), 0.01 to 2.5 mg/L for TP (mean = 0.34 ± 0.37 mg/L), 0.015 to 2.7 mg/L for nitrite+nitrate (mean = 0.43 ± 0.41 mg/L), 10 to 1174 µg/L for zinc (mean = 168 ± 167 µg/L), and 2.5 to 92 µg/L for copper (mean = 15 ± 14 µg/L). Other metals (cadmium, chromium, lead, and nickel) were below measurable levels in a majority of the samples collected from all sites. Samples collected from Mississippi River headwaters showed that the roadway runoff concentrations were higher and affected by the adjoining land.
2) There were substantial differences in the runoff concentrations of sites with wooded land cover versus sites with agricultural land use along the low-volume roads. Wooded sites had lower mean total phosphorus and zinc concentrations and higher nitrite+nitrate concentrations. We believe that this is related to the land use and the corresponding soil that wind and car tires would pull onto the roadways.
3) Surrounding soil type also influenced the runoff constituent concentrations. The overall mean TSS, TP and metal levels in the initial runoff were higher at sites with loam soil when compared to sandy loam, possibly because finer soil particles in loamy soil are easily transported by wind and vehicle tires. There was cross correlation between land use and soil types, however, and this was a confounding factor in conclusions 2) and 3).
4) The concentrations of all measured metals (cadmium, chromium, copper, lead, nickel and zinc) in the runoff of low-volume roads were found to be substantially lower than those of high-volume roads.
5) The other runoff constituents (TSS, total phosphorus, and nitrite+nitrate) had an estimated median EMC (estimated from the product of the initial median concentration and the EMC:first flush ratio) that was present at slightly lower levels for low-volume roads than high-volume roads.
6) Unlike some high-volume roads, no correlation was observed between runoff constituent concentrations and ADT, antecedent dry period, and rainfall depth. This is attributed to wind transport of solids and the carried constituents being dominant on low-volume roads.
7) Roadside drainage ditches or grassed swales are potential cost-effective stormwater treatment option for low-volume roads. Swales are an excellent means to remediate runoff concentrations through infiltration and deposition of suspended solids. They fit into the road right-of-way, and thus are a common method to remove excess runoff. In Minnesota, such roadside swales generally have high infiltration rates that result in runoff constituent removal from surface waters.
8) Drainage swales can also provide cost savings. Swales alone are less expensive to install and maintain, especially when the swale is in the right-of-way and purchase of additional land for

stormwater treatment is not necessary. Swales remove more runoff constituents than other practices such as wet ponds.

9) Example road widening projects (that create more than 1 ac impervious area) were modeled in the MIDS calculator to show how stormwater management requirements of the road widening projects can be achieved using swales. Depending on the swale width scenario modeled and hydrologic soil type (HSG), swales alone were sufficient to satisfy the volume retention requirement in some cases, and additional BMPs were required to provide additional capture volume in other cases.
10) The Roadside Swale Calculator (RSC) was also used for confirmation and comparison with the MIDS model. Some discrepancies were found between the RSC calculator and MIDS calculator results.
11) There are advantages and disadvantages to using the RSC over the MIDS calculator. The MIDS calculator does not give adequate credit for infiltration on the side slopes of swales, which we believe is insufficient. The RSC, however, has only a 1.64 ft (0.5 m) swale bottom width which will reduce the amount of infiltration that occurs in the RSC mode. We recommend that calculations be done using both the MIDS and RSC calculators since both methods have their own limitations, and both are conservative regarding the water infiltrated.

REFERENCES

AASHTO. (2019). *Guidelines for geometric design of low-volume roads*, Second Ed. American Association of State Highway and Transportation Officials (AASHTO), Washington, DC.

Abaza, O., Dotson, A. D., & Verdick, T. (2012). Environmental impacts of roadside snow. Proceedings of the 15th International Specialty Conference on Cold Regions Engineering, Quebec City, Canada, August 19-22.

Abida, H., & Sabourin, J. F. (2006). Grass swale-perforated pipe systems for stormwater management. *Journal of Irrigation and Drainage Engineering*, 132(1): 55-63.

Ahearn, D., & Tveten, R. (2008). Legacy LID: Stormwater treatment in unimproved embankments along highway shoulders in Western Washington. International Low Impact Development Conference, November 16-19, 2008, Seattle, WA.

Ahmed, F., Natarajan, P., Gulliver, J. S., Weiss, P. T., & Nieber, J. L. (2014). *Assessing and improving pollution prevention by swales* (Final Report 2014-30). Research Services and Library, Office of Transportation System Management, Minnesota Department of Transportation, St Paul, MN. http://www.lrrb.org/PDF/201430.pdf

Backstrom, M. (2002). Grassed swales for urban storm drainage. Doctoral thesis, Division of Sanitary Engineering Lulea University of Technology, Lulea, Sweden.

Bahar, B., Herting, G., Wallinder, I., Hakkila, K., Leygraf, C., & Virta, M. (2008). The interaction between concrete pavement and corrosion-induced copper runoff from buildings. *Environmental Monitoring and Assessment, 140*(1), 175-189.

Ball, J. E., Jenks, R., & Aubourg, D. (1998). An assessment of the availability of pollutant constituents on road surfaces. *The Science of the Total Environment, 209,* 243-254.

Barber, M. E., Brown, M. G., & Lingenfelder, K. M. (2006). *Phase I: Preliminary environmental investigation of heavy metals in highway runoff.* Washington State Transportation Center, Pullman, WA.

Barrett, M. E., Irish L. B., Malina J. F., & Charbeneau R. J. (1998). Characterization of highway runoff in Austin, Texas area. *J. Environ. Eng., 124*(2), 131-137.

Brandt, H. C. A., & de Groot, P. C. (2001). Aqueous leaching of polycyclic aromatic hydrocarbons from bitumen and asphalt. *Water Research, 35*(17), 4200-4207.

Caltrans. (2003). *Final Report: Roadside Vegetated Treatment Sites (RVTS) Study* (CTSW-RT-03-028). Caltrans Division of Environmental Analysis, Sacramento, CA.

Chow, M. F., Zulkifli, Y., & Abustan, I. (2015). Relationship between sediment build-up characteristics and antecedent dry days on different urban road surfaces in Malaysia. *Urban Water Journal, 12*(3), 240-247.

Coghlan, G. T. (1999). *Opportunities for low-volume roads* (Transportation Research Board (TRB) A5002, Committee on Low Volume Roads). Unpublished. Retrieved from http://onlinepubs.trb.org/onlinepubs/millennium/00068.pdf

Davis, B., & Birch, G. (2010). Comparison of heavy metal loads in stormwater runoff from major and minor urban roads using pollutant yield rating curves. *Environmental Pollution, 158,* 2541-2545.

Davis, A. P., Shokouhian, M., & Ni, S. (2001). Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere, 44,* 997-1009.

Dong, T. T. T., & Lee, B. K. (2009). Characteristics, toxicity, and source apportionment of polycylic aromatic hydrocarbons (PAHs) in road dust of Ulsan, Korea. *Chemosphere, 74*, 1245-1253.

Drapper, D., Tomlinson, R., & Williams, P. (2000). Pollutant concentrations in road runoff: Southeast Queensland case study. *Journal of Environmental Engineering, 126*(4), 313-320.

Driscoll, E. D., Shelley, P. E., & Strecker, E. W. (1990a). *Pollutant loadings and impacts from highway stormwater runoff volume 1: Design procedure*. Federal Highway Administration, McLean, VA.

Driscoll, E. D., Shelley, P. E., & Strecker, E. W. (1990b). *Pollutant loadings and impacts from highway stormwater runoff, volume III-analytical investigation and research report* (Report #FHWA-RD-88-08). Federal Highway Administration, McLean, VA.

Egodawatta, P., Ziyath, A. M., & Goonetilleke, A. (2013). Characterizing metal build-up on urban road surfaces. *Environmental Pollution, 176,* 87-91.

Ellis, J. B., Harrop, D .O., & Revitt, D.M., (1986). Hydrological controls of pollutant removal from highway surfaces. *Water Research, 20*(5), 589-595.

Finney, K., Gharabaghi, B., McBean, E., Rudra, R., & MacMillan, G. (2010). Compost biofilters for highway stormwater runoff treatment. *Water Quality Res. J. Can., 45*(4), 391-402.

Gan, H., Zhuo, M., Li, D., & Zhou, Y. (2008). Quality characterization and impact assessment of highway runoff in urban and rural area of Guangzhou, China. *Environ. Monit. Assess, 140,* 147-159.

Garcia-Serrana, M., Gulliver, J. S., & Nieber, J. L. (2016). *Enhancement and application of the Minnesota Dry Swale Calculator*. Minnesota Department of Transportation, St. Paul, MN.

Garcia-Serrana, M., Gulliver, J. S. & Nieber, J. L. (2017a). Infiltration capacity of roadside filter strips with non-uniform overland flow. *Journal of Hydrology, 545,* 451-462.

Garcia-Serrana, M., Gulliver, J. S. & Nieber, J. L. (2017b). Non-uniform overland flow-infiltration model for roadside swales. *Journal of Hydrology, 552,* 586-599.

Garcia-Serrana, M., Nieber, J. L. & Gulliver, J. S. (2018). Infiltration flux for parallel strip water sources. *Vadose Zone, 16*(11), 1-12. https://doi.org/10.2136/vzj2017.07.0137

Garcia-Serrana, M., Gulliver, J. S., & Nieber, J. L. (2018). Calculator to estimate annual infiltration performance of roadside swales. *Journal of Hydrologic Engineering, 23*(6), 04018017.

Glenn, D. W., & Sansalone, J.J. (2002). Accretion and partitioning of heavy metals associated with snow exposed to urban traffic and winter storm maintenance activities. *Journal of Environmental Engineering, 128*(2), 167-185.

Gunawardena, J., Egodawatta, P., Ayoko, G. A., & Goonetilleke, A. (2012). Role of traffic in atmospheric accumulation of heavy metals and polycyclic aromatic hydrocarbons. *Atmospheric Environment, 54*, 502-510.

Gunawardena, J., Egodawatta, P., Ayoko, G. A., & Goonetilleke, A. (2013). Atmospheric deposition as a source of heavy metals in urban stormwater. *Atmospheric Environment, 68*, 235-242.

Gunawardena, J., Ziyath, A. M., Egodawatta, P., Ayoko, G. A., & Goonetilleke, A. (2014). Mathematical relationships for metal build-up on urban road surfaces based on traffic and land use characteristics. *Chemosphere, 99*, 267-271.

Haselbach, L., Poor, C., & Tilson, J. (2014). Dissolved zinc and copper retention from stormwater runoff in ordinary Portland cement pervious concrete. *Construction and Building Materials, 53,* 652–657. doi:10.1016/j.conbuildmat.2013. 12.013

Helmreich, B., Hilliges, R., Schriewer, A., & Horn, H., (2010). Runoff pollutants of a highly trafficked urban road — Correlation analysis and seasonal influences. *Chemosphere, 80*, 991-997.

Herngren, L., Goonetilleke, A., Ayoko, G. A., & Mostert, M. M. M. (2010). Distribution of polycyclic aromatic hydrocarbons in urban stormwater in Queensland, Austalia. *Environ. Pollut. 158*, 2848-2856.

Huber, M., & Helmreich, B. (2016). Stormwater management: Calculation of traffic area runoff loads and traffic related emissions. *Water, 8*, 294. doi:10.3390/w8070294

Huber, M., Welker, A., & Helmreich, B. (2016). Critical review of heavy metal pollution of traffic area runoff: Occurrence, influencing factors, and partitioning. *Science of the Total Environment, 541*, 895-919.

Hussain, K., Rahman, M., Prakash, A., & Hoque, R. R. (2015). Street dust bound PAHs, carbon and heavy metals in Guwahati city – seasonality, toxicity and sources. *Sustain. Cities Soc., 19*, 17-25.

Hwang, H. M., & Foster, G. D. (2006). Characterization of polycyclic aromatic hydrocarbons in urban stormwater runoff flowing into the tidal Anocostia River, Washington, D.C., USA. *Environmental Pollution, 140*, 416-426.

Irish, Jr. L. B., Malina, J. F., Charbeneau, R. J., & Ward, G. H. (1995). Solids loading model for an urban highway. *Proc., 1st Int. Conf. om Water Resources*, Part 2. San Antonio, TX.

Irish, Jr., L. B., Barrett, M. E., Malina M. E., & Charbeneau R. J. (1998). Use of regression models for analyzing highway stormwater loads. *J. Environ. Eng., 124*(10), 987-993.

Kaighn, R. J., & Yu, S. L. (1996). Testing of roadside vegetation for highway runoff pollutant removal. *Transportation Research Record*, *1523*, 116-123.

Kayhanian, M., Singh, A., Suverkropp, C., & Borroum, S. (2003). Impact of annual average daily traffic on highway runoff pollutant concentrations. *Journal of Environmental Engineering, 129*(11), 975-990.

Kayhanian, M., Suverkropp, C., Ruby, A., & Tsay, K. (2007). Characterization and prediction of highway runoff constituent event mean concentration. *Journal of Environmental Management, 85*, 279-295.

Kayhanian, M., Vichare, A., Green, P. G., & Harvey, J. (2009). Leachability of dissolved chromium in asphalt and concrete surfaces. *Journal of Environmental Management, 90*(11), 3574-3580.

Kayhanian, M., Fruchtman, B., Gulliver, J. S., Montanaro, C., Raniere, E., & Wuertz, S. (2012). Review of highway runoff characteristics: Comparative analysis and universal implications. *Water Research*, *46*(9), 6609-6624.

Kerri, K. D., Racin, J. A., & Howell, R. B. (1985). Forecasting pollutant loads from highway runoff. *Transportation Research Record, 1017*, 39-46.

Kim, L. H., Kayhanian, M., Zoh, K. D., & Stenstrom, M. K. (2005). Modeling of highway stormwater runoff. *Science of the Total Environment, 348*,1-18.

Klimaszewska, K., Polkowska, Z., & Namiesnik, J. (2007). Influence of mobile sources on pollution of runoff waters from roads with high traffic intensity. *Polish Journal of Environmental Studies, 16*(6), 889-897.

Lancaster, C. D. (2005). *A low impact development method for mitigating highway stormwater runoff — Using natural roadside environments for metals retention and infiltration*, M.S. Thesis. Washington State University, Department of Civil and Environmental Engineering, Pullman, WA.

Li, M. H., & Barrett, M .B. (2008). Relationship between antecedent dry period and highway pollutant: Conceptual models of buildup and removal processes. *Water Environment Research, 80*(8), 740-747.

Li, M. H., Barrett, M. B., Rammohan, P., Olivera, F., & Landphair, H. C. (2008). Documenting stormwater quality on Texas highways and adjacent vegetated roadsides. *Journal of Environmental Engineering, 134*(1), 48-59.

Li, Y. X., Song, N., N., Yu, Y., Yang, Z. F., & Shen, Z. Y. (2016). Characteristics of PAHs in street dust of Beijing and the annual wash-off load using an improved load calculation method. *Sci. Total Environ*. doi.org/10.1016/j.scitotenv.2016.12.133

Liu, A., Liu, L., Li, D., & Guan, Y. (2015). Characterizing heavy metal build-up on urban road surfaces: Implication for stormwater reuse. *Science of the Total Environment, 515-516*, 20-29.

Liu, A., Gunawardana, C., Gunawardena, J., Egodawatta, P., Ayoko, G. A., & Goonetilleke, A. (2016a). Taxonomy of factors which influence heavy metal build-up on urban road surfaces. *Journal of Hazardous Materials, 310*(5):20-29.

Liu, L., Liu, A., Li, Y., Zhang, L. X., Zhang, G. J., & Guan, Y. T. (2016b). Polycyclic aromatic hydrocarbons associated with road deposited solid and their ecological risk: implications for road stormwater reuse. *Sci. Total Environ, 563–564*: 190-198.

Liu, A., Ma, Y., Deilami, K., Egodawatta, P., & Goonetilleke, A. (2017). Ranking the factors influencing polycyclic aromatic hydrocarbons (PAHs) build-up on urban roads. *Ecotoxicology and Environmental Safety, 139*, 416-422.

MacKay, A. A., Zinke, S., Mahoney, J., & Bushey, J. T. (2011). Roadway runoff water quality from milled and unaltered surfaces during convective storms. *Journal of Environmental Engineering, 137*(12), 1165-1175.

Maestre, A., & Pitt, R. (2005). *The National Stormwater Quality Database, Version 1.1: A Compilation and Analysis of NPDES Stormwater Monitoring Information*. University of Alabama, Tuscaloosa, AL, and Center for Watershed Protection, Ellicott City, MD.

Mahbub, P., Ayoko, G. A., Goonetilleke, A., & Egodawatta, P. (2011). Analysis of the build-up of semi and non-volatile organic compounds on urban roads. *Water Research, 45*, 2838-2844.

Miguntanna, N. P., Goonetilleke, A., Egodowatta, P., & Kokot, S. (2010). Understanding nutrient build-up on urban road surfaces. *Journal of Environmental Sciences, 22*(6), 806-812.

MPCA (2018). *Minnesota Stormwater Manual. Chapter III. Stormwater discharge design requirements*. Minnesota Pollution Control Agency, St. Paul, MN. Retrieved from https://stormwater.pca.state.mn.us/index.php?title=III._STORMWATER_DISCHARGE_DESIGN_REQUIREMENTS

MPCA (2020). *Minnesota Stormwater Manual. Minimal Impact Design Standards.* Minnesota Pollution Control Agency, St. Paul, MN. Retrieved from https://stormwater.pca.state.mn.us/index.php?title=Updates_to_the_MIDS_calculator

MnDOT. (2018). *Low-volume roads: Rural and urban*. Minnesota temporary traffic control field manual 2018. Minnesota Department of Transportation, St. Paul MN. Retrieved from http://www.dot.state.mn.us/trafficeng/publ/fieldmanual/index.html

Moffet, M. C. (2017). *Preliminary characterization of highway stormwater runoff from various sites in Tennessee*, M.S. Thesis. Tennessee Technological University, Cookeville, TN.

Moghadas, S., Paus, K. H., Muthanna, T. M., Herrmann, I., Marsalek, J., & Viklander, M. (2015). Accumulation of traffic-related trace metals in urban winter-long roadside snowbanks. *Water, Air, Soil Pollution, 226*(12), 404.

Mummullage, S., Egodawatta, P., Ayoko, G. A., & Goonetilleke, A. (2016). Sources of hydrocarbons in urban road dust: Identification, quantification and prediction. *Environmental Pollution, 216*, 80-85.

Murphy, L. U., Cochrane, T. A., & O'Sullivan, A. (2015). The influence of different pavement surfaces on atmospheric copper, lead, zinc, and suspended solids attenuation and wash-off. *Water Air Soil Pollution, 226*, 232.

Rodriguez-Hernandez, J., Fernandez-Barrera, A. H., Andres-Valeri, V. C. A., Vega-Zamanillo, A., & Castro-Fresno, D. (2013). Relationship between urban runoff pollutant and chatchment characteristics. *Journal of Irrigation and Drainage Engineering, 139*(10), 833-840.

Sadler, R., Delamont, C., White, P., & Connell, D. (1999). Contaminants in soil as a result of leaching from asphalt. *Toxicological & Environmental Chemistry, 68*(1-2), 71-81.

SAFL. (2019). *Roadside swale calculator*. Retrieved from http://stormwater.safl.umn.edu/resources/roadside-swale-calculator

Sansalone, J. J., Koran, J. M., Smithson, J .A., & Buchberger, S. G. (1998). Physical characteristics of urban roadway solids transported during rain events. *Journal of Environmental Engineering, 124*(5), 427-440.

Sansalone, J. J., & Glenn, D. W. (2002). Accretion of pollutants in snow exposed to urban traffic and winter storm maintenance activities. *Journal of Environmental Engineering, 128*(2), 151-166.

Selbig, W. R. (2015). Characterizing the distribution of particles in urban stormwater: Advancements through improved sampling technology. *Urban Water Journal, 12*(2), 111-119.

Smith, K. P., & Granato, G .E. (2010). *Quality of stormwater runoff discharged from Massachusetts highways.* 2005–07: U.S. Geological Survey Scientific Investigations (Report 2009-5269). U.S. Geological Survey, Reston, VA.

Stagge, J. H., Davis, A. P., Jamil, E., & Hunho, K. (2012). Performance of grass swales for improving water quality from highway runoff. *Water Research*, *46*(20), 6731-6742.

Stenstrom, M. K., & Kayhanian, M. (2005). *First flush phenomenon characterization*. Prepared for California Department of Transportation, Division of Environmental Analysis, Sacramento, CA.

Soil Science Division Staff. (2017). *Soil Survey Manual*. C. Ditzler, K. Scheffe, and H.C. Monger (eds.), USDA Handbook 18. Government Printing Office, Washington, D.C.

Thiem, L. T., Alkhatib, E. A., Bade, S. K., & Panganamamula, A. (1998). *Characterization of roadway runoff prior to treatment*. Rhode Island Department of Transportation, Providence, RI.

US EPA. (2000). *Guidance for data quality assessment: Practical methods for data analysis: EPA QA/G9: QA00 Update: July 2000*. US EPA, Washington D.C. Retrieved from https://www.epa.gov/quality/guidance-data-quality-assessment

Vaze, J., & Chiew, F. H. S. (2002). Experimental study of pollutant accumulation on an urban road surface. *Urban Water, 4*, 379-389.

Wang, S., He, Q., Ai, H., Wang, Z., & Zhang, Q. (2013). Pollutant concentrations and pollutant loads in stormwater runoff from different land uses in Chongqing. *Journal of Environmental Sciences*, *25*(3), 502-510.

Weiss, P. T., Gulliver, J. S., & Erickson, A. J. (2005). *The cost and effectiveness of stormwater management practices.* Minnesota Department of Transportation, St. Paul, MN.

Wicke, D., Cochrane, T. A., & O'Sullivan, A. D. (2012). Atmospheric deposition and storm induced runoff of heavy metals from different impermeable urban surfaces. *Journal of Environmental Monitoring, 14*(1), 209-216.

Winston, R. J., & Hunt, W. F. (2017). Characterizing runoff from roads: Particle size distributions, nutrients, and gross solids. *Journal of Environmental Engineering, 143*(1), 04016074. doi.10.1061/(ASCE)EE.1943-7870.0001148

Wu, J. S., Allan, C. J., Saunders, W. L., & Evett, J. B. (1998). Characterization of pollutant loading estimation for highway runoff. *Journal of Environmental Engineering, 124*(7), 584-592.

Yonge, D. R. (2000). *Contaminant detention in highway grass filter strips* (Report No. WA-RD 474.1). Washington State Department of Transportation, Olympia, WA.

Yousef, Y. A., Hvitved-Jacobsen, T., Wanielista, M. P., & Harper, H. H. (1987). Removal of contaminants in highway runoff flowing through swales. *Science of the Total Environment*, *59*, 391-399.

Yu, S. L., Kuo, J. T., Fassman, E. A., & Pan, H. (2001). Field test of grassed-swale performance in removing runoff pollution. *Journal of Water Resources Planning and Management*, *127*(3), 168-171.

Zhang, J., Hua, P., & Krebs, P. (2015). The build-up dynamic and chemical fractionation of Cu, Zn and Cd in road-deposited sediment. *Science of the Total Environment*, 532, 723-732.

Zhao, H., & Li, X. (2013). Understanding the relationship between heavy metals in road-deposited sediments and wash-off particles in urban stormwater using simulated rainfall. *Journal of Hazardous Materials, 246-247*, 267-276.

APPENDIX A
2018 AND 2019 WATER QUALITY DATA FOR THE LOW-VOLUME ROAD MONITORING SITES

Table A- 1. Runoff quality sampled at the ten low-volume road sampling sites and the Mississippi river headwaters in 2018 and 2019.

County	Site ID	ADT	Land use	Rainfall	Rainfall depth (in)	ADP days	TSS mg/L	TP mg/L	NO_2+NO_3 mg/L	T. Cd µg/L	T. Cr µg/L	T. Cu µg/L	T. Pb µg/L	T. Ni µg/L	T. Zn µg/L
Aitkin	CSAH 39	660	Wooded	6/26/18	0.10	9	89	0.18	1.78	< 3	< 10	15	< 10	< 20	93
Aitkin	CSAH 39	660	Wooded	6/30/18	0.70	5	136	0.22	0.96	< 20	< 10	14	< 20	< 10	81
Aitkin	CSAH 39	660	Wooded	7/12/18	4.4	4	84	0.16	1.18	< 20	< 10	16	< 20	< 10	75
Aitkin	CSAH 39	660	Wooded	7/19/18	0.60	4	42	0.13	1.08	< 20	< 10	14	< 20	< 10	54
Aitkin	CSAH 39	660	Wooded	8/3/18	1.9	2	62	0.05	0.68	< 3	< 10	< 10	< 10	< 20	42
Aitkin	CSAH 39	660	Wooded	8/20/18	0.9	17	86	0.15	0.92	< 3	< 10	22	< 10	< 20	145
Aitkin	CSAH 39	660	Wooded	9/4/18	0.40	2	205	0.26	0.48	< 3	15	23	< 10	< 20	124
Aitkin	CSAH 39	660	Wooded	9/14/18	2.0	10	94	0.13	1.04	< 3	< 10	< 10	< 10	< 20	60
Aitkin	CSAH 39	660	Wooded	9/24/18	0.25	4	20	0.08	0.90	< 3	< 4	11	< 6.8	3.2	62
Aitkin	CSAH 4	600	Wooded	6/28/18	0.30	11	528	0.82	0.76	< 3	25	42	11	26	131
Aitkin	CSAH 4	600	Wooded	7/3/18	0.20	2	140	0.23	1.06	< 20	< 10	18	< 20	< 10	56
Aitkin	CSAH 4	600	Wooded	7/12/18	4.4	4	654	0.52	0.78	< 20	30	47	21	28	124
Aitkin	CSAH 4	600	Wooded	7/19/18	0.60	4	255	0.68	0.62	< 20	12	24	< 20	< 10	80
Aitkin	CSAH 4	600	Wooded	8/3/18	1.9	2	115	0.27	1.29	< 3	< 10	18.3	< 10	< 20	90
Aitkin	CSAH 4	600	Wooded	8/20/18	1.3	17	408	0.60	1.06	< 3	23	48	< 10	27	187
Aitkin	CSAH 4	600	Wooded	9/20/18	0.8	5	60	0.08	0.11	< 3	< 10	< 10	< 10	< 20	59
Aitkin	CSAH 4	600	Wooded	10/8/18	0.25	1	194	0.25	0.28	< 3	17	28	< 6.8	15	86.5
Aitkin	CSAH 4	600	Wooded	10/25/18	1.1	15	308	1.14	0.16	< 3	19	52	< 6.8	18	134
Cass	CSAH 31	740	Agricultural	7/1/18	0.81	13	132	0.45	0.25	< 20	< 10	< 10	< 20	< 10	58
Cass	CSAH 31	740	Agricultural	7/12/18	0.92	2	304	0.37	0.23	< 20	< 10	< 10	< 20	< 10	70
Cass	CSAH 31	740	Agricultural	7/19/18	0.19	7	160	2.04	< 0.03	< 3	< 10	< 10	< 10	< 20	95
Cass	CSAH 31	740	Agricultural	8/3/18	1.68	10	5	0.45	< 0.03	< 3	< 10	< 10	< 10	< 20	85.6
Cass	CSAH 31	740	Agricultural	9/14/18	0.12	14	24	1.34	0.03	< 3	< 10	< 10	< 10	< 20	123
Chisago	CSAH 1	1400	Agricultural	7/12/18	2.83	8	321	0.48	0.73	< 20	15	60	< 20	19	529
Chisago	CSAH 1	1400	Agricultural	7/19/18	0.19	7	n/a	0.66	0.10	n/a	n/a	n/a	n/a	n/a	n/a
Chisago	CSAH 1	1400	Agricultural	7/25/18	0.16	5	158	0.19	0.23	< 3	< 10	54	< 10	< 20	422
Chisago	CSAH 1	1400	Agricultural	8/3/18	0.39	9	314	0.52	0.05	< 3	< 10	10	< 10	< 20	145
Chisago	CSAH 1	1400	Agricultural	8/26/18	0.49	2	151	0.90	0.18	< 3	< 10	15	< 10	< 20	209

County	Site ID	ADT	Land use	Rainfall	Rainfall depth (in)	ADP days	TSS mg/L	TP mg/L	NO_2+NO_3 mg/L	T. Cd µg/L	T. Cr µg/L	T. Cu µg/L	T. Pb µg/L	T. Ni µg/L	T. Zn µg/L
Chisago	CSAH 1	1400	Agricultural	9/4/18	0.37	8	n/a	0.82	0.30	< 3	< 10	24.9	< 10	< 20	227
Chisago	CSAH 1	1400	Agricultural	9/21/18	1.18	3	167	0.31	0.44	< 3	< 10	15.5	< 10	< 20	172
Chisago	CSAH 1	1400	Agricultural	10/1/18	0.03	6	n/a	0.13	1.23	< 3	< 4	12	< 6.8	< 3	186
Chisago	CSAH 1	1400	Agricultural	10/3/18	0.12	2	106	0.14	0.43	< 3	< 4	12	< 6.8	< 3	112
Chisago	CSAH 1	1400	Agricultural	10/26/18	0.16	17	199	0.48	< 0.03	< 3	< 4	< 6	< 6.8	< 3	166
Chisago	CSAH 1	1400	Agricultural	11/4/18	0.13	7	73	0.17	0.38	< 3	5	15	< 6.8	5.3	251
Chisago	CSAH 21	560	Agricultural	7/19/18	0.51	6	72	0.09	0.07	< 20	< 10	10	< 5	< 10	284
Chisago	CSAH 21	560	Agricultural	8/3/18	0.41	2	n/a	0.20	0.34	< 3	< 10	27	< 10	< 20	455
Chisago	CSAH 21	560	Agricultural	8/20/18	0.07	13	71	0.37	< 0.03	< 3	< 10	13.5	< 10	< 20	366
Chisago	CSAH 21	560	Agricultural	10/1/18	0.13	7	56	0.22	0.55	< 3	< 4	11	< 6.8	< 3	124
Chisago	CSAH 21	560	Agricultural	10/3/18	0.35	2	184	0.25	0.74	< 3	7	20	< 6.8	6.7	109
Chisago	CSAH 21	560	Agricultural	10/8/18	0.34	1	133	0.13	0.22	< 3	< 4	< 6	< 6.8	< 3	65
Chisago	CSAH 21	560	Agricultural	10/26/18	0.24	12	132	2.22	0.03	< 3	10	30	< 6.8	11	361
Chisago	CSAH 21	560	Agricultural	11/4/18	0.15	7	47	0.10	0.14	< 3	< 4	< 6	< 6.8	< 3	133
Chisago	CSAH 86	1150	Agricultural	6/26/18	0.86	6	107	0.64	0.16	0.32	3.1	15	2.1	11	99
Chisago	CSAH 86	1150	Agricultural	7/19/18	0.70	6	55	0.84	0.42	< 20	< 10	33	< 20	44	758
Chisago	CSAH 86	1150	Agricultural	7/25/18	0.25	5	86	0.33	< 0.03	< 3	< 10	15	< 10	< 20	596
Chisago	CSAH 86	1150	Agricultural	8/3/18	0.37	2	59	0.32	< 0.03	< 3	< 10	< 10	< 10	< 20	431
Chisago	CSAH 86	1150	Agricultural	8/20/18	0.21	13	49	0.54	< 0.03	< 3	< 10	11	< 10	< 20	537
Chisago	CSAH 86	1150	Agricultural	8/26/18	0.81	2	n/a	0.08	0.22	< 3	< 10	< 10	< 10	< 20	435
Chisago	CSAH 86	1150	Agricultural	9/2/18	0.18	2	n/a	0.21	0.50	< 3	< 10	12	< 10	< 20	251
Chisago	CSAH 86	1150	Agricultural	9/20/18	3.83	3	26	0.11	0.27	< 3	< 10	< 10	< 10	< 20	180
Chisago	CSAH 86	1150	Agricultural	10/1/18	0.13	7	50	0.53	0.90	< 3	< 4	12	< 6.8	< 20	135
Chisago	CSAH 86	1150	Agricultural	10/3/18	0.24	2	28	0.17	0.95	< 3	< 4	< 6	< 6.8	< 3	70
Chisago	CSAH 86	1150	Agricultural	10/8/18	0.37	1	20	0.06	0.25	< 3	< 4	8	< 6.8	3.1	66
Chisago	CSAH 86	1150	Agricultural	10/26/18	0.16	12	10	0.31	< 0.03	< 3	8	92	< 6.8	7.3	301
Chisago	CSAH 86	1150	Agricultural	11/4/18	0.15	7	19	0.22	0.38	< 3	< 4	< 6	< 6.8	< 3	94
Clearwater	CSAH 37	195	Wooded	6/23/18	1.12	5	98	0.14	2.74	< 3	< 10	< 10	< 10	< 20	98
Clearwater	CSAH 37	195	Wooded	7/19/18	0.93	8	84	0.01	0.35	< 20	< 10	< 10	< 20	< 10	51

County	Site ID	ADT	Land use	Rainfall	Rainfall depth (in)	ADP days	TSS mg/L	TP mg/L	NO_2+NO_3 mg/L	T. Cd µg/L	T. Cr µg/L	T. Cu µg/L	T. Pb µg/L	T. Ni µg/L	T. Zn µg/L
Clearwater	CSAH 37	195	Wooded	7/31/18	1.33	9	158	0.28	0.41	< 3	< 10	< 10	< 10	< 20	90
Clearwater	CSAH 37	195	Wooded	8/24/18	0.64	23	128	0.37	0.48	< 3	< 10	10	< 10	< 20	139
Clearwater	CSAH 37	195	Wooded	9/14/18	3.96	7	93	0.25	0.25	< 3	< 10	< 10	< 20	< 20	91
Clearwater	CSAH 37	195	Wooded	10/3/18	0.4	5	60	0.10	0.82	< 3	< 4	< 6	< 6.8	< 3	38.9
Fairbault	CSAH 1	530	Agricultural	6/25/18	0.18	3	1700	1.31	0.50	< 3	33	37	29	59	211
Fairbault	CSAH 1	530	Agricultural	7/9/18	0.10	5	133	0.18	0.52	< 20	< 10	< 10	< 20	< 10	37
Fairbault	CSAH 1	530	Agricultural	7/19/18	1.05	6	628	0.18	< 0.03	< 3	< 10	10	< 10	31	174
Fairbault	CSAH 1	530	Agricultural	7/25/18	0.54	5	466	0.59	< 0.03	< 3	11	14	< 10	35	175
Fairbault	CSAH 1	530	Agricultural	8/5/18	0.21	10	566	0.65	< 0.03	< 3	17	26	15	50	290
Fairbault	CSAH 1	530	Agricultural	8/16/18	1.71	9	240	2.46	0.45	< 3	13	17	12	< 20	167
Fairbault	CSAH 1	530	Agricultural	8/24/18	0.48	4	7	0.10	0.43	< 3	< 10	< 10	< 10	< 20	< 20
Fairbault	CSAH 1	530	Agricultural	9/4/18	5.01	1	18	0.27	< 0.03	< 3	< 10	< 10	< 10	< 20	64
Fairbault	CSAH 1	530	Agricultural	10/15/18	0.25	5	234	0.52	< 0.03	< 3	6.4	7.7	< 6.8	21	88
Polk	CSAH 13	271	Agricultural	7/3/18	0.48	5	410	0.54	0.096	23	< 10	19	< 37	15	110
Polk	CSAH 13	271	Agricultural	9/6/18	0.43	5	794	1.70	< 0.03	< 3	< 10	20	< 10	< 20	140
St Louis	CSAH 133	1450	Wooded	7/19/18	0.32	4	51	0.19	0.45	< 3	< 10	22	< 10	< 20	84
St Louis	CSAH 133	1450	Wooded	7/8/18	0.93	2	201	1.06	0.26	< 20	13	42	< 20	21	105
St Louis	CSAH 133	1450	Wooded	7/12/18	0.16	4	32	0.34	0.94	< 20	< 10	< 10	< 20	< 10	59
St Louis	CSAH 133	1450	Wooded	8/1/18	0.38	4	213	0.21	0.1	< 3	< 10	16	< 10	< 20	148
St Louis	CSAH 133	1450	Wooded	9/2/18	0.12	2	162	0.17	0.58	< 3	< 10	13	< 10	< 20	43
St Louis	CSAH 133	1450	Wooded	10/25/18	0.21	5	51	0.23	0.22	< 9.3	< 12	< 18	< 20	< 9	526
St Louis	CSAH 133	1450	Wooded	8/26/18	0.60	2	66	0.15	< 0.03	< 3	< 10	11	< 10	< 20	82
Clearwater	Mississippi		River	7/31/18	1.33	9	< 1	0.02	< 0.03	< 3	< 10	< 10	< 10	< 20	< 20
Clearwater	Mississippi		River	8/24/18	0.64	23	< 1	0.06	< 0.03	< 3	< 10	< 10	< 10	< 20	< 20
Clearwater	Mississippi		River	10/3/18	0.40	5	2.4	0.04	< 0.03	< 3.1	< 4	< 6	< 6.8	< 3	< 15
County	**Site ID**	**ADT**	**Land use**	**Rainfall**	**Rainfall depth (in)**	**ADP days**	**TSS mg/L**	**TP mg/L**	**NO_2+NO_3 mg/L**	**T. Cd µg/L**	**T. Cr µg/L**	**T. Cu µg/L**	**T. Pb µg/L**	**T. Ni µg/L**	**T. Zn µg/L**
Aitkin	CSAH 39	660	Wooded	6/4/2019	0.24	13	84	n/a	n/a	0.28	3.2	43	< 2.8	5.1	84
Aitkin	CSAH 39	660	Wooded	6/23/2019	1.35	9	261	0.20	1.25	0.25	15	30	4.3	15	118
Aitkin	CSAH 39	660	Wooded	7/5/2019	0.30	4	44	0.55	1.21	0.25	26	49	9.0	26	125

County	Site ID	ADT	Land use	Rainfall	Rainfall depth (in)	ADP days	TSS mg/L	TP mg/L	NO_2+NO_3 mg/L	T. Cd µg/L	T. Cr µg/L	T. Cu µg/L	T. Pb µg/L	T. Ni µg/L	T. Zn µg/L
Aitkin	CSAH 39	660	Wooded	7/14/2019	1.90	6	245	0.30	0.31	< 0.77	13	21	< 6.3	< 20	131
Aitkin	CSAH 39	660	Wooded	7/25/2019	0.20	11	64	0.15	0.94	< 0.77	2.9	14	< 6.3	< 20	76
Aitkin	CSAH 39	660	Wooded	7/28/2019	1.20	3	89	0.19	0.70	< 0.77	4.2	15	< 6.3	< 20	72
Aitkin	CSAH 39	660	Wooded	8/7/2019	1.00	2	118	0.25	0.28	< 0.77	4.8	11	< 6.3	< 20	47
Aitkin	CSAH 39	660	Wooded	8/18/2019	0.25	11	60	0.08	1.10	< 0.77	3.3	15	< 6.3	< 20	140
Aitkin	CSAH 39	660	Wooded	8/26/2019	0.07	4	82	0.13	0.35	< 0.77	5.5	8.1	< 6.3	< 20	34
Aitkin	CSAH 39	660	Wooded	9/3/2019	1.10	5	74	0.13	0.65	< 0.77	2.0	11	< 6.3	< 20	60
Aitkin	CSAH 39	660	Wooded	9/9/2019	0.70	4	52	0.13	0.72	< 0.77	2.7	7.7	< 6.3	< 20	50
Aitkin	CSAH 39	660	Wooded	9/17/2019	0.60	4	48	0.11	0.38	< 0.77	2.8	7.3	< 6.3	< 20	22
Aitkin	CSAH 39	660	Wooded	10/11/2019	0.30	4	97	0.16	0.46	< 0.77	4.6	5.7	< 6.3	< 20	28
Aitkin	CSAH 4	600	Wooded	6/4/2019	0.54	13	622	0.84	0.32	0.47	40.5	71.5	14.1	36	234
Aitkin	CSAH 4	600	Wooded	6/23/2019	1.62	9	66	0.20	1.33	< 0.50	6.0	17.8	1.9	7.9	105
Aitkin	CSAH 4	600	Wooded	7/4/2019	0.30	4	182	0.20	0.54	< 0.50	7.5	14.5	2.6	8.3	112
Aitkin	CSAH 4	600	Wooded	7/10/2019	0.50	6	54	0.15	0.87	< 0.77	4.4	32.0	< 6.3	< 20	96
Aitkin	CSAH 4	600	Wooded	7/25/2019	0.20	11	97	0.29	0.93	< 0.77	5.1	21.2	< 6.3	< 20	74
Aitkin	CSAH 4	600	Wooded	7/28/2019	1.20	3	41	0.23	0.53	< 0.77	1.8	15.4	< 6.3	< 20	41
Aitkin	CSAH 4	600	Wooded	8/7/2019	0.80	2	258	0.43	0.39	< 0.77	12.5	21.3	< 6.3	< 20	104
Aitkin	CSAH 4	600	Wooded	8/18/2019	0.25	11	63	0.16	1.12	< 0.77	3.5	17.4	< 6.3	< 20	108
Aitkin	CSAH 4	600	Wooded	8/26/2019	0.60	4	150	0.31	0.53	< 0.77	9.3	19.3	< 6.3	< 20	80
Aitkin	CSAH 4	600	Wooded	9/3/2019	1.10	5	71	0.19	0.82	< 0.77	3.3	13.5	< 6.3	< 20	64
Aitkin	CSAH 4	600	Wooded	9/9/2019	0.70	4	150	0.30	0.72	< 0.77	13.9	24.4	< 6.3	< 20	92
Aitkin	CSAH 4	600	Wooded	9/17/2019	0.70	4	394	0.36	0.55	< 0.77	14.9	22.5	< 6.3	< 20	99
Aitkin	CSAH 4	600	Wooded	10/10/2019	0.30	4	85	0.18	0.59	< 0.77	7.1	12.2	< 6.3	< 20	51
Cass	CSAH 31	740	Agricultural	8/4/2019	0.50	8	220	0.37	0.37	< 0.77	8.0	18.9	< 6.3	< 20	979
Cass	CSAH 31	740	Agricultural	8/13/2019	0.40	6	64	0.60	0.15	< 0.77	5.0	14.4	< 6.3	< 20	1174
Cass	CSAH 31	740	Agricultural	8/17/2019	0.60	3	67	1.17	0.26	< 0.77	2.8	5.1	< 6.3	< 20	405
Cass	CSAH 31	740	Agricultural	9/3/2019	0.70	7	54	0.28	0.18	< 0.77	2.4	7.5	< 6.3	< 20	328
Cass	CSAH 31	740	Agricultural	9/10/2019	0.80	4	59	0.17	0.11	< 0.77	4.4	6.3	< 6.3	< 20	299
Chisago	CSAH 1	1400	Agricultural	6/14/2019	0.43	13	19	0.12	0.62	< 10	< 10	24	< 50	< 25	270

County	Site ID	ADT	Land use	Rainfall	Rainfall depth (in)	ADP days	TSS mg/L	TP mg/L	NO_2+NO_3 mg/L	T. Cd µg/L	T. Cr µg/L	T. Cu µg/L	T. Pb µg/L	T. Ni µg/L	T. Zn µg/L
Chisago	CSAH 1	1400	Agricultural	6/23/2019	0.75	9	65	0.08	0.19	< 0.50	< 5.0	6.9	0.8	2.5	102
Chisago	CSAH 1	1400	Agricultural	6/27/2019	0.62	1	89	0.22	0.85	< 0.50	< 5.0	21	2.1	7.0	165
Chisago	CSAH 1	1400	Agricultural	7/9/2019	0.22	5	38	0.09	0.41	< 0.50	< 5.0	17	1.0	6.0	168
Chisago	CSAH 1	1400	Agricultural	7/14/2019	0.88	5	256	0.33	0.06	< 0.77	8.8	35	< 6.3	< 20	365
Chisago	CSAH 1	1400	Agricultural	7/26/2019	0.21	6	60	0.06	0.16	< 0.77	2.0	15	< 6.3	< 20	475
Chisago	CSAH 1	1400	Agricultural	8/5/2019	0.59	8	141	0.12	0.24	< 0.77	0.7	13	< 6.3	< 20	469
Chisago	CSAH 1	1400	Agricultural	8/16/2019	0.23	11	29	0.11	0.10	< 0.77	2.3	2	< 6.3	< 20	359
Chisago	CSAH 1	1400	Agricultural	8/26/2019	0.98	8	n/a	0.09	0.57	< 0.77	1.9	2	< 6.3	< 20	479
Chisago	CSAH 1	1400	Agricultural	9/2/2019	0.83	7	121	0.10	0.07	< 0.77	< 1.4	12	< 6.3	< 20	417
Chisago	CSAH 1	1400	Agricultural	9/9/2019	0.23	7	210	0.25	0.06	< 0.77	< 1.4	< 5.0	< 6.3	< 20	260
Chisago	CSAH 1	1400	Agricultural	10/21/2019	1.99	9	107	0.10	1.19	< 0.77	4.0	16.1	< 6.3	< 20	168
Chisago	CSAH 21	560	Agricultural	7/9/2019	0.29	5	89	0.04	0.03	< 0.50	< 5.0	< 5.0	0.5	< 5.0	171
Chisago	CSAH 21	560	Agricultural	7/14/2019	1.77	5	257	0.24	0.06	< 0.77	1.9	10.7	< 6.3	< 20	298
Chisago	CSAH 21	560	Agricultural	7/19/2019	0.57	4	252	0.18	0.06	< 0.77	< 1.4	< 5.0	< 10	< 20	173
Chisago	CSAH 21	560	Agricultural	7/28/2019	1.06	8	107	0.05	0.11	< 0.77	< 1.4	< 5.0	< 6.3	< 20	90
Chisago	CSAH 21	560	Agricultural	8/5/2019	0.13	8	12	0.08	0.29	< 0.77	< 1.4	5.5	< 6.3	< 20	99
Chisago	CSAH 21	560	Agricultural	8/26/2019	0.65	6	63	0.10	0.41	< 0.77	2.1	5.4	< 6.3	< 20	55
Chisago	CSAH 21	560	Agricultural	9/2/2019	1.19	6	211	1.14	0.06	< 0.77	2.6	12.6	< 6.3	< 20	117
Chisago	CSAH 21	560	Agricultural	9/9/2019	0.22	7	425	0.29	0.06	< 0.77	2.4	9.5	< 6.3	< 20	76
Chisago	CSAH 21	560	Agricultural	9/18/2019	0.27	6	309	0.18	0.27	< 0.77	< 1.4	6.5	< 6.3	< 20	111
Chisago	CSAH 21	560	Agricultural	9/21/2019	0.2	3	121	0.06	0.11	< 0.77	< 1.4	< 5.0	< 6.3	< 20	47
Chisago	CSAH 21	560	Agricultural	10/21/2019	1.58	6	154	0.42	0.76	< 0.77	6.0	18.2	< 6.3	< 20	77
Chisago	CSAH 86	1150	Agricultural	6/14/2019	0.16	13	n/a	0.35	0.75	< 10	< 10	< 10	< 50	< 25	270
Chisago	CSAH 86	1150	Agricultural	7/9/2019	0.3	7	68	0.33	<0.03	< 0.50	< 5.0	30.2	1.2	16	266
Chisago	CSAH 86	1150	Agricultural	7/14/2019	2.54	5	80	0.26	0.05	< 0.77	2.1	27.1	< 6.3	< 20	343
Chisago	CSAH 86	1150	Agricultural	7/20/2019	0.32	6	79	0.27	0.05	< 0.77	2.8	18.3	< 10	< 20	253
Chisago	CSAH 86	1150	Agricultural	7/28/2019	0.95	7	93	0.25	0.06	< 0.77	< 1.4	16.3	< 6.3	< 20	332
Chisago	CSAH 86	1150	Agricultural	8/5/2019	0.35	8	52	0.27	0.07	< 0.77	< 1.4	20.6	< 6.3	< 20	344
Chisago	CSAH 86	1150	Agricultural	8/10/2019	0.14	5	19	0.36	0.15	< 0.77	3.0	44.8	< 6.3	27	422

County	Site ID	ADT	Land use	Rainfall	Rainfall depth (in)	ADP days	TSS mg/L	TP mg/L	NO_2+NO_3 mg/L	T. Cd µg/L	T. Cr µg/L	T. Cu µg/L	T. Pb µg/L	T. Ni µg/L	T. Zn µg/L
Chisago	CSAH 86	1150	Agricultural	8/16/2019	0.18	3	34	0.10	0.06	< 0.77	< 1.4	13.2	< 6.3	< 20	181
Chisago	CSAH 86	1150	Agricultural	8/26/2019	0.68	6	14	0.45	0.17	< 0.77	1.6	35.4	< 6.3	21	333
Chisago	CSAH 86	1150	Agricultural	9/2/2019	1.03	7	34	0.06	0.16	< 0.77	< 1.4	5.7	< 6.3	< 20	111
Chisago	CSAH 86	1150	Agricultural	9/9/2019	0.21	7	19	0.17	0.05	< 0.77	< 1.4	15.0	< 6.3	< 20	114
Chisago	CSAH 86	1150	Agricultural	9/18/2019	0.28	6	73	0.18	0.09	< 0.77	< 1.4	11.2	< 6.3	< 20	102
Chisago	CSAH 86	1150	Agricultural	9/21/2019	0.19	3	20	0.41	0.06	< 0.77	< 1.4	13.6	< 6.3	< 20	89
Chisago	CSAH 86	1150	Agricultural	10/21/2019	1.8	6	358	0.56	1.11	< 0.77	11.5	35.6	< 6.3	< 20	54
Clearwater	CSAH 37	195	Wooded	6/21/2019	0.29	10	114	0.28	0.60	< 0.50	< 5.0	7.0	1.5	6.6	56
Clearwater	CSAH 37	195	Wooded	7/8/2019	1.15	15	137	0.24	0.15	< 0.50	< 5.0	< 5.0	1.4	< 5.0	53
Clearwater	CSAH 37	195	Wooded	7/14/2019	0.22	5	142	0.23	0.50	< 0.77	3.7	8.6	< 6.3	< 20	80
Clearwater	CSAH 37	195	Wooded	8/13/2019	0.25	1	132	0.77	0.06	< 0.77	1.6	8.5	< 6.3	< 20	106
Clearwater	CSAH 37	195	Wooded	8/17/2019	0.78	4	327	0.20	0.08	< 0.77	7.4	8.8	< 6.3	< 20	81
Clearwater	CSAH 37	195	Wooded	8/26/2019	0.21	6	121	0.24	0.13	< 0.77	4.4	6.0	< 6.3	< 20	39
Clearwater	CSAH 37	195	Wooded	9/2/2019	0.27	6	130	0.27	0.40	< 0.77	2.1	6.9	< 6.3	< 20	36
Clearwater	CSAH 37	195	Wooded	9/21/2019	0.60	3	130	0.20	0.29	< 0.77	2.9	< 5.0	< 6.3	< 20	37
Clearwater	CSAH 37	195	Wooded	9/29/2019	0.55	8	132	0.13	0.28	< 0.77	3.1	5.4	< 6.3	< 20	51
Clearwater	CSAH 37	195	Wooded	10/21/2019	1.32	8	158	0.31	0.96	< 0.77	5.4	7.8	< 6.3	< 20	62
Fairbault	CSAH 1	530	Agricultural	7/20/2019	0.37	2	441	0.74	0.04	< 0.77	7.4	9.6	10.2	< 20	167
Fairbault	CSAH 1	530	Agricultural	8/5/2019	1.13	1	270	0.30	0.27	< 0.77	3.8	5.6	< 6.3	< 20	74
Fairbault	CSAH 1	530	Agricultural	8/10/2019	0.15	3	194	0.29	0.06	< 0.77	2.9	8.6	< 6.3	< 20	155
Fairbault	CSAH 1	530	Agricultural	9/12/2019	0.75	3	292	0.25	0.80	< 0.77	8.0	11.9	< 6.3	< 20	153
Fairbault	CSAH 1	530	Agricultural	9/18/2019	0.60	7	235	0.24	0.59	< 0.77	4.1	6.5	< 6.3	< 20	83
Fairbault	CSAH 1	530	Agricultural	9/19/2019	0.53	1	1900	0.83	0.58	< 0.77	19	18.0	< 6.3	29	201
Fairbault	CSAH 1	530	Agricultural	10/1/2019	3.65	7	780	0.46	0.56	0.79	19	20	18	35	205
St Louis	CSAH 133	1450	Wooded	6/30/2019	1.45	3	10	0.04	0.14	< 0.50	< 5.0	7.7	1.2	< 5.0	69
St Louis	CSAH 133	1450	Wooded	8/7/2019	0.15	4	3	0.13	0.04	< 0.77	< 1.4	< 5.0	< 6.3	< 20	51
St Louis	CSAH 133	1450	Wooded	8/16/2019	0.21	9	4	0.10	0.87	< 0.77	< 1.4	11.7	< 6.3	< 20	53
St Louis	CSAH 133	1450	Wooded	8/26/2019	0.77	2	10	0.14	0.75	< 0.77	< 1.4	11.9	< 6.3	< 20	47
St Louis	CSAH 133	1450	Wooded	8/27/2019	0.20	1	32	0.08	0.10	< 0.77	< 1.4	5.8	< 6.3	< 20	21

County	Site ID	ADT	Land use	Rainfall	Rainfall depth (in)	ADP days	TSS mg/L	TP mg/L	NO_2+NO_3 mg/L	T. Cd µg/L	T. Cr µg/L	T. Cu µg/L	T. Pb µg/L	T. Ni µg/L	T. Zn µg/L
St Louis	CSAH 133	1450	Wooded	9/2/2019	0.31	3	4	0.07	0.43	< 0.77	< 1.4	< 5.0	< 6.3	< 20	30
St Louis	CSAH 133	1450	Wooded	9/10/2019	1.37	5	10	0.09	0.61	< 0.77	< 1.4	< 5.0	< 6.3	< 20	30
St Louis	CSAH 133	1450	Wooded	9/13/2019	0.16	1	7	0.04	0.47	< 0.77	< 1.4	< 5.0	< 2.5	< 20	48
St Louis	CSAH 133	1450	Wooded	10/13/2019	0.14	2	51	0.04	0.82	< 0.77	< 1.4	5.8	< 6.3	< 20	40
St Louis	CSAH 133	1450	Wooded	10/21/2019	1.33	8	54	0.10	0.76	< 0.77	< 1.4	6.1	< 6.3	< 20	25
Clearwater	Mississippi River		Wooded	6/21/2019	0.29	10	4.5	0.05	< 0.03	< 0.50	< 5.0	< 5.0	< 0.50	< 5.0	< 20

ADT = average daily traffic; ADP = antecedent dry period; TSS = total suspended solids; TP = total phosphorus; NO_2+NO_3 = nitrite+nitrate; T.Cd = total cadmium; T.Cr = total chromium; T.Cu = total copper, T.Pb = total lead; T.Ni = total nickel; T.Zn = total zinc.

n/a: not analyzed

Concentrations below the laboratory reporting limit (RL) are reported as “< RL”.

APPENDIX B
MIDS CALCULATOR REPORTS FOR THE FIVE CASE STUDIES ON MEETING STORMWATER MANAGEMENT REQUIREMENTS FOR PAVED RURAL ROADS USING ROADSIDE SWALES

The results from the MIDS Calculator modeling of five case studies of road widening projects to meet the stormwater management requirements using roadside swales are provided.

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 1 - Existing Road in 5 segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, 2' shoulder, 5:1 side slope, 3' swale depth, 3' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55902
Annual Rainfall (inches):	32.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.3635				0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.818				1.818
				Impervious Area (acres)	1.697
				Total Area (acres)	3.8785

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.3635				0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.818				1.818
				Impervious Area (acres)	1.697
				Total Area (acres)	3.8785

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6776	ft3
Volume removed by BMPs towards performance goal:	2702	ft^3
Percent volume removed towards performance goal	**40**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.5695	acre-ft
Annual runoff volume removed by BMPs:	3.8615	acre-ft
Percent annual runoff volume removed:	**85**	**%**
Post development annual particulate P load:	2.051	lbs
Annual particulate P removed by BMPs:	1.997	lbs
Post development annual dissolved P load:	1.678	lbs
Annual dissolved P removed by BMPs:	1.418	lbs
Percent annual total phosphorus removed:	**92**	**%**
Post development annual TSS load:	677.4	lbs
Annual TSS removed by BMPs:	655.8	lbs
Percent annual TSS removed:	**97**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	28	1355	28	1327	2
2 - Swale Side Slope	28	1355	28	1327	2
3 - Swale Side Slope	28	1355	28	1327	2
4 - Swale Side Slope	28	1355	28	1327	2
5 - Swale Side Slope	28	1355	28	1327	2
1 - Swale main channel	370	1327	370	958	28
2 - Swale main channel	446	2285	446	1839	20
3 - Swale main channel	523	3166	523	2643	17
4 - Swale main channel	588	3970	588	3383	15
5 - Swale main channel	636	4710	636	4074	14

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9104	0	0.1681	0.7423	18
2 - Swale Side Slope	0.9104	0	0.1681	0.7423	18
3 - Swale Side Slope	0.9104	0	0.1681	0.7423	18
4 - Swale Side Slope	0.9104	0	0.1681	0.7423	18
5 - Swale Side Slope	0.9104	0	0.1681	0.7423	18
1 - Swale main channel	0.0035	0.7423	0.5236	0.2222	70
2 - Swale main channel	0.0035	0.9645	0.5725	0.3955	59
3 - Swale main channel	0.0035	1.1378	0.6141	0.5272	54
4 - Swale main channel	0.0035	1.2696	0.646	0.6271	51
5 - Swale main channel	0.0035	1.3694	0.665	0.7079	48

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4086	0	0.0754	0.3332	18
2 - Swale Side Slope	0.4086	0	0.0754	0.3332	18
3 - Swale Side Slope	0.4086	0	0.0754	0.3332	18
4 - Swale Side Slope	0.4086	0	0.0754	0.3332	18
5 - Swale Side Slope	0.4086	0	0.0754	0.3332	18
1 - Swale main channel	0.0016	0.3332	0.3079	0.0269	92
2 - Swale main channel	0.0016	0.3601	0.3218	0.0399	89
3 - Swale main channel	0.0016	0.3731	0.328	0.0467	88
4 - Swale main channel	0.0016	0.3799	0.3308	0.0507	87
5 - Swale main channel	0.0016	0.3839	0.3318	0.0537	86

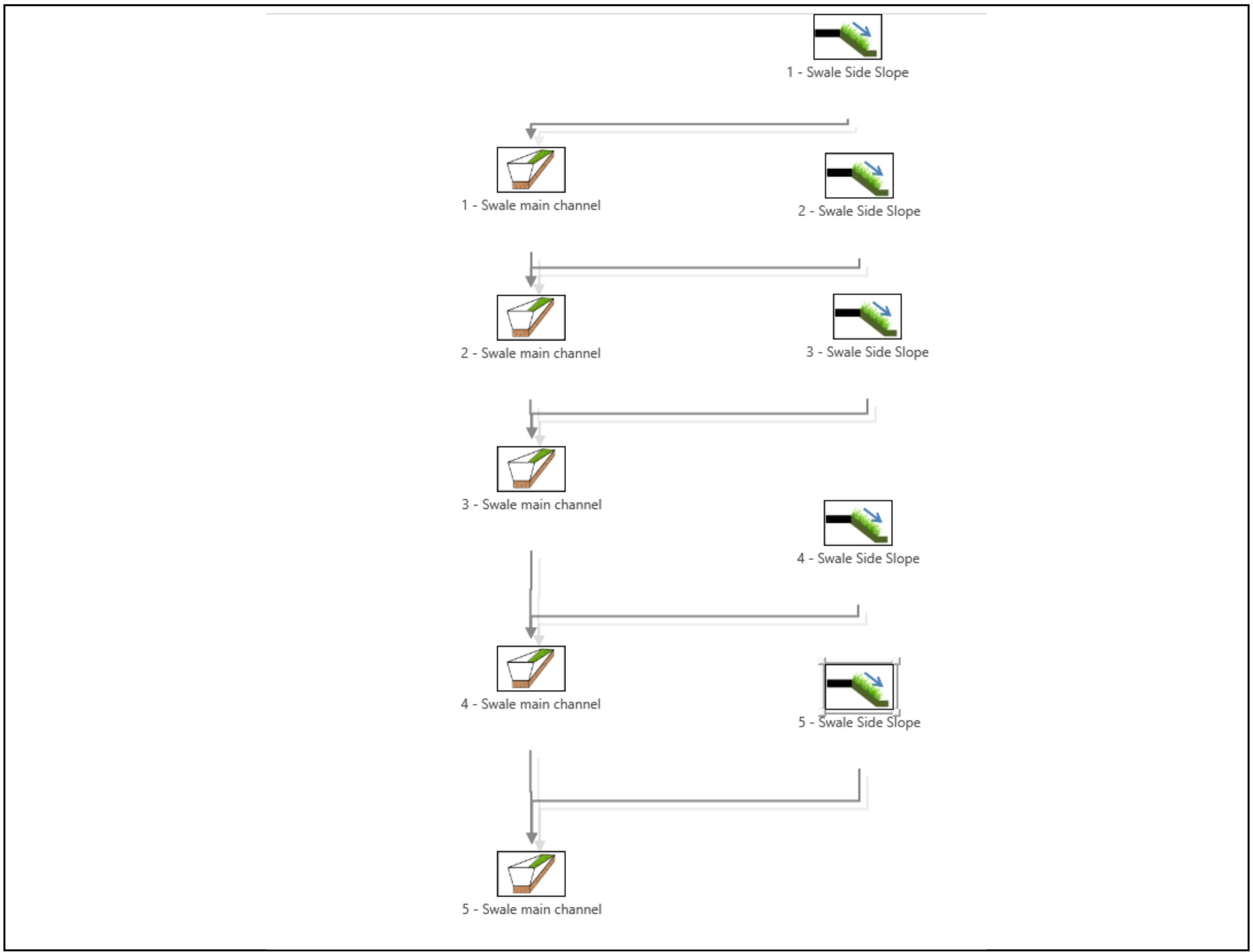
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3343	0	0.0617	0.2726	18
2 - Swale Side Slope	0.3343	0	0.0617	0.2726	18
3 - Swale Side Slope	0.3343	0	0.0617	0.2726	18
4 - Swale Side Slope	0.3343	0	0.0617	0.2726	18
5 - Swale Side Slope	0.3343	0	0.0617	0.2726	18
1 - Swale main channel	0.0013	0.2726	0.1923	0.0816	70
2 - Swale main channel	0.0013	0.3542	0.2102	0.1453	59
3 - Swale main channel	0.0013	0.4179	0.2255	0.1937	54
4 - Swale main channel	0.0013	0.4663	0.2373	0.2303	51
5 - Swale main channel	0.0013	0.5029	0.2442	0.26	48

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	134.96	0	24.91	110.05	18
2 - Swale Side Slope	134.96	0	24.91	110.05	18
3 - Swale Side Slope	134.96	0	24.91	110.05	18
4 - Swale Side Slope	134.96	0	24.91	110.05	18
5 - Swale Side Slope	134.96	0	24.91	110.05	18
1 - Swale main channel	0.52	110.05	100.03	10.54	90
2 - Swale main channel	0.52	120.59	105.27	15.84	87
3 - Swale main channel	0.52	125.89	107.72	18.69	85
4 - Swale main channel	0.52	128.74	108.89	20.37	84
5 - Swale main channel	0.52	130.42	109.33	21.610000000	83

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 1 - Existing Road in 5 segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12′ lane, 2′ shoulder, 5:1 side slope, 3′ swale depth, 3′ bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55902
Annual Rainfall (inches):	32.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.3635			0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.818			1.818
			Impervious Area (acres)		1.697
			Total Area (acres)		3.8785

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.3635			0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.818			1.818
			Impervious Area (acres)		1.697
			Total Area (acres)		3.8785

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6776	ft3
Volume removed by BMPs towards performance goal:	2403	ft^3
Percent volume removed towards performance goal	**35**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.7978	acre-ft
Annual runoff volume removed by BMPs:	3.2934	acre-ft
Percent annual runoff volume removed:	**69**	**%**
Post development annual particulate P load:	2.153	lbs
Annual particulate P removed by BMPs:	2.064	lbs
Post development annual dissolved P load:	1.762	lbs
Annual dissolved P removed by BMPs:	1.209	lbs
Percent annual total phosphorus removed:	**84**	**%**
Post development annual TSS load:	711.2	lbs
Annual TSS removed by BMPs:	674.6	lbs
Percent annual TSS removed:	**95**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	13	1355	13	1342	1
2 - Swale Side Slope	13	1355	13	1342	1
3 - Swale Side Slope	13	1355	13	1342	1
4 - Swale Side Slope	13	1355	13	1342	1
5 - Swale Side Slope	13	1355	13	1342	1
1 - Swale main channel	326	1342	326	1016	24
2 - Swale main channel	419	2358	419	1939	18
3 - Swale main channel	488	3282	488	2794	15
4 - Swale main channel	536	4136	536	3601	13
5 - Swale main channel	570	4943	570	4374	12

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9543	0	0.0417	0.9126	4
2 - Swale Side Slope	0.9543	0	0.0417	0.9126	4
3 - Swale Side Slope	0.9543	0	0.0417	0.9126	4
4 - Swale Side Slope	0.9543	0	0.0417	0.9126	4
5 - Swale Side Slope	0.9543	0	0.0417	0.9126	4
1 - Swale main channel	0.0053	0.9126	0.4412	0.4767	48
2 - Swale main channel	0.0053	1.3894	0.5765	0.8182	41
3 - Swale main channel	0.0053	1.7308	0.6343	1.1018	37
4 - Swale main channel	0.0053	2.0144	0.6739	1.3458	33
5 - Swale main channel	0.0053	2.2584	0.7592	1.5045	34

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4283	0	0.0187	0.4096	4
2 - Swale Side Slope	0.4283	0	0.0187	0.4096	4
3 - Swale Side Slope	0.4283	0	0.0187	0.4096	4
4 - Swale Side Slope	0.4283	0	0.0187	0.4096	4
5 - Swale Side Slope	0.4283	0	0.0187	0.4096	4
1 - Swale main channel	0.0024	0.4096	0.3542	0.0578	86
2 - Swale main channel	0.0024	0.4674	0.3954	0.0744	84
3 - Swale main channel	0.0024	0.484	0.4031	0.0833	83
4 - Swale main channel	0.0024	0.4929	0.4062	0.0891	82
5 - Swale main channel	0.0024	0.4987	0.4112	0.0899	82

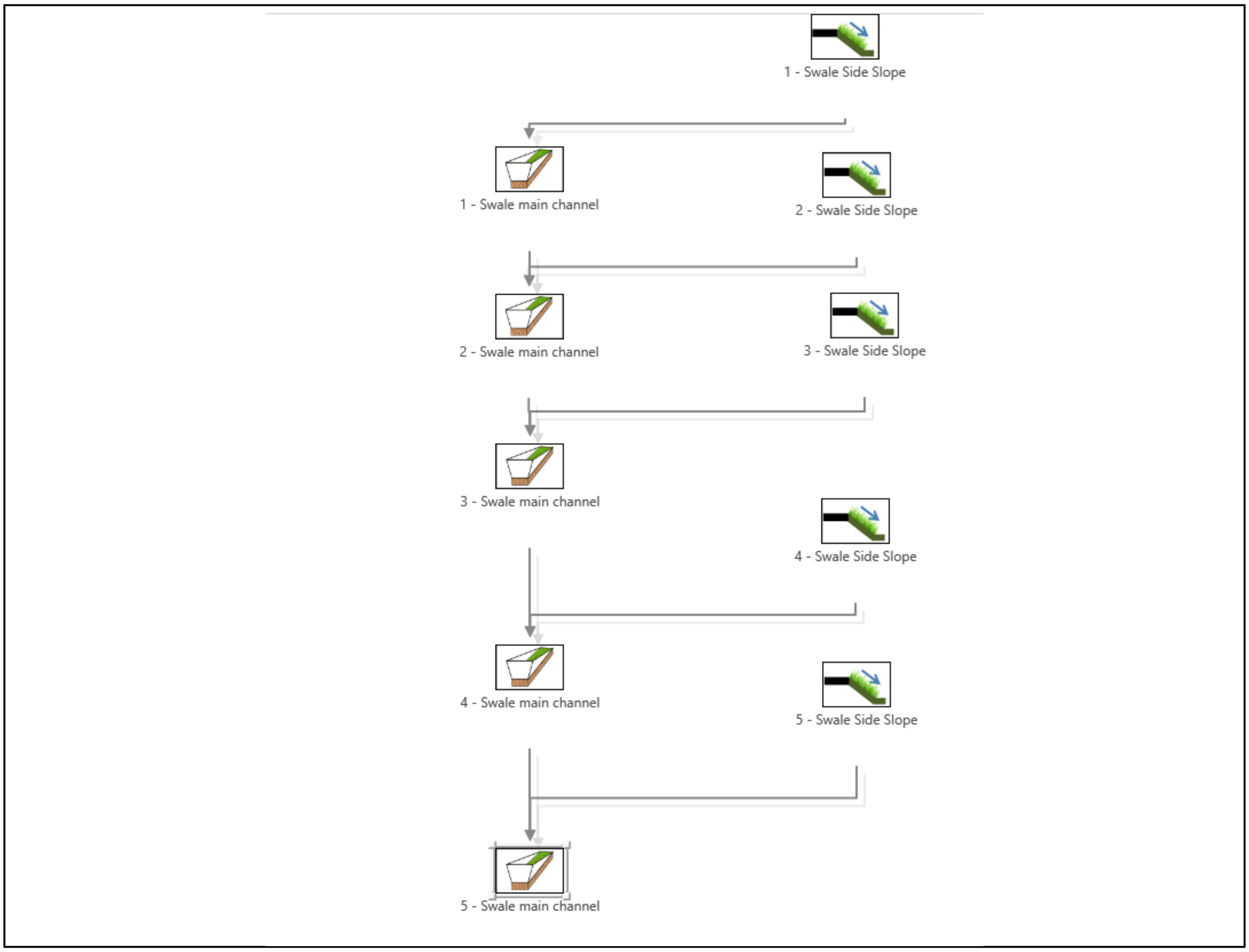
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3504	0	0.0153	0.3351	4
2 - Swale Side Slope	0.3504	0	0.0153	0.3351	4
3 - Swale Side Slope	0.3504	0	0.0153	0.3351	4
4 - Swale Side Slope	0.3504	0	0.0153	0.3351	4
5 - Swale Side Slope	0.3504	0	0.0153	0.3351	4
1 - Swale main channel	0.0019	0.3351	0.162	0.175	48
2 - Swale main channel	0.0019	0.5101	0.2116	0.3004	41
3 - Swale main channel	0.0019	0.6355	0.2329	0.4045	37
4 - Swale main channel	0.0019	0.7396	0.2474	0.4941	33
5 - Swale main channel	0.0019	0.8292	0.2787	0.5524	34

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	141.46	0	6.18	135.28	4
2 - Swale Side Slope	141.46	0	6.18	135.28	4
3 - Swale Side Slope	141.46	0	6.18	135.28	4
4 - Swale Side Slope	141.46	0	6.18	135.28	4
5 - Swale Side Slope	141.46	0	6.18	135.28	4
1 - Swale main channel	0.78	135.28	113.45	22.61	83
2 - Swale main channel	0.78	157.89	128.88	29.79	81
3 - Swale main channel	0.78	165.07	132.17	33.68	80
4 - Swale main channel	0.78	168.96	133.55	36.19	79
5 - Swale main channel	0.78	171.47	135.62	36.63	79

BMP Schematic



CASE STUDY 1, HSG C, EXISTING ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 1 - Existing Road in 5 segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12’ lane, 2’ shoulder, 5:1 side slope, 3’ swale depth, 3’ bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55902
Annual Rainfall (inches):	32.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.3635		0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.818		1.818
			Impervious Area (acres)		1.697
			Total Area (acres)		3.8785

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.3635		0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.818		1.818
			Impervious Area (acres)		1.697
			Total Area (acres)		3.8785

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6776	ft3
Volume removed by BMPs towards performance goal:	1763	ft^3
Percent volume removed towards performance goal	**26**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.8944	acre-ft
Annual runoff volume removed by BMPs:	2.5074	acre-ft
Percent annual runoff volume removed:	**51**	**%**
Post development annual particulate P load:	2.197	lbs
Annual particulate P removed by BMPs:	2.082	lbs
Post development annual dissolved P load:	1.797	lbs
Annual dissolved P removed by BMPs:	0.921	lbs
Percent annual total phosphorus removed:	**75**	**%**
Post development annual TSS load:	725.5	lbs
Annual TSS removed by BMPs:	678.1	lbs
Percent annual TSS removed:	**93**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	5	1355	5	1350	0
2 - Swale Side Slope	5	1355	5	1350	0
3 - Swale Side Slope	5	1355	5	1350	0
4 - Swale Side Slope	5	1355	5	1350	0
5 - Swale Side Slope	5	1355	5	1350	0
1 - Swale main channel	251	1350	251	1099	19
2 - Swale main channel	327	2449	327	2123	13
3 - Swale main channel	364	3473	364	3109	10
4 - Swale main channel	389	4459	389	4070	9
5 - Swale main channel	407	5420	407	5013	8

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9718	0	0.0151	0.9567	2
2 - Swale Side Slope	0.9718	0	0.0151	0.9567	2
3 - Swale Side Slope	0.9718	0	0.0151	0.9567	2
4 - Swale Side Slope	0.9718	0	0.0151	0.9567	2
5 - Swale Side Slope	0.9718	0	0.0151	0.9567	2
1 - Swale main channel	0.007	0.9568	0.3317	0.6321	34
2 - Swale main channel	0.007	1.5889	0.426	1.1699	27
3 - Swale main channel	0.007	2.1268	0.4735	1.6603	22
4 - Swale main channel	0.007	2.6171	0.4996	2.1245	19
5 - Swale main channel	0.007	3.0813	0.7013	2.387	23

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4362	0	0.0068	0.4294	2
2 - Swale Side Slope	0.4362	0	0.0068	0.4294	2
3 - Swale Side Slope	0.4362	0	0.0068	0.4294	2
4 - Swale Side Slope	0.4362	0	0.0068	0.4294	2
5 - Swale Side Slope	0.4362	0	0.0068	0.4294	2
1 - Swale main channel	0.0032	0.4294	0.356	0.0766	82
2 - Swale main channel	0.0032	0.506	0.4084	0.1008	80
3 - Swale main channel	0.0032	0.5302	0.4213	0.1121	79
4 - Swale main channel	0.0032	0.5415	0.4256	0.1191	78
5 - Swale main channel	0.0032	0.5485	0.4366	0.1151	79

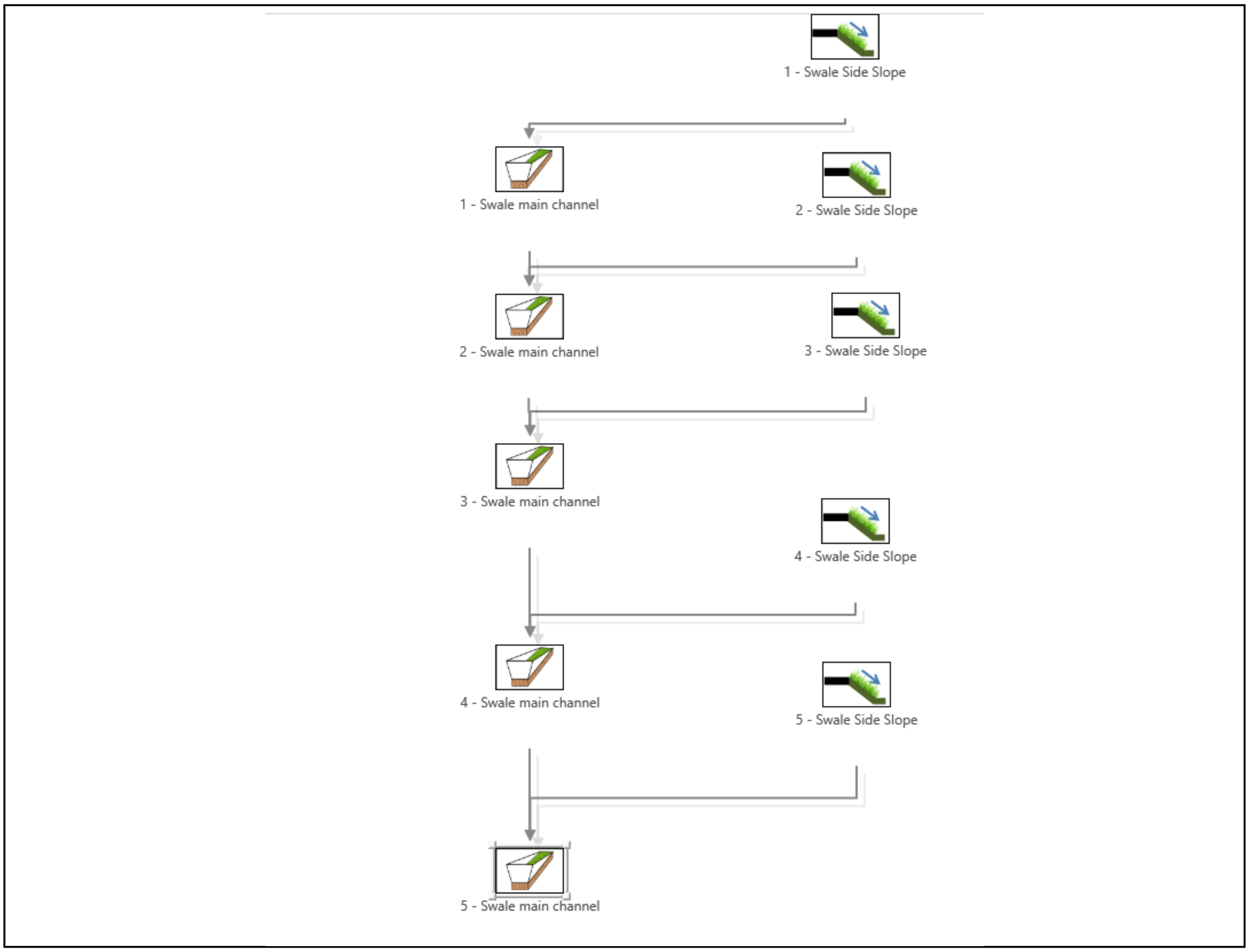
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3569	0	0.0055	0.3514	2
2 - Swale Side Slope	0.3569	0	0.0055	0.3514	2
3 - Swale Side Slope	0.3569	0	0.0055	0.3514	2
4 - Swale Side Slope	0.3569	0	0.0055	0.3514	2
5 - Swale Side Slope	0.3569	0	0.0055	0.3514	2
1 - Swale main channel	0.0026	0.3514	0.1218	0.2322	34
2 - Swale main channel	0.0026	0.5836	0.1565	0.4297	27
3 - Swale main channel	0.0026	0.7811	0.1739	0.6098	22
4 - Swale main channel	0.0026	0.9612	0.1835	0.7803	19
5 - Swale main channel	0.0026	1.1317	0.2576	0.8767	23

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	144.07	0	2.23	141.84	2
2 - Swale Side Slope	144.07	0	2.23	141.84	2
3 - Swale Side Slope	144.07	0	2.23	141.84	2
4 - Swale Side Slope	144.07	0	2.23	141.84	2
5 - Swale Side Slope	144.07	0	2.23	141.84	2
1 - Swale main channel	1.04	141.84	112.89	29.99	79
2 - Swale main channel	1.04	171.83	132.32	40.55	77
3 - Swale main channel	1.04	182.39	137.76	45.67	75
4 - Swale main channel	1.04	187.51	139.7	48.85	74
5 - Swale main channel	1.04	190.69	144.31	47.42	75

BMP Schematic



CASE STUDY 1, HSG D, EXISTING ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 1 - Existing Road in 5 segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, 2' shoulder, 5:1 side slope, 3' swale depth, 3' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55902
Annual Rainfall (inches):	32.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.3635	0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.818	1.818
			Impervious Area (acres)		1.697
			Total Area (acres)		3.8785

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.3635	0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.818	1.818
			Impervious Area (acres)		1.697
			Total Area (acres)		3.8785

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6776	ft3
Volume removed by BMPs towards performance goal:	1465	ft^3
Percent volume removed towards performance goal	**22**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.0349	acre-ft
Annual runoff volume removed by BMPs:	1.0299	acre-ft
Percent annual runoff volume removed:	**20**	**%**
Post development annual particulate P load:	2.26	lbs
Annual particulate P removed by BMPs:	2.108	lbs
Post development annual dissolved P load:	1.849	lbs
Annual dissolved P removed by BMPs:	0.378	lbs
Percent annual total phosphorus removed:	**61**	**%**
Post development annual TSS load:	746.4	lbs
Annual TSS removed by BMPs:	683	lbs
Percent annual TSS removed:	**92**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	1	1355	1	1354	0
2 - Swale Side Slope	1	1355	1	1354	0
3 - Swale Side Slope	1	1355	1	1354	0
4 - Swale Side Slope	1	1355	1	1354	0
5 - Swale Side Slope	1	1355	1	1354	0
1 - Swale main channel	233	1354	233	1121	17
2 - Swale main channel	284	2476	284	2192	11
3 - Swale main channel	306	3546	306	3240	9
4 - Swale main channel	318	4595	318	4277	7
5 - Swale main channel	319	5631	319	5312	6

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9982	0	0.0022	0.996	0
2 - Swale Side Slope	0.9982	0	0.0022	0.996	0
3 - Swale Side Slope	0.9982	0	0.0022	0.996	0
4 - Swale Side Slope	0.9982	0	0.0022	0.996	0
5 - Swale Side Slope	0.9982	0	0.0022	0.996	0
1 - Swale main channel	0.0088	0.996	0.1319	0.8729	13
2 - Swale main channel	0.0088	1.869	0.1822	1.6956	10
3 - Swale main channel	0.0088	2.6916	0.2062	2.4942	8
4 - Swale main channel	0.0088	3.4903	0.2203	3.2788	6
5 - Swale main channel	0.0088	4.2748	0.2786	4.005	7

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.448	0	0.001	0.447	0
2 - Swale Side Slope	0.448	0	0.001	0.447	0
3 - Swale Side Slope	0.448	0	0.001	0.447	0
4 - Swale Side Slope	0.448	0	0.001	0.447	0
5 - Swale Side Slope	0.448	0	0.001	0.447	0
1 - Swale main channel	0.0039	0.447	0.3451	0.1058	77
2 - Swale main channel	0.0039	0.5528	0.421	0.1357	76
3 - Swale main channel	0.0039	0.5827	0.4403	0.1463	75
4 - Swale main channel	0.0039	0.5933	0.4461	0.1511	75
5 - Swale main channel	0.0039	0.5981	0.45	0.152	75

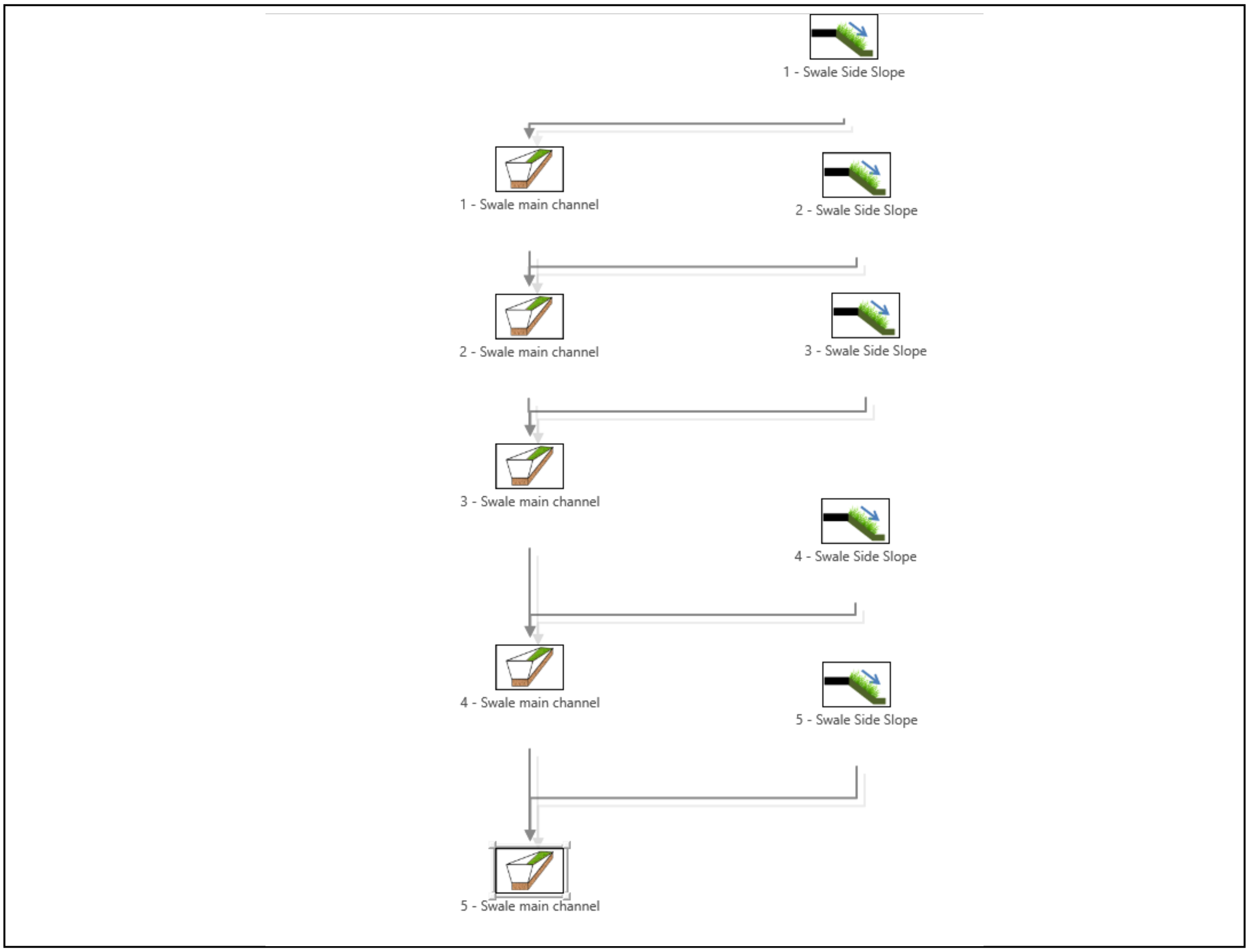
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3665	0	0.0008	0.3657	0
2 - Swale Side Slope	0.3665	0	0.0008	0.3657	0
3 - Swale Side Slope	0.3665	0	0.0008	0.3657	0
4 - Swale Side Slope	0.3665	0	0.0008	0.3657	0
5 - Swale Side Slope	0.3665	0	0.0008	0.3657	0
1 - Swale main channel	0.0032	0.3657	0.0484	0.3205	13
2 - Swale main channel	0.0032	0.6862	0.0669	0.6225	10
3 - Swale main channel	0.0032	0.9882	0.0757	0.9157	8
4 - Swale main channel	0.0032	1.2814	0.0809	1.2037	6
5 - Swale main channel	0.0032	1.5694	0.1023	1.4703	7

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	147.97	0	0.32	147.65	0
2 - Swale Side Slope	147.97	0	0.32	147.65	0
3 - Swale Side Slope	147.97	0	0.32	147.65	0
4 - Swale Side Slope	147.97	0	0.32	147.65	0
5 - Swale Side Slope	147.97	0	0.32	147.65	0
1 - Swale main channel	1.3	147.65	107.54	41.41	72
2 - Swale main channel	1.3	189.06	135.35	55.01	71
3 - Swale main channel	1.3	202.66	143.68	60.28	70
4 - Swale main channel	1.3	207.93	146.49	62.74	70
5 - Swale main channel	1.3	210.39	148.36	63.33	70

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 1 - New Road in 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 3' swale depth, 3' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55902
Annual Rainfall (inches):	32.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.3635				0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.455				1.455
				Impervious Area (acres)	2.06
				Total Area (acres)	3.8785

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.3635				0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.455				1.455
				Impervious Area (acres)	2.06
				Total Area (acres)	3.8785

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	3295	ft^3
Percent volume removed towards performance goal	**40**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.2708	acre-ft
Annual runoff volume removed by BMPs:	4.088	acre-ft
Percent annual runoff volume removed:	**78**	**%**
Post development annual particulate P load:	2.366	lbs
Annual particulate P removed by BMPs:	2.275	lbs
Post development annual dissolved P load:	1.935	lbs
Annual dissolved P removed by BMPs:	1.501	lbs
Percent annual total phosphorus removed:	**88**	**%**
Post development annual TSS load:	781.3	lbs
Annual TSS removed by BMPs:	745	lbs
Percent annual TSS removed:	**95**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	28	1645	28	1617	2
2 - Swale Side Slope	28	1645	28	1617	2
3 - Swale Side Slope	28	1645	28	1617	2
4 - Swale Side Slope	28	1645	28	1617	2
5 - Swale Side Slope	28	1645	28	1617	2
1 - Swale main channel	444	1617	444	1173	27
2 - Swale main channel	548	2790	548	2242	20
3 - Swale main channel	653	3859	653	3206	17
4 - Swale main channel	727	4823	727	4095	15
5 - Swale main channel	782	5712	782	4931	14

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	1.0506	0	0.1518	0.8988	14
2 - Swale Side Slope	1.0506	0	0.1518	0.8988	14
3 - Swale Side Slope	1.0506	0	0.1518	0.8988	14
4 - Swale Side Slope	1.0506	0	0.1518	0.8988	14
5 - Swale Side Slope	1.0506	0	0.1518	0.8988	14
1 - Swale main channel	0.0035	0.8988	0.6325	0.2698	70
2 - Swale main channel	0.0035	1.1687	0.7026	0.4696	60
3 - Swale main channel	0.0035	1.3685	0.7521	0.6199	55
4 - Swale main channel	0.0035	1.5188	0.7749	0.7474	51
5 - Swale main channel	0.0035	1.6462	0.4669	1.1828	28

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4715	0	0.0681	0.4034	14
2 - Swale Side Slope	0.4715	0	0.0681	0.4034	14
3 - Swale Side Slope	0.4715	0	0.0681	0.4034	14
4 - Swale Side Slope	0.4715	0	0.0681	0.4034	14
5 - Swale Side Slope	0.4715	0	0.0681	0.4034	14
1 - Swale main channel	0.0016	0.4034	0.3723	0.0327	92
2 - Swale main channel	0.0016	0.4361	0.3904	0.0473	89
3 - Swale main channel	0.0016	0.4507	0.3971	0.0552	88
4 - Swale main channel	0.0016	0.4586	0.3992	0.061	87
5 - Swale main channel	0.0016	0.4644	0.3758	0.0902	81

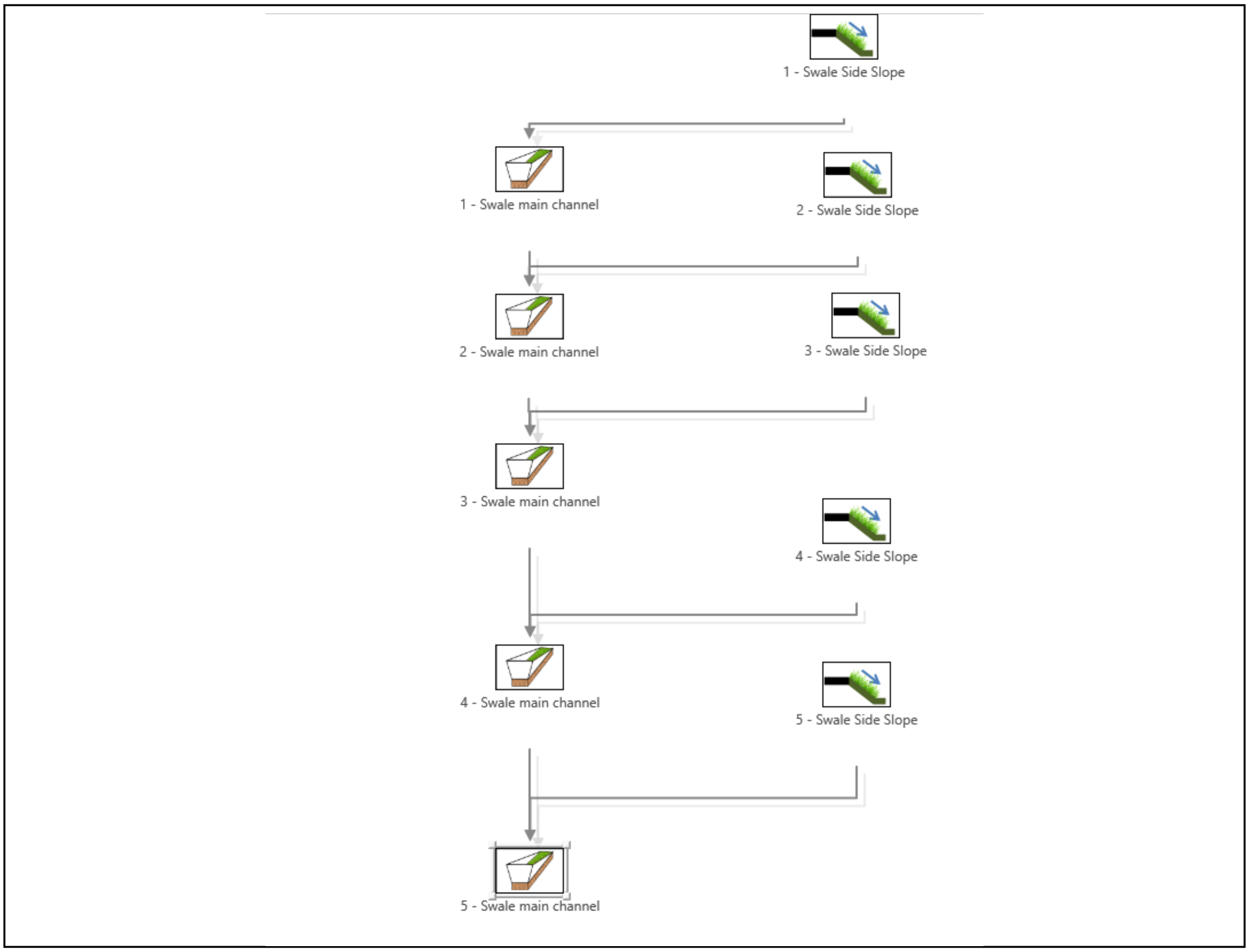
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3858	0	0.0557	0.3301	14
2 - Swale Side Slope	0.3858	0	0.0557	0.3301	14
3 - Swale Side Slope	0.3858	0	0.0557	0.3301	14
4 - Swale Side Slope	0.3858	0	0.0557	0.3301	14
5 - Swale Side Slope	0.3858	0	0.0557	0.3301	14
1 - Swale main channel	0.0013	0.3301	0.2323	0.0991	70
2 - Swale main channel	0.0013	0.4292	0.258	0.1725	60
3 - Swale main channel	0.0013	0.5026	0.2762	0.2277	55
4 - Swale main channel	0.0013	0.5578	0.2846	0.2745	51
5 - Swale main channel	0.0013	0.6046	0.1715	0.4344	28

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	155.75	0	22.51	133.24	14
2 - Swale Side Slope	155.75	0	22.51	133.24	14
3 - Swale Side Slope	155.75	0	22.51	133.24	14
4 - Swale Side Slope	155.75	0	22.51	133.24	14
5 - Swale Side Slope	155.75	0	22.51	133.24	14
1 - Swale main channel	0.52	133.24	120.96	12.8	90
2 - Swale main channel	0.52	146.04	127.77	18.79	87
3 - Swale main channel	0.52	152.03	130.49	22.06	86
4 - Swale main channel	0.52	155.3	131.34	24.48	84
5 - Swale main channel	0.52	157.72	121.93	36.310000000	77

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 1 - New Road in 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 3' swale depth, 3' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55902
Annual Rainfall (inches):	32.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.3635			0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.455			1.455
			Impervious Area (acres)		2.06
			Total Area (acres)		3.8785

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.3635			0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.455			1.455
			Impervious Area (acres)		2.06
			Total Area (acres)		3.8785

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	2728	ft^3
Percent volume removed towards performance goal	**33**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.4553	acre-ft
Annual runoff volume removed by BMPs:	3.6422	acre-ft
Percent annual runoff volume removed:	**67**	**%**
Post development annual particulate P load:	2.448	lbs
Annual particulate P removed by BMPs:	2.343	lbs
Post development annual dissolved P load:	2.003	lbs
Annual dissolved P removed by BMPs:	1.337	lbs
Percent annual total phosphorus removed:	**83**	**%**
Post development annual TSS load:	808.7	lbs
Annual TSS removed by BMPs:	765.6	lbs
Percent annual TSS removed:	**95**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	8	1645	8	1637	1
2 - Swale Side Slope	8	1645	8	1637	1
3 - Swale Side Slope	8	1645	8	1637	1
4 - Swale Side Slope	8	1645	8	1637	1
5 - Swale Side Slope	8	1645	8	1637	1
1 - Swale main channel	363	1637	363	1273	22
2 - Swale main channel	484	2910	484	2426	17
3 - Swale main channel	564	4063	564	3499	14
4 - Swale main channel	615	5136	615	4520	12
5 - Swale main channel	659	6157	659	5497	11

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	1.0858	0	0.0245	1.0613	2
2 - Swale Side Slope	1.0858	0	0.0245	1.0613	2
3 - Swale Side Slope	1.0858	0	0.0245	1.0613	2
4 - Swale Side Slope	1.0858	0	0.0245	1.0613	2
5 - Swale Side Slope	1.0858	0	0.0245	1.0613	2
1 - Swale main channel	0.0053	1.0612	0.4868	0.5797	46
2 - Swale main channel	0.0053	1.641	0.6602	0.9861	40
3 - Swale main channel	0.0053	2.0473	0.7164	1.3362	35
4 - Swale main channel	0.0053	2.3974	0.7526	1.6501	31
5 - Swale main channel	0.0053	2.7113	0.9035	1.8131	33

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4873	0	0.011	0.4763	2
2 - Swale Side Slope	0.4873	0	0.011	0.4763	2
3 - Swale Side Slope	0.4873	0	0.011	0.4763	2
4 - Swale Side Slope	0.4873	0	0.011	0.4763	2
5 - Swale Side Slope	0.4873	0	0.011	0.4763	2
1 - Swale main channel	0.0024	0.4763	0.4084	0.0703	85
2 - Swale main channel	0.0024	0.5466	0.4602	0.0888	84
3 - Swale main channel	0.0024	0.5651	0.4678	0.0997	82
4 - Swale main channel	0.0024	0.576	0.4711	0.1073	81
5 - Swale main channel	0.0024	0.5836	0.4804	0.1056	82

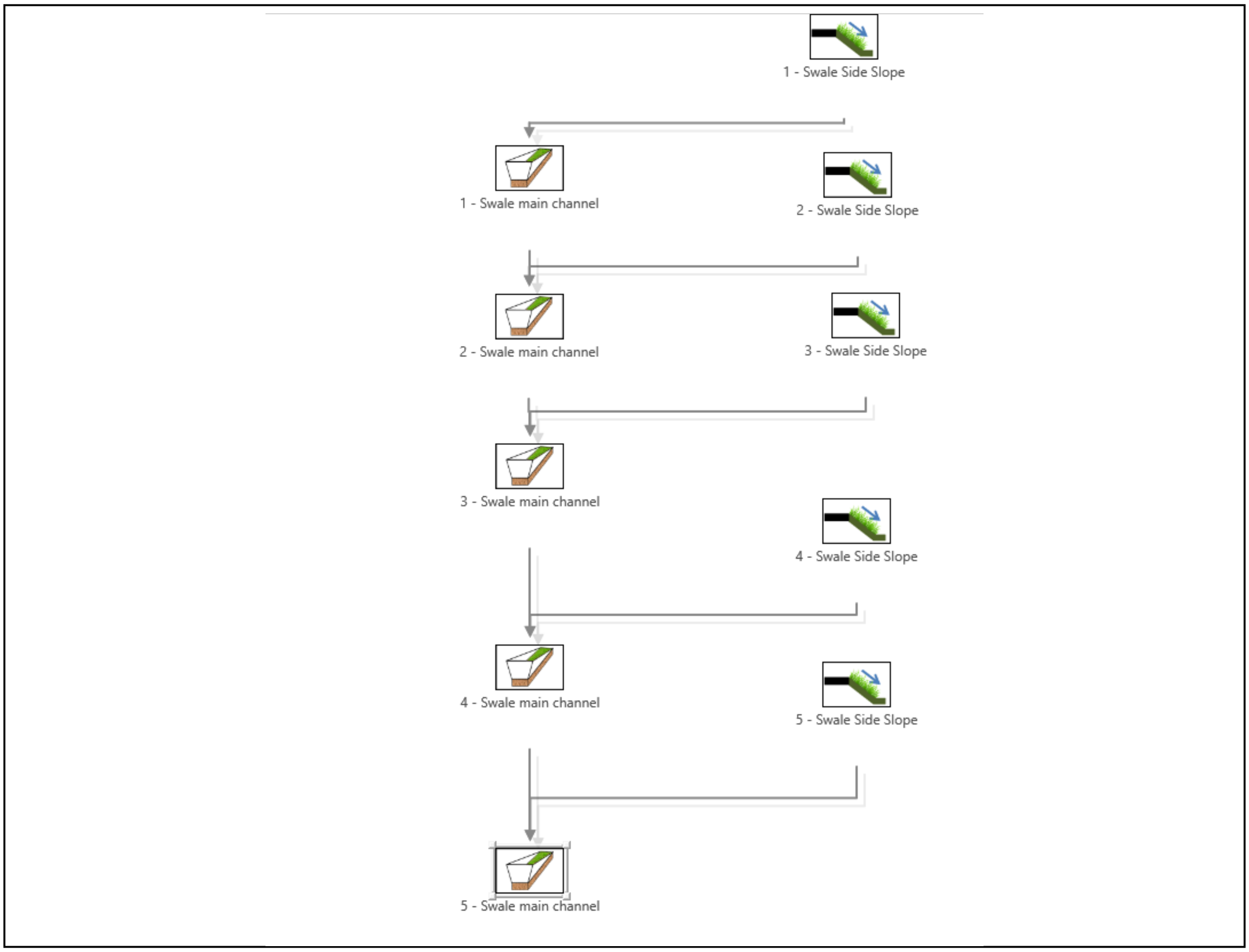
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3987	0	0.009	0.3897	2
2 - Swale Side Slope	0.3987	0	0.009	0.3897	2
3 - Swale Side Slope	0.3987	0	0.009	0.3897	2
4 - Swale Side Slope	0.3987	0	0.009	0.3897	2
5 - Swale Side Slope	0.3987	0	0.009	0.3897	2
1 - Swale main channel	0.0019	0.3897	0.1787	0.2129	46
2 - Swale main channel	0.0019	0.6026	0.2424	0.3621	40
3 - Swale main channel	0.0019	0.7518	0.2631	0.4906	35
4 - Swale main channel	0.0019	0.8803	0.2763	0.6059	31
5 - Swale main channel	0.0019	0.9956	0.3317	0.6658	33

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	160.96	0	3.64	157.32	2
2 - Swale Side Slope	160.96	0	3.64	157.32	2
3 - Swale Side Slope	160.96	0	3.64	157.32	2
4 - Swale Side Slope	160.96	0	3.64	157.32	2
5 - Swale Side Slope	160.96	0	3.64	157.32	2
1 - Swale main channel	0.78	157.32	130.6	27.5	83
2 - Swale main channel	0.78	184.82	150.03	35.570000000	81
3 - Swale main channel	0.78	192.89	153.33	40.340000000	79
4 - Swale main channel	0.78	197.66	154.83	43.610000000	78
5 - Swale main channel	0.78	200.93	158.63	43.080000000	79

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 1 - New Road in 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 3' swale depth, 3' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55902
Annual Rainfall (inches):	32.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.3635		0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.455		1.455
			Impervious Area (acres)		2.06
			Total Area (acres)		3.8785

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.3635		0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.455		1.455
			Impervious Area (acres)		2.06
			Total Area (acres)		3.8785

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	1970	ft^3
Percent volume removed towards performance goal	**24**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.5343	acre-ft
Annual runoff volume removed by BMPs:	2.7104	acre-ft
Percent annual runoff volume removed:	**49**	**%**
Post development annual particulate P load:	2.484	lbs
Annual particulate P removed by BMPs:	2.35	lbs
Post development annual dissolved P load:	2.032	lbs
Annual dissolved P removed by BMPs:	0.995	lbs
Percent annual total phosphorus removed:	**74**	**%**
Post development annual TSS load:	820.4	lbs
Annual TSS removed by BMPs:	765.1	lbs
Percent annual TSS removed:	**93**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1645	0	1645	0
2 - Swale Side Slope	0	1645	0	1645	0
3 - Swale Side Slope	0	1645	0	1645	0
4 - Swale Side Slope	0	1645	0	1645	0
5 - Swale Side Slope	0	1645	0	1645	0
1 - Swale main channel	287	1645	287	1358	17
2 - Swale main channel	372	3003	372	2631	12
3 - Swale main channel	413	4276	413	3862	10
4 - Swale main channel	440	5507	440	5067	8
5 - Swale main channel	456	6712	456	6256	7

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	1.0998	0	0.0005	1.0993	0
2 - Swale Side Slope	1.0998	0	0.0005	1.0993	0
3 - Swale Side Slope	1.0998	0	0.0005	1.0993	0
4 - Swale Side Slope	1.0998	0	0.0005	1.0993	0
5 - Swale Side Slope	1.0998	0	0.0005	1.0993	0
1 - Swale main channel	0.007	1.0993	0.3773	0.729	34
2 - Swale main channel	0.007	1.8283	0.4716	1.3637	26
3 - Swale main channel	0.007	2.4631	0.5228	1.9473	21
4 - Swale main channel	0.007	3.0467	0.5491	2.5046	18
5 - Swale main channel	0.007	3.6039	0.7871	2.8238	22

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4936	0	0.0002	0.4934	0
2 - Swale Side Slope	0.4936	0	0.0002	0.4934	0
3 - Swale Side Slope	0.4936	0	0.0002	0.4934	0
4 - Swale Side Slope	0.4936	0	0.0002	0.4934	0
5 - Swale Side Slope	0.4936	0	0.0002	0.4934	0
1 - Swale main channel	0.0032	0.4934	0.4082	0.0884	82
2 - Swale main channel	0.0032	0.5818	0.4676	0.1174	80
3 - Swale main channel	0.0032	0.6108	0.4833	0.1307	79
4 - Swale main channel	0.0032	0.6241	0.4884	0.1389	78
5 - Swale main channel	0.0032	0.6323	0.5013	0.1342	79

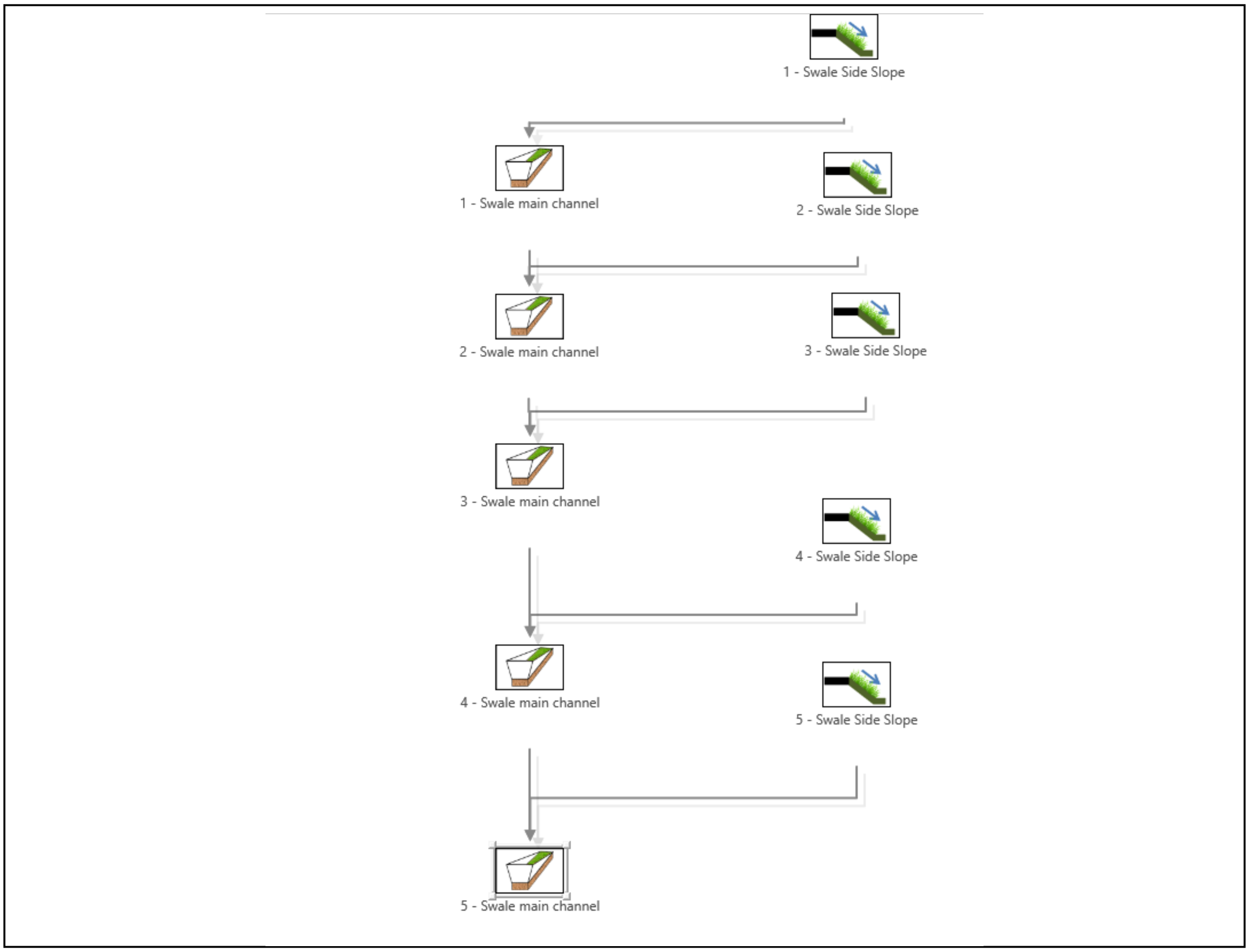
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4039	0	0.0002	0.4037	0
2 - Swale Side Slope	0.4039	0	0.0002	0.4037	0
3 - Swale Side Slope	0.4039	0	0.0002	0.4037	0
4 - Swale Side Slope	0.4039	0	0.0002	0.4037	0
5 - Swale Side Slope	0.4039	0	0.0002	0.4037	0
1 - Swale main channel	0.0026	0.4037	0.1386	0.2677	34
2 - Swale main channel	0.0026	0.6714	0.1732	0.5008	26
3 - Swale main channel	0.0026	0.9045	0.192	0.7151	21
4 - Swale main channel	0.0026	1.1188	0.2016	0.9198	18
5 - Swale main channel	0.0026	1.3235	0.289	1.0371	22

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	163.04	0	0.08	162.96	0
2 - Swale Side Slope	163.04	0	0.08	162.96	0
3 - Swale Side Slope	163.04	0	0.08	162.96	0
4 - Swale Side Slope	163.04	0	0.08	162.96	0
5 - Swale Side Slope	163.04	0	0.08	162.96	0
1 - Swale main channel	1.04	162.96	129.42	34.58	79
2 - Swale main channel	1.04	197.54	151.36	47.219999999	76
3 - Swale main channel	1.04	210.18	157.93	53.289999999	75
4 - Swale main channel	1.04	216.25	160.26	57.029999999	74
5 - Swale main channel	1.04	219.99	165.72	55.309999999	75

BMP Schematic



CASE STUDY 2, HSG D, NEW ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 1 - New Road in 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 3' swale depth, 3' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55902
Annual Rainfall (inches):	32.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.3635	0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.455	1.455
			Impervious Area (acres)		2.06
			Total Area (acres)		3.8785

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.3635	0.3635
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.455	1.455
			Impervious Area (acres)		2.06
			Total Area (acres)		3.8785

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	1542	ft^3
Percent volume removed towards performance goal	**19**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.6485	acre-ft
Annual runoff volume removed by BMPs:	0.9759	acre-ft
Percent annual runoff volume removed:	**17**	**%**
Post development annual particulate P load:	2.535	lbs
Annual particulate P removed by BMPs:	2.36	lbs
Post development annual dissolved P load:	2.074	lbs
Annual dissolved P removed by BMPs:	0.358	lbs
Percent annual total phosphorus removed:	**59**	**%**
Post development annual TSS load:	837.3	lbs
Annual TSS removed by BMPs:	764.4	lbs
Percent annual TSS removed:	**91**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1645	0	1645	0
2 - Swale Side Slope	0	1645	0	1645	0
3 - Swale Side Slope	0	1645	0	1645	0
4 - Swale Side Slope	0	1645	0	1645	0
5 - Swale Side Slope	0	1645	0	1645	0
1 - Swale main channel	251	1645	251	1394	15
2 - Swale main channel	304	3040	304	2736	10
3 - Swale main channel	328	4381	328	4053	7
4 - Swale main channel	334	5698	334	5364	6
5 - Swale main channel	325	7009	325	6684	5

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	1.1209	0	0	1.1209	0
2 - Swale Side Slope	1.1209	0	0	1.1209	0
3 - Swale Side Slope	1.1209	0	0	1.1209	0
4 - Swale Side Slope	1.1209	0	0	1.1209	0
5 - Swale Side Slope	1.1209	0	0	1.1209	0
1 - Swale main channel	0.0088	1.1209	0.1392	0.9905	12
2 - Swale main channel	0.0088	2.1114	0.1864	1.9338	9
3 - Swale main channel	0.0088	3.0547	0.2107	2.8528	7
4 - Swale main channel	0.0088	3.9737	0.2199	3.7626	6
5 - Swale main channel	0.0088	4.8835	0.2196	4.6727	4

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.5031	0	0	0.5031	0
2 - Swale Side Slope	0.5031	0	0	0.5031	0
3 - Swale Side Slope	0.5031	0	0	0.5031	0
4 - Swale Side Slope	0.5031	0	0	0.5031	0
5 - Swale Side Slope	0.5031	0	0	0.5031	0
1 - Swale main channel	0.0039	0.5031	0.387	0.12	76
2 - Swale main channel	0.0039	0.6231	0.4726	0.1544	75
3 - Swale main channel	0.0039	0.6575	0.4951	0.1663	75
4 - Swale main channel	0.0039	0.6694	0.5015	0.1718	74
5 - Swale main channel	0.0039	0.6749	0.5038	0.175	74

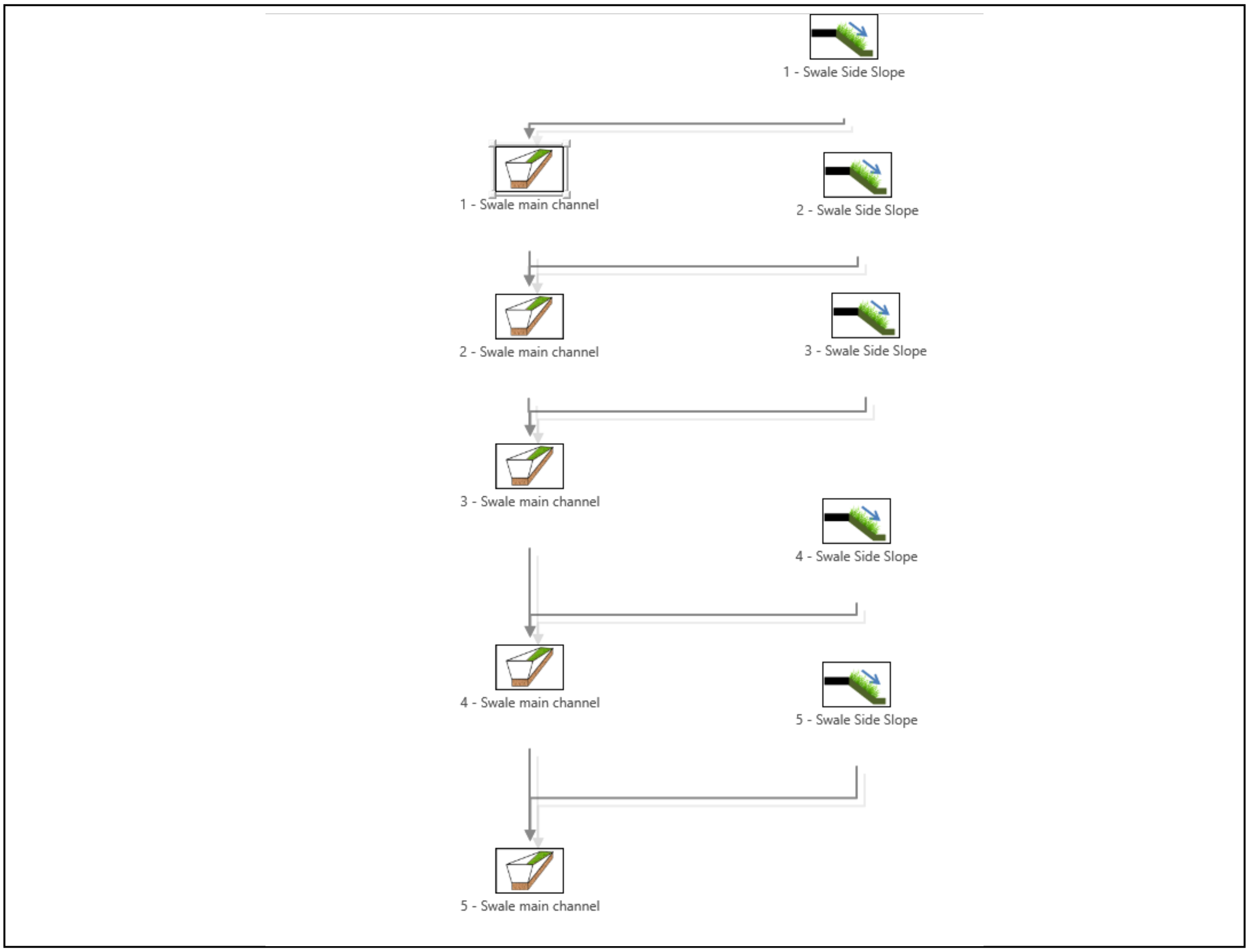
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4116	0	0	0.4116	0
2 - Swale Side Slope	0.4116	0	0	0.4116	0
3 - Swale Side Slope	0.4116	0	0	0.4116	0
4 - Swale Side Slope	0.4116	0	0	0.4116	0
5 - Swale Side Slope	0.4116	0	0	0.4116	0
1 - Swale main channel	0.0032	0.4116	0.0511	0.3637	12
2 - Swale main channel	0.0032	0.7753	0.0685	0.71	9
3 - Swale main channel	0.0032	1.1216	0.0773	1.0475	7
4 - Swale main channel	0.0032	1.4591	0.0807	1.3816	6
5 - Swale main channel	0.0032	1.7932	0.0806	1.7158	4

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	166.17	0	0	166.17	0
2 - Swale Side Slope	166.17	0	0	166.17	0
3 - Swale Side Slope	166.17	0	0	166.17	0
4 - Swale Side Slope	166.17	0	0	166.17	0
5 - Swale Side Slope	166.17	0	0	166.17	0
1 - Swale main channel	1.3	166.17	120.48	46.99	72
2 - Swale main channel	1.3	213.16	151.87	62.59	71
3 - Swale main channel	1.3	228.76	161.5	68.56	70
4 - Swale main channel	1.3	234.73	164.67	71.36	70
5 - Swale main channel	1.3	237.53	165.84	72.99	69

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 2 - Existing Road - 1 Segment - HSG A
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55604
Annual Rainfall (inches):	29.5
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.242				0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.455				1.455
				Impervious Area (acres)	1.695
				Total Area (acres)	3.392

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.242				0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.455				1.455
				Impervious Area (acres)	1.695
				Total Area (acres)	3.392

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	6768	ft^3
Percent volume removed towards performance goal	**100**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.0563	acre-ft
Annual runoff volume removed by BMPs:	4.0498	acre-ft
Percent annual runoff volume removed:	**100**	**%**
Post development annual particulate P load:	1.82	lbs
Annual particulate P removed by BMPs:	1.82	lbs
Post development annual dissolved P load:	1.49	lbs
Annual dissolved P removed by BMPs:	1.487	lbs
Percent annual total phosphorus removed:	**100**	**%**
Post development annual TSS load:	601.3	lbs
Annual TSS removed by BMPs:	601	lbs
Percent annual TSS removed:	**100**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	108	6768	108	6660	2
1 - Swale main channel	21604	6660	6660	0	100

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	4.0456	0	0.5597	3.4859	14
1 - Swale main channel	0.0107	3.4859	3.4901	0.0064999999	100

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	1.8156	0	0.2512	1.5644	14
1 - Swale main channel	0.0048	1.5644	1.5684	0.0008	100

Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	1.4855	0	0.2055	1.28	14
1 - Swale main channel	0.0039	1.28	1.2815	0.0024	100

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	599.71	0	82.96	516.75	14
1 - Swale main channel	1.59	516.75	518.03	0.3100000000	100

BMP Schematic

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 2 - Existing Road - 1 Segment
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55604
Annual Rainfall (inches):	29.5
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.242			0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.455			1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.242			0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.455			1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	6768	ft^3
Percent volume removed towards performance goal	**100**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.2226	acre-ft
Annual runoff volume removed by BMPs:	4.2225	acre-ft
Percent annual runoff volume removed:	**100**	**%**
Post development annual particulate P load:	1.895	lbs
Annual particulate P removed by BMPs:	1.895	lbs
Post development annual dissolved P load:	1.55	lbs
Annual dissolved P removed by BMPs:	1.55	lbs
Percent annual total phosphorus removed:	**100**	**%**
Post development annual TSS load:	626	lbs
Annual TSS removed by BMPs:	626	lbs
Percent annual TSS removed:	**100**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	29	6768	29	6739	0
1 - Swale main channel	29411	6739	6739	0	100

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	4.2065	0	0.0816	4.1249	2
1 - Swale main channel	0.0161	4.1249	4.141	0	100

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	1.8879	0	0.0366	1.8513	2
1 - Swale main channel	0.0072	1.8513	1.8585	0	100

Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	1.5446	0	0.03	1.5146	2
1 - Swale main channel	0.0059	1.5146	1.5205	0	100

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	623.57	0	12.1	611.47	2
1 - Swale main channel	2.38	611.47	613.85	0	100

BMP Schematic

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 2 - Existing Road - 1 Segment
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55604
Annual Rainfall (inches):	29.5
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.242		0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.455		1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.242		0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.455		1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	6768	ft^3
Percent volume removed towards performance goal	**100**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.2923	acre-ft
Annual runoff volume removed by BMPs:	4.2922	acre-ft
Percent annual runoff volume removed:	**100**	**%**
Post development annual particulate P load:	1.926	lbs
Annual particulate P removed by BMPs:	1.926	lbs
Post development annual dissolved P load:	1.576	lbs
Annual dissolved P removed by BMPs:	1.576	lbs
Percent annual total phosphorus removed:	**100**	**%**
Post development annual TSS load:	636.3	lbs
Annual TSS removed by BMPs:	636.3	lbs
Percent annual TSS removed:	**100**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	6768	0	6768	0
1 - Swale main channel	29532	6768	6768	0	100

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	4.2709	0	0	4.2709	0
1 - Swale main channel	0.0214	4.2709	4.2922	9.9999999999	100

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	1.9168	0	0	1.9168	0
1 - Swale main channel	0.0096	1.9168	1.9264	0	100

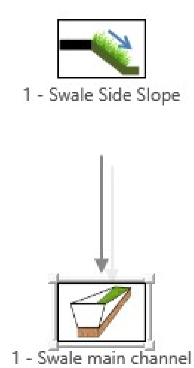
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	1.5683	0	0	1.5683	0
1 - Swale main channel	0.0079	1.5683	1.5762	0	100

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	633.12	0	0	633.12	0
1 - Swale main channel	3.17	633.12	636.29	0	100

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 2 - Existing Road - 1 Segment
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55604
Annual Rainfall (inches):	29.5
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.242	0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.455	1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.242	0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.455	1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	6768	ft^3
Percent volume removed towards performance goal	**100**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.3942	acre-ft
Annual runoff volume removed by BMPs:	1.7796	acre-ft
Percent annual runoff volume removed:	**40**	**%**
Post development annual particulate P load:	1.972	lbs
Annual particulate P removed by BMPs:	1.655	lbs
Post development annual dissolved P load:	1.614	lbs
Annual dissolved P removed by BMPs:	0.654	lbs
Percent annual total phosphorus removed:	**64**	**%**
Post development annual TSS load:	651.4	lbs
Annual TSS removed by BMPs:	527.4	lbs
Percent annual TSS removed:	**81**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	6768	0	6768	0
1 - Swale main channel	10245	6768	6768	0	100

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	4.3675	0	0	4.3675	0
1 - Swale main channel	0.0268	4.3675	1.7797	2.6146	40

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	1.9601	0	0	1.9601	0
1 - Swale main channel	0.012	1.9601	1.6553	0.3168	84

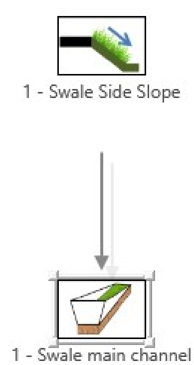
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	1.6037	0	0	1.6037	0
1 - Swale main channel	0.0098	1.6037	0.6535	0.96	40

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	647.43	0	0	647.43	0
1 - Swale main channel	3.97	647.43	527.37	124.03	81

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 2 - New Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55604
Annual Rainfall (inches):	29.5
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.97				0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.94				1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.97				0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.94				1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	8226	ft^3
Percent volume removed towards performance goal	**100**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.0166	acre-ft
Annual runoff volume removed by BMPs:	4.9991	acre-ft
Percent annual runoff volume removed:	**100**	**%**
Post development annual particulate P load:	2.252	lbs
Annual particulate P removed by BMPs:	2.249	lbs
Post development annual dissolved P load:	1.842	lbs
Annual dissolved P removed by BMPs:	1.836	lbs
Percent annual total phosphorus removed:	**100**	**%**
Post development annual TSS load:	743.7	lbs
Annual TSS removed by BMPs:	742.8	lbs
Percent annual TSS removed:	**100**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	34	1645	34	1612	2
2 - Swale Side Slope	34	1645	34	1612	2
3 - Swale Side Slope	34	1645	34	1612	2
4 - Swale Side Slope	34	1645	34	1612	2
5 - Swale Side Slope	34	1645	34	1612	2
1 - Swale main channel	2031	1612	1612	0	100
2 - Swale main channel	2031	1612	1612	0	100
3 - Swale main channel	2031	1612	1612	0	100
4 - Swale main channel	2031	1612	1612	0	100
5 - Swale main channel	2031	1612	1612	0	100

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9947	0	0.1769	0.8178	18
2 - Swale Side Slope	0.9947	0	0.1769	0.8178	18
3 - Swale Side Slope	0.9947	0	0.1769	0.8178	18
4 - Swale Side Slope	0.9947	0	0.1769	0.8178	18
5 - Swale Side Slope	0.9947	0	0.1769	0.8178	18
1 - Swale main channel	0.0086	0.8178	0.8092	0.0172	98
2 - Swale main channel	0.0086	0.835	0.8261	0.0175000000	98
3 - Swale main channel	0.0086	0.8354	0.8264	0.0176000000	98
4 - Swale main channel	0.0086	0.8354	0.8264	0.0176000000	98
5 - Swale main channel	0.0086	0.8354	0.8264	0.0176000000	98

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4464	0	0.0794	0.367	18
2 - Swale Side Slope	0.4464	0	0.0794	0.367	18
3 - Swale Side Slope	0.4464	0	0.0794	0.367	18
4 - Swale Side Slope	0.4464	0	0.0794	0.367	18
5 - Swale Side Slope	0.4464	0	0.0794	0.367	18
1 - Swale main channel	0.0039	0.367	0.3688	0.0021	99
2 - Swale main channel	0.0039	0.3691	0.3709	0.0021	99
3 - Swale main channel	0.0039	0.3691	0.3709	0.0021	99
4 - Swale main channel	0.0039	0.3691	0.3709	0.0021	99
5 - Swale main channel	0.0039	0.3691	0.3709	0.0021	99

Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3653	0	0.065	0.3003	18
2 - Swale Side Slope	0.3653	0	0.065	0.3003	18
3 - Swale Side Slope	0.3653	0	0.065	0.3003	18
4 - Swale Side Slope	0.3653	0	0.065	0.3003	18
5 - Swale Side Slope	0.3653	0	0.065	0.3003	18
1 - Swale main channel	0.0032	0.3003	0.2972	0.0063	98
2 - Swale main channel	0.0032	0.3066	0.3034	0.0064	98
3 - Swale main channel	0.0032	0.3067	0.3035	0.0064	98
4 - Swale main channel	0.0032	0.3067	0.3035	0.0064	98
5 - Swale main channel	0.0032	0.3067	0.3035	0.0064	98

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	147.46	0	26.22	121.24	18
2 - Swale Side Slope	147.46	0	26.22	121.24	18
3 - Swale Side Slope	147.46	0	26.22	121.24	18
4 - Swale Side Slope	147.46	0	26.22	121.24	18
5 - Swale Side Slope	147.46	0	26.22	121.24	18
1 - Swale main channel	1.27	121.24	121.69	0.8200000000	99
2 - Swale main channel	1.27	122.06	122.51	0.8200000000	99
3 - Swale main channel	1.27	122.06	122.51	0.8200000000	99
4 - Swale main channel	1.27	122.06	122.51	0.8200000000	99
5 - Swale main channel	1.27	122.06	122.51	0.8200000000	99

BMP Schematic

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 2 - New Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55604
Annual Rainfall (inches):	29.5
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.97			0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.94			1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.97			0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.94			1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	4453	ft^3
Percent volume removed towards performance goal	**54**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.2527	acre-ft
Annual runoff volume removed by BMPs:	4.2626	acre-ft
Percent annual runoff volume removed:	**81**	**%**
Post development annual particulate P load:	2.357	lbs
Annual particulate P removed by BMPs:	2.283	lbs
Post development annual dissolved P load:	1.929	lbs
Annual dissolved P removed by BMPs:	1.565	lbs
Percent annual total phosphorus removed:	**90**	**%**
Post development annual TSS load:	778.7	lbs
Annual TSS removed by BMPs:	748.7	lbs
Percent annual TSS removed:	**96**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	15	1645	15	1631	1
2 - Swale Side Slope	15	1645	15	1631	1
3 - Swale Side Slope	15	1645	15	1631	1
4 - Swale Side Slope	15	1645	15	1631	1
5 - Swale Side Slope	15	1645	15	1631	1
1 - Swale main channel	667	1631	667	963	41
2 - Swale main channel	802	2594	802	1792	31
3 - Swale main channel	897	3423	897	2525	26
4 - Swale main channel	975	4156	975	3181	23
5 - Swale main channel	1039	4811	1039	3772	22

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	1.0377	0	0.0415	0.9962	4
2 - Swale Side Slope	1.0377	0	0.0415	0.9962	4
3 - Swale Side Slope	1.0377	0	0.0415	0.9962	4
4 - Swale Side Slope	1.0377	0	0.0415	0.9962	4
5 - Swale Side Slope	1.0377	0	0.0415	0.9962	4
1 - Swale main channel	0.0129	0.9961	0.6462	0.3628	64
2 - Swale main channel	0.0129	1.3589	0.8011	0.5707	58
3 - Swale main channel	0.0129	1.5669	0.845	0.7348	53
4 - Swale main channel	0.0129	1.7309	0.8758	0.868	50
5 - Swale main channel	0.0129	1.8641	0.8869	0.9901	47

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4657	0	0.0186	0.4471	4
2 - Swale Side Slope	0.4657	0	0.0186	0.4471	4
3 - Swale Side Slope	0.4657	0	0.0186	0.4471	4
4 - Swale Side Slope	0.4657	0	0.0186	0.4471	4
5 - Swale Side Slope	0.4657	0	0.0186	0.4471	4
1 - Swale main channel	0.0058	0.4471	0.4089	0.044	90
2 - Swale main channel	0.0058	0.4911	0.4411	0.0558	89
3 - Swale main channel	0.0058	0.5029	0.4448	0.0639	87
4 - Swale main channel	0.0058	0.511	0.4473	0.0695	87
5 - Swale main channel	0.0058	0.5166	0.448	0.0744	86

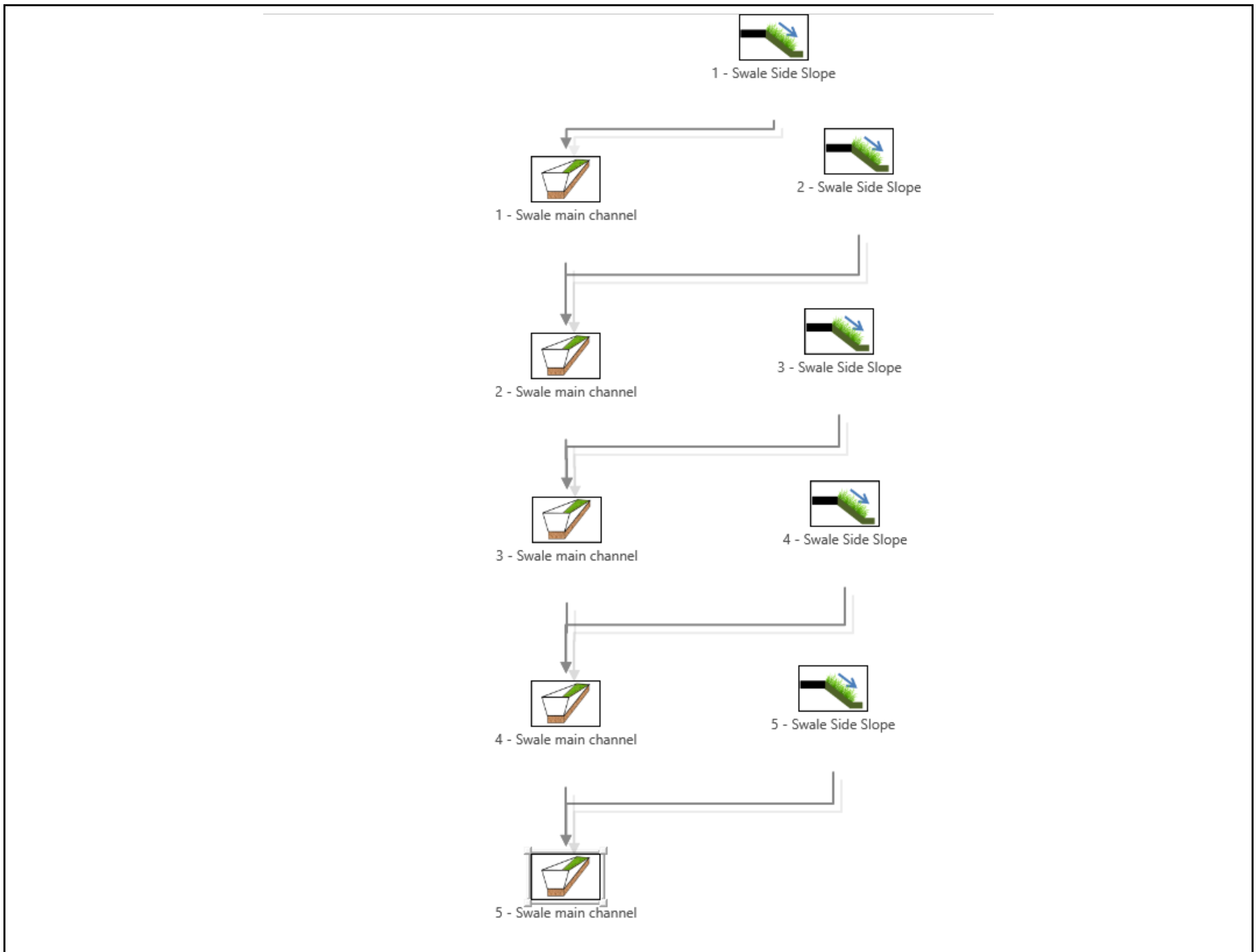
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.381	0	0.0152	0.3658	4
2 - Swale Side Slope	0.381	0	0.0152	0.3658	4
3 - Swale Side Slope	0.381	0	0.0152	0.3658	4
4 - Swale Side Slope	0.381	0	0.0152	0.3658	4
5 - Swale Side Slope	0.381	0	0.0152	0.3658	4
1 - Swale main channel	0.0047	0.3658	0.2373	0.1332	64
2 - Swale main channel	0.0047	0.499	0.2941	0.2096	58
3 - Swale main channel	0.0047	0.5754	0.3103	0.2698	53
4 - Swale main channel	0.0047	0.6356	0.3216	0.3187	50
5 - Swale main channel	0.0047	0.6845	0.3256	0.3636	47

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	153.82	0	6.16	147.66	4
2 - Swale Side Slope	153.82	0	6.16	147.66	4
3 - Swale Side Slope	153.82	0	6.16	147.66	4
4 - Swale Side Slope	153.82	0	6.16	147.66	4
5 - Swale Side Slope	153.82	0	6.16	147.66	4
1 - Swale main channel	1.91	147.66	132.36	17.21	88
2 - Swale main channel	1.91	164.87	144.58	22.2	87
3 - Swale main channel	1.91	169.86	146.2	25.57	85
4 - Swale main channel	1.91	173.23	147.24	27.899999999	84
5 - Swale main channel	1.91	175.56	147.51	29.96	83

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 2 - New Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55604
Annual Rainfall (inches):	29.5
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.97		0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.94		1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.97		0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.94		1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	3503	ft^3
Percent volume removed towards performance goal	**43**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.36	acre-ft
Annual runoff volume removed by BMPs:	3.451	acre-ft
Percent annual runoff volume removed:	**64**	**%**
Post development annual particulate P load:	2.406	lbs
Annual particulate P removed by BMPs:	2.294	lbs
Post development annual dissolved P load:	1.968	lbs
Annual dissolved P removed by BMPs:	1.267	lbs
Percent annual total phosphorus removed:	**81**	**%**
Post development annual TSS load:	794.6	lbs
Annual TSS removed by BMPs:	749.2	lbs
Percent annual TSS removed:	**94**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	5	1645	5	1640	0
2 - Swale Side Slope	5	1645	5	1640	0
3 - Swale Side Slope	5	1645	5	1640	0
4 - Swale Side Slope	5	1645	5	1640	0
5 - Swale Side Slope	5	1645	5	1640	0
1 - Swale main channel	496	1640	496	1144	30
2 - Swale main channel	635	2783	635	2149	23
3 - Swale main channel	714	3788	714	3075	19
4 - Swale main channel	786	4714	786	3928	17
5 - Swale main channel	846	5568	846	4722	15

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	1.0548	0	0.0135	1.0413	1
2 - Swale Side Slope	1.0548	0	0.0135	1.0413	1
3 - Swale Side Slope	1.0548	0	0.0135	1.0413	1
4 - Swale Side Slope	1.0548	0	0.0135	1.0413	1
5 - Swale Side Slope	1.0548	0	0.0135	1.0413	1
1 - Swale main channel	0.0172	1.0413	0.5091	0.5494	48
2 - Swale main channel	0.0172	1.5907	0.6433	0.9646	40
3 - Swale main channel	0.0172	2.0059	0.6957	1.3274	34
4 - Swale main channel	0.0172	2.3686	0.7473	1.6385	31
5 - Swale main channel	0.0172	2.6797	0.7879	1.909	29

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4734	0	0.0061	0.4673	1
2 - Swale Side Slope	0.4734	0	0.0061	0.4673	1
3 - Swale Side Slope	0.4734	0	0.0061	0.4673	1
4 - Swale Side Slope	0.4734	0	0.0061	0.4673	1
5 - Swale Side Slope	0.4734	0	0.0061	0.4673	1
1 - Swale main channel	0.0077	0.4673	0.4084	0.0666	86
2 - Swale main channel	0.0077	0.5339	0.4539	0.0877	84
3 - Swale main channel	0.0077	0.555	0.463	0.0997	82
4 - Swale main channel	0.0077	0.567	0.4681	0.1066	81
5 - Swale main channel	0.0077	0.5739	0.4704	0.1112	81

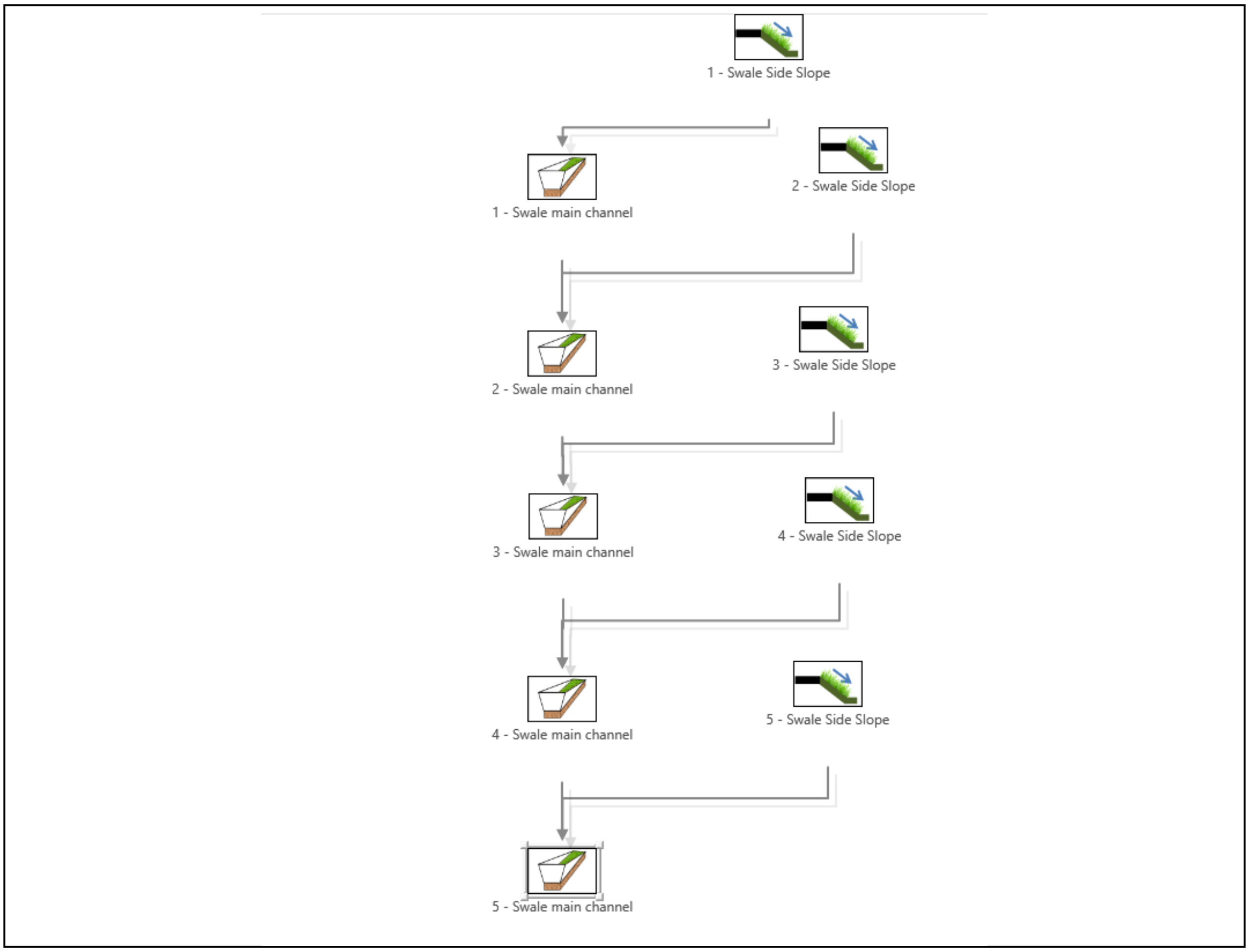
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3873	0	0.005	0.3823	1
2 - Swale Side Slope	0.3873	0	0.005	0.3823	1
3 - Swale Side Slope	0.3873	0	0.005	0.3823	1
4 - Swale Side Slope	0.3873	0	0.005	0.3823	1
5 - Swale Side Slope	0.3873	0	0.005	0.3823	1
1 - Swale main channel	0.0063	0.3823	0.1869	0.2017	48
2 - Swale main channel	0.0063	0.584	0.2362	0.3541	40
3 - Swale main channel	0.0063	0.7364	0.2554	0.4873	34
4 - Swale main channel	0.0063	0.8696	0.2744	0.6015	31
5 - Swale main channel	0.0063	0.9838	0.2893	0.7008	29

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	156.37	0	2.01	154.36	1
2 - Swale Side Slope	156.37	0	2.01	154.36	1
3 - Swale Side Slope	156.37	0	2.01	154.36	1
4 - Swale Side Slope	156.37	0	2.01	154.36	1
5 - Swale Side Slope	156.37	0	2.01	154.36	1
1 - Swale main channel	2.55	154.36	130.85	26.06	83
2 - Swale main channel	2.55	180.42	147.84	35.130000000	81
3 - Swale main channel	2.55	189.49	151.72	40.320000000	79
4 - Swale main channel	2.55	194.68	153.89	43.340000000	78
5 - Swale main channel	2.55	197.7	154.89	45.360000000	77

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 2 - New Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	55604
Annual Rainfall (inches):	29.5
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.97	0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.94	1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.97	0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.94	1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	3263	ft^3
Percent volume removed towards performance goal	**40**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.5102	acre-ft
Annual runoff volume removed by BMPs:	1.79	acre-ft
Percent annual runoff volume removed:	**32**	**%**
Post development annual particulate P load:	2.473	lbs
Annual particulate P removed by BMPs:	2.318	lbs
Post development annual dissolved P load:	2.023	lbs
Annual dissolved P removed by BMPs:	0.657	lbs
Percent annual total phosphorus removed:	**66**	**%**
Post development annual TSS load:	816.8	lbs
Annual TSS removed by BMPs:	752.8	lbs
Percent annual TSS removed:	**92**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1645	0	1645	0
2 - Swale Side Slope	0	1645	0	1645	0
3 - Swale Side Slope	0	1645	0	1645	0
4 - Swale Side Slope	0	1645	0	1645	0
5 - Swale Side Slope	0	1645	0	1645	0
1 - Swale main channel	482	1645	482	1163	29
2 - Swale main channel	597	2808	597	2211	21
3 - Swale main channel	678	3856	678	3178	18
4 - Swale main channel	731	4823	731	4092	15
5 - Swale main channel	774	5737	774	4962	14

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	1.0806	0	0.0001	1.0805	0
2 - Swale Side Slope	1.0806	0	0.0001	1.0805	0
3 - Swale Side Slope	1.0806	0	0.0001	1.0805	0
4 - Swale Side Slope	1.0806	0	0.0001	1.0805	0
5 - Swale Side Slope	1.0806	0	0.0001	1.0805	0
1 - Swale main channel	0.0215	1.0805	0.2103	0.8917	19
2 - Swale main channel	0.0215	1.9721	0.3055	1.6881	15
3 - Swale main channel	0.0215	2.7685	0.3684	2.4216	13
4 - Swale main channel	0.0215	3.502	0.4165	3.107	12
5 - Swale main channel	0.0215	4.1874	0.4886	3.7203	12

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.485	0	0.0001	0.4849	0
2 - Swale Side Slope	0.485	0	0.0001	0.4849	0
3 - Swale Side Slope	0.485	0	0.0001	0.4849	0
4 - Swale Side Slope	0.485	0	0.0001	0.4849	0
5 - Swale Side Slope	0.485	0	0.0001	0.4849	0
1 - Swale main channel	0.0096	0.4849	0.3865	0.108	78
2 - Swale main channel	0.0096	0.5929	0.4648	0.1377	77
3 - Swale main channel	0.0096	0.6226	0.484	0.1482	77
4 - Swale main channel	0.0096	0.6331	0.4897	0.153	76
5 - Swale main channel	0.0096	0.6379	0.493	0.1545	76

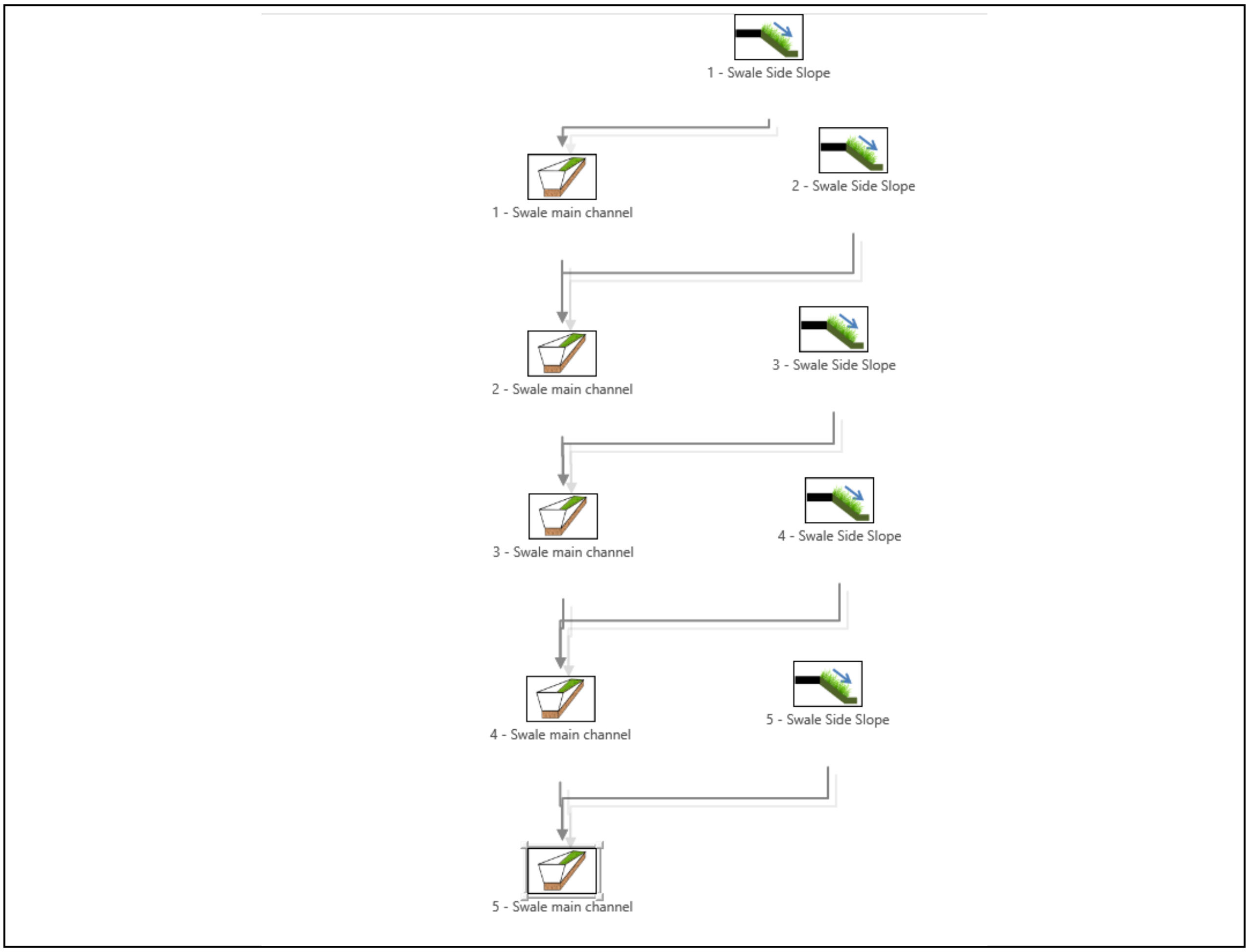
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3968	0	0	0.3968	0
2 - Swale Side Slope	0.3968	0	0	0.3968	0
3 - Swale Side Slope	0.3968	0	0	0.3968	0
4 - Swale Side Slope	0.3968	0	0	0.3968	0
5 - Swale Side Slope	0.3968	0	0	0.3968	0
1 - Swale main channel	0.0079	0.3968	0.0772	0.3275	19
2 - Swale main channel	0.0079	0.7243	0.1122	0.62	15
3 - Swale main channel	0.0079	1.0168	0.1353	0.8894	13
4 - Swale main channel	0.0079	1.2862	0.153	1.1411	12
5 - Swale main channel	0.0079	1.5379	0.1795	1.3663	12

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	160.19	0	0.02	160.17	0
2 - Swale Side Slope	160.19	0	0.02	160.17	0
3 - Swale Side Slope	160.19	0	0.02	160.17	0
4 - Swale Side Slope	160.19	0	0.02	160.17	0
5 - Swale Side Slope	160.19	0	0.02	160.17	0
1 - Swale main channel	3.18	160.17	121.05	42.3	74
2 - Swale main channel	3.18	202.47	149.93	55.72	73
3 - Swale main channel	3.18	215.89	158.23	60.84	72
4 - Swale main channel	3.18	221.01	160.93	63.26	72
5 - Swale main channel	3.18	223.43	162.51	64.1	72

BMP Schematic



CASE STUDY 3, HSG A, EXISTING ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 3 - Existing Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, no shoulder, 3:1 side slope, 3' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56701
Annual Rainfall (inches):	22.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	.242				0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.09				1.09
			Impervious Area (acres)		1.455
			Total Area (acres)		2.787

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.242				0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.09				1.09
			Impervious Area (acres)		1.455
			Total Area (acres)		2.787

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	5810	ft3
Volume removed by BMPs towards performance goal:	2656	ft^3
Percent volume removed towards performance goal	**46**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	2.5817	acre-ft
Annual runoff volume removed by BMPs:	2.2362	acre-ft
Percent annual runoff volume removed:	**87**	**%**
Post development annual particulate P load:	1.159	lbs
Annual particulate P removed by BMPs:	1.13	lbs
Post development annual dissolved P load:	0.948	lbs
Annual dissolved P removed by BMPs:	0.821	lbs
Percent annual total phosphorus removed:	**93**	**%**
Post development annual TSS load:	382.7	lbs
Annual TSS removed by BMPs:	371.4	lbs
Percent annual TSS removed:	**97**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	18	1162	18	1144	2
2 - Swale Side Slope	18	1162	18	1144	2
3 - Swale Side Slope	18	1162	18	1144	2
4 - Swale Side Slope	18	1162	18	1144	2
5 - Swale Side Slope	18	1162	18	1144	2
1 - Swale main channel	383	1144	383	761	33
2 - Swale main channel	459	1905	459	1447	24
3 - Swale main channel	514	2591	514	2077	20
4 - Swale main channel	580	3221	580	2641	18
5 - Swale main channel	631	3785	631	3154	17

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.5147	0	0.0668	0.4479	13
2 - Swale Side Slope	0.5147	0	0.0668	0.4479	13
3 - Swale Side Slope	0.5147	0	0.0668	0.4479	13
4 - Swale Side Slope	0.5147	0	0.0668	0.4479	13
5 - Swale Side Slope	0.5147	0	0.0668	0.4479	13
1 - Swale main channel	0.0016	0.4479	0.3396	0.1099	76
2 - Swale main channel	0.0016	0.5578	0.3671	0.1923	66
3 - Swale main channel	0.0016	0.6402	0.3864	0.2554	60
4 - Swale main channel	0.0016	0.7033	0.4011	0.3038	57
5 - Swale main channel	0.0016	0.7517	0.4078	0.3455	54

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.231	0	0.03	0.201	13
2 - Swale Side Slope	0.231	0	0.03	0.201	13
3 - Swale Side Slope	0.231	0	0.03	0.201	13
4 - Swale Side Slope	0.231	0	0.03	0.201	13
5 - Swale Side Slope	0.231	0	0.03	0.201	13
1 - Swale main channel	0.0007	0.201	0.1884	0.0133	93
2 - Swale main channel	0.0007	0.2143	0.195	0.02	91
3 - Swale main channel	0.0007	0.221	0.1979	0.0238	89
4 - Swale main channel	0.0007	0.2248	0.1993	0.0262	88
5 - Swale main channel	0.0007	0.2272	0.1997	0.0282	88

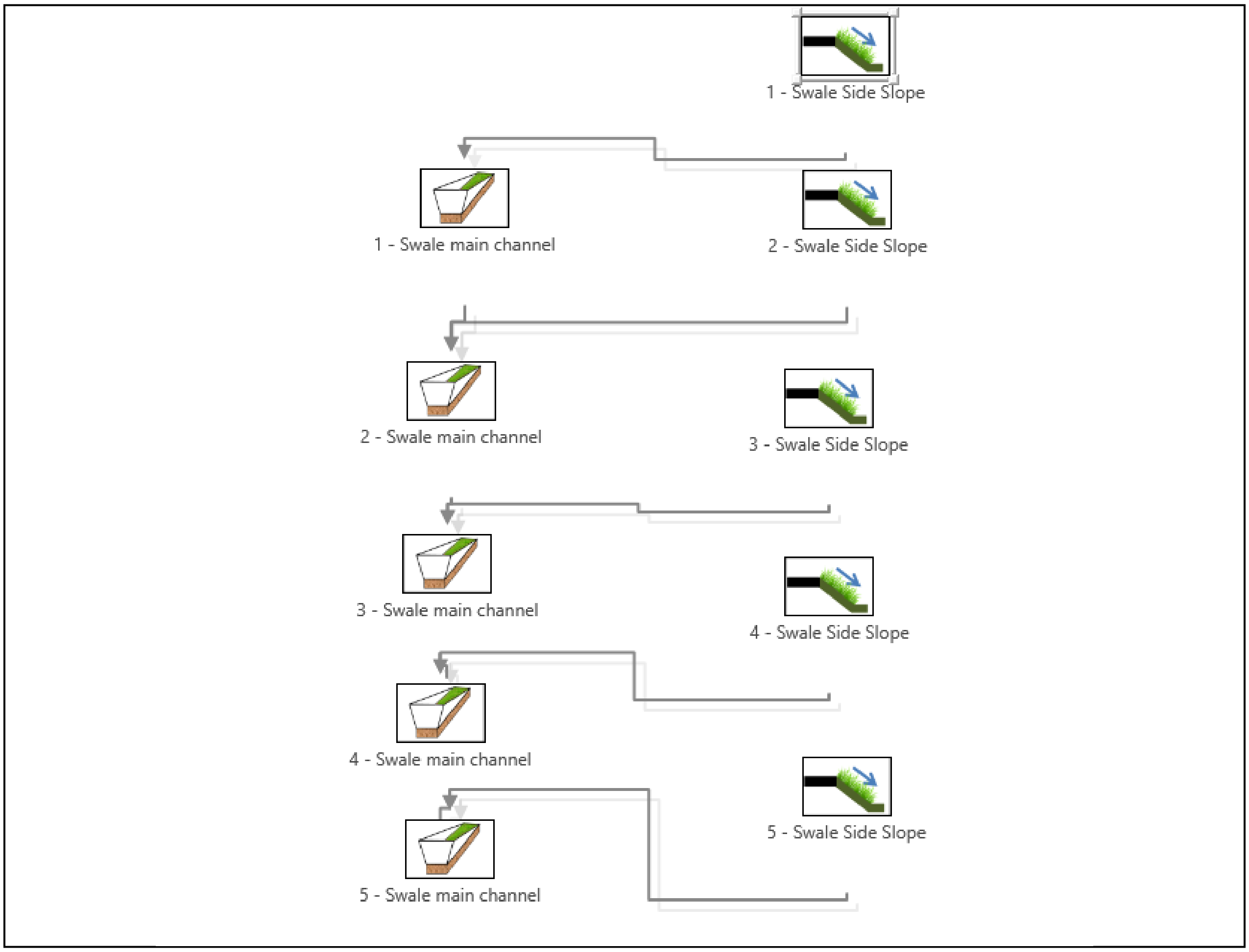
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.189	0	0.0245	0.1645	13
2 - Swale Side Slope	0.189	0	0.0245	0.1645	13
3 - Swale Side Slope	0.189	0	0.0245	0.1645	13
4 - Swale Side Slope	0.189	0	0.0245	0.1645	13
5 - Swale Side Slope	0.189	0	0.0245	0.1645	13
1 - Swale main channel	0.0006	0.1645	0.1247	0.0404	76
2 - Swale main channel	0.0006	0.2049	0.1349	0.0706	66
3 - Swale main channel	0.0006	0.2351	0.1419	0.0938	60
4 - Swale main channel	0.0006	0.2583	0.1473	0.1116	57
5 - Swale main channel	0.0006	0.2761	0.1498	0.1269	54

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	76.3	0	9.91	66.39	13
2 - Swale Side Slope	76.3	0	9.91	66.39	13
3 - Swale Side Slope	76.3	0	9.91	66.39	13
4 - Swale Side Slope	76.3	0	9.91	66.39	13
5 - Swale Side Slope	76.3	0	9.91	66.39	13
1 - Swale main channel	0.24	66.39	61.42	5.2099999999	92
2 - Swale main channel	0.24	71.6	63.94	7.8999999999	89
3 - Swale main channel	0.24	74.29	65.04	9.4899999999	87
4 - Swale main channel	0.24	75.88	65.62	10.5	86
5 - Swale main channel	0.24	76.89	65.81	11.32	85

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 3 - Existing Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, no shoulder, 3:1 side slope, 3' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56701
Annual Rainfall (inches):	22.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		.242			0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.09			1.09
			Impervious Area (acres)		1.455
			Total Area (acres)		2.787

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.242			0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.09			1.09
			Impervious Area (acres)		1.455
			Total Area (acres)		2.787

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	5810	ft3
Volume removed by BMPs towards performance goal:	2246	ft^3
Percent volume removed towards performance goal	**39**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	2.6765	acre-ft
Annual runoff volume removed by BMPs:	1.924	acre-ft
Percent annual runoff volume removed:	**72**	**%**
Post development annual particulate P load:	1.201	lbs
Annual particulate P removed by BMPs:	1.154	lbs
Post development annual dissolved P load:	0.983	lbs
Annual dissolved P removed by BMPs:	0.707	lbs
Percent annual total phosphorus removed:	**85**	**%**
Post development annual TSS load:	396.8	lbs
Annual TSS removed by BMPs:	377.6	lbs
Percent annual TSS removed:	**95**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	4	1162	4	1158	0
2 - Swale Side Slope	4	1162	4	1158	0
3 - Swale Side Slope	4	1162	4	1158	0
4 - Swale Side Slope	4	1162	4	1158	0
5 - Swale Side Slope	4	1162	4	1158	0
1 - Swale main channel	301	1158	301	857	26
2 - Swale main channel	395	2015	395	1620	20
3 - Swale main channel	463	2778	463	2315	17
4 - Swale main channel	515	3473	515	2959	15
5 - Swale main channel	553	4116	553	3563	13

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.5329	0	0.0082	0.5247	2
2 - Swale Side Slope	0.5329	0	0.0082	0.5247	2
3 - Swale Side Slope	0.5329	0	0.0082	0.5247	2
4 - Swale Side Slope	0.5329	0	0.0082	0.5247	2
5 - Swale Side Slope	0.5329	0	0.0082	0.5247	2
1 - Swale main channel	0.0024	0.5247	0.266	0.2611	50
2 - Swale main channel	0.0024	0.7858	0.3567	0.4315	45
3 - Swale main channel	0.0024	0.9562	0.3836	0.575	40
4 - Swale main channel	0.0024	1.0997	0.4029	0.6992	37
5 - Swale main channel	0.0024	1.2239	0.4738	0.7525	39

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2392	0	0.0037	0.2355	2
2 - Swale Side Slope	0.2392	0	0.0037	0.2355	2
3 - Swale Side Slope	0.2392	0	0.0037	0.2355	2
4 - Swale Side Slope	0.2392	0	0.0037	0.2355	2
5 - Swale Side Slope	0.2392	0	0.0037	0.2355	2
1 - Swale main channel	0.0011	0.2355	0.205	0.0316	87
2 - Swale main channel	0.0011	0.2671	0.2286	0.0396	85
3 - Swale main channel	0.0011	0.2751	0.2315	0.0447	84
4 - Swale main channel	0.0011	0.2802	0.2331	0.0482	83
5 - Swale main channel	0.0011	0.2837	0.2376	0.0472	83

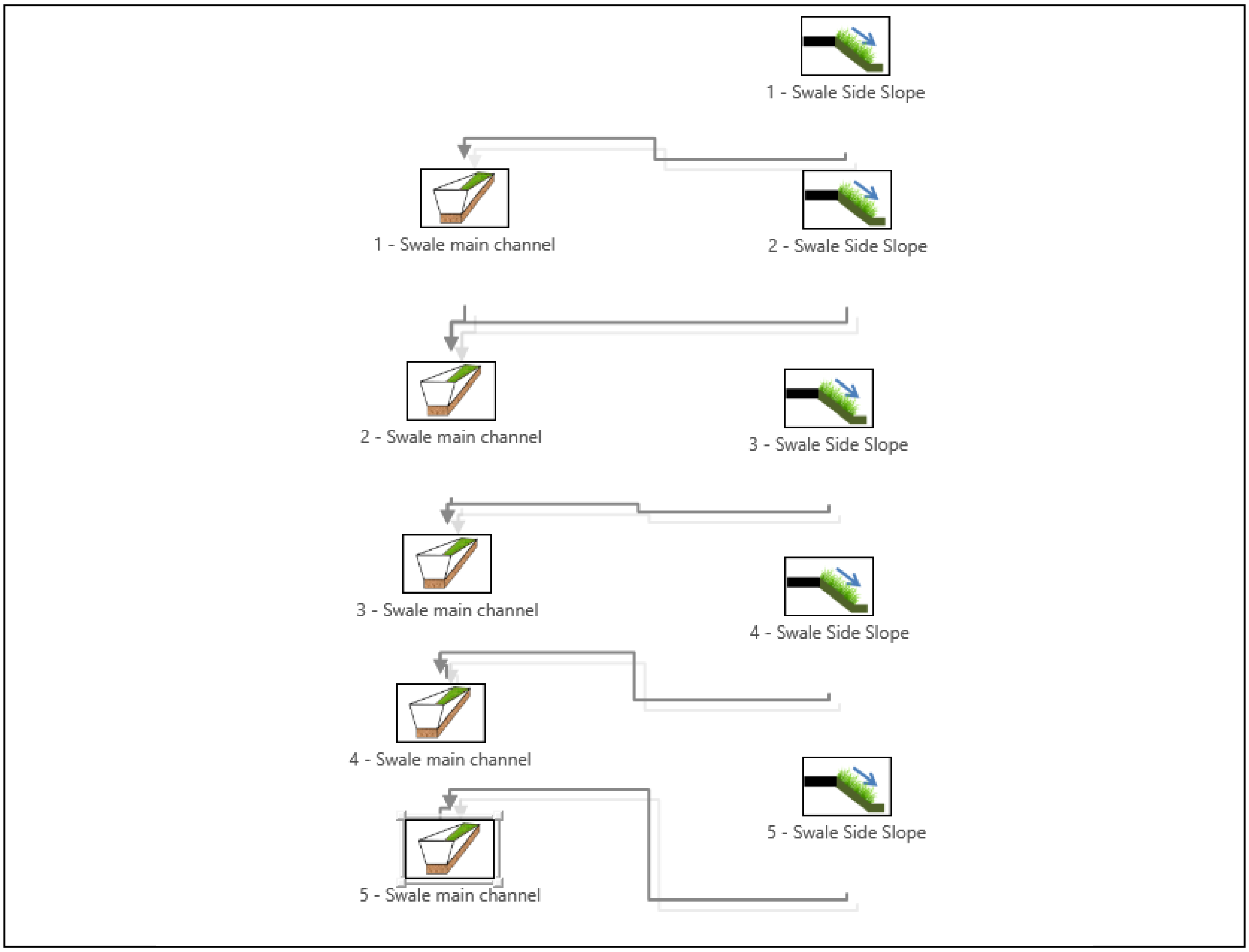
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.1957	0	0.003	0.1927	2
2 - Swale Side Slope	0.1957	0	0.003	0.1927	2
3 - Swale Side Slope	0.1957	0	0.003	0.1927	2
4 - Swale Side Slope	0.1957	0	0.003	0.1927	2
5 - Swale Side Slope	0.1957	0	0.003	0.1927	2
1 - Swale main channel	0.0009	0.1927	0.0977	0.0959	50
2 - Swale main channel	0.0009	0.2886	0.131	0.1585	45
3 - Swale main channel	0.0009	0.3512	0.1409	0.2112	40
4 - Swale main channel	0.0009	0.4039	0.148	0.2568	37
5 - Swale main channel	0.0009	0.4495	0.174	0.2764	39

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	78.99	0	1.21	77.78	2
2 - Swale Side Slope	78.99	0	1.21	77.78	2
3 - Swale Side Slope	78.99	0	1.21	77.78	2
4 - Swale Side Slope	78.99	0	1.21	77.78	2
5 - Swale Side Slope	78.99	0	1.21	77.78	2
1 - Swale main channel	0.36	77.78	65.76	12.38	84
2 - Swale main channel	0.36	90.16	74.66	15.86	82
3 - Swale main channel	0.36	93.64	75.96	18.04	81
4 - Swale main channel	0.36	95.82	76.65	19.53	80
5 - Swale main channel	0.36	97.31	78.49	19.18	80

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 3 - Existing Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, no shoulder, 3:1 side slope, 3' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56701
Annual Rainfall (inches):	22.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			.242		0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.09		1.09
			Impervious Area (acres)		1.455
			Total Area (acres)		2.787

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.242		0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.09		1.09
			Impervious Area (acres)		1.455
			Total Area (acres)		2.787

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	5810	ft3
Volume removed by BMPs towards performance goal:	1699	ft^3
Percent volume removed towards performance goal	**29**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	2.7168	acre-ft
Annual runoff volume removed by BMPs:	1.5011	acre-ft
Percent annual runoff volume removed:	**55**	**%**
Post development annual particulate P load:	1.219	lbs
Annual particulate P removed by BMPs:	1.158	lbs
Post development annual dissolved P load:	0.998	lbs
Annual dissolved P removed by BMPs:	0.551	lbs
Percent annual total phosphorus removed:	**77**	**%**
Post development annual TSS load:	402.7	lbs
Annual TSS removed by BMPs:	377.5	lbs
Percent annual TSS removed:	**94**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1162	0	1162	0
2 - Swale Side Slope	0	1162	0	1162	0
3 - Swale Side Slope	0	1162	0	1162	0
4 - Swale Side Slope	0	1162	0	1162	0
5 - Swale Side Slope	0	1162	0	1162	0
1 - Swale main channel	233	1162	233	929	20
2 - Swale main channel	315	2091	315	1776	15
3 - Swale main channel	360	2938	360	2578	12
4 - Swale main channel	384	3740	384	3356	10
5 - Swale main channel	407	4518	407	4111	9

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.5401	0	0	0.5401	0
2 - Swale Side Slope	0.5401	0	0	0.5401	0
3 - Swale Side Slope	0.5401	0	0	0.5401	0
4 - Swale Side Slope	0.5401	0	0	0.5401	0
5 - Swale Side Slope	0.5401	0	0	0.5401	0
1 - Swale main channel	0.0032	0.5401	0.2057	0.3376	38
2 - Swale main channel	0.0032	0.8778	0.2641	0.6169	30
3 - Swale main channel	0.0032	1.1571	0.294	0.8663	25
4 - Swale main channel	0.0032	1.4064	0.3115	1.0981	22
5 - Swale main channel	0.0032	1.6383	0.4258	1.2157	26

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2424	0	0	0.2424	0
2 - Swale Side Slope	0.2424	0	0	0.2424	0
3 - Swale Side Slope	0.2424	0	0	0.2424	0
4 - Swale Side Slope	0.2424	0	0	0.2424	0
5 - Swale Side Slope	0.2424	0	0	0.2424	0
1 - Swale main channel	0.0014	0.2424	0.2029	0.0409	83
2 - Swale main channel	0.0014	0.2833	0.2309	0.0538	81
3 - Swale main channel	0.0014	0.2962	0.2376	0.06	80
4 - Swale main channel	0.0014	0.3024	0.2399	0.0639	79
5 - Swale main channel	0.0014	0.3063	0.2462	0.0615	80

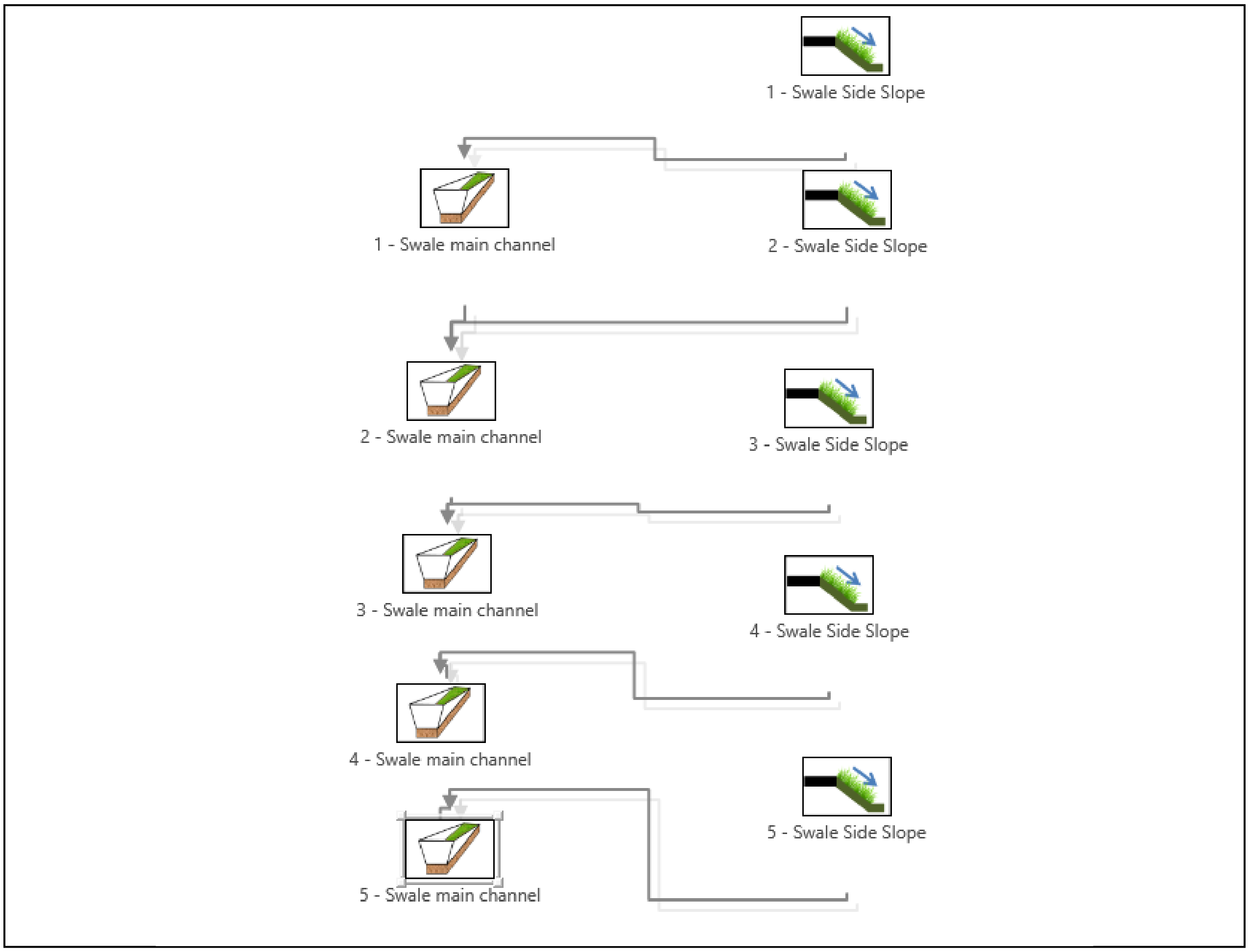
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.1983	0	0	0.1983	0
2 - Swale Side Slope	0.1983	0	0	0.1983	0
3 - Swale Side Slope	0.1983	0	0	0.1983	0
4 - Swale Side Slope	0.1983	0	0	0.1983	0
5 - Swale Side Slope	0.1983	0	0	0.1983	0
1 - Swale main channel	0.0012	0.1983	0.0755	0.124	38
2 - Swale main channel	0.0012	0.3223	0.097	0.2265	30
3 - Swale main channel	0.0012	0.4248	0.1079	0.3181	25
4 - Swale main channel	0.0012	0.5164	0.1144	0.4032	22
5 - Swale main channel	0.0012	0.6015	0.1563	0.4464	26

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	80.07	0	0	80.07	0
2 - Swale Side Slope	80.07	0	0	80.07	0
3 - Swale Side Slope	80.07	0	0	80.07	0
4 - Swale Side Slope	80.07	0	0	80.07	0
5 - Swale Side Slope	80.07	0	0	80.07	0
1 - Swale main channel	0.48	80.07	64.53	16.02	80
2 - Swale main channel	0.48	96.09	74.93	21.64	78
3 - Swale main channel	0.48	101.71	77.77	24.42	76
4 - Swale main channel	0.48	104.49	78.8	26.17	75
5 - Swale main channel	0.48	106.24	81.43	25.29	76

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 3 - Existing Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12’ lane, no shoulder, 3:1 side slope, 3’ swale depth, 2’ bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56701
Annual Rainfall (inches):	22.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				.242	0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.09	1.09
			Impervious Area (acres)		1.455
			Total Area (acres)		2.787

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.242	0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.09	1.09
			Impervious Area (acres)		1.455
			Total Area (acres)		2.787

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	5810	ft3
Volume removed by BMPs towards performance goal:	1406	ft^3
Percent volume removed towards performance goal	**24**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	2.7753	acre-ft
Annual runoff volume removed by BMPs:	0.6345	acre-ft
Percent annual runoff volume removed:	**23**	**%**
Post development annual particulate P load:	1.246	lbs
Annual particulate P removed by BMPs:	1.163	lbs
Post development annual dissolved P load:	1.019	lbs
Annual dissolved P removed by BMPs:	0.233	lbs
Percent annual total phosphorus removed:	**62**	**%**
Post development annual TSS load:	411.4	lbs
Annual TSS removed by BMPs:	377	lbs
Percent annual TSS removed:	**92**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1162	0	1162	0
2 - Swale Side Slope	0	1162	0	1162	0
3 - Swale Side Slope	0	1162	0	1162	0
4 - Swale Side Slope	0	1162	0	1162	0
5 - Swale Side Slope	0	1162	0	1162	0
1 - Swale main channel	210	1162	210	952	18
2 - Swale main channel	270	2114	270	1845	13
3 - Swale main channel	295	3007	295	2712	10
4 - Swale main channel	312	3874	312	3562	8
5 - Swale main channel	320	4724	320	4404	7

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.551	0	0	0.551	0
2 - Swale Side Slope	0.551	0	0	0.551	0
3 - Swale Side Slope	0.551	0	0	0.551	0
4 - Swale Side Slope	0.551	0	0	0.551	0
5 - Swale Side Slope	0.551	0	0	0.551	0
1 - Swale main channel	0.004	0.551	0.0784	0.4766	14
2 - Swale main channel	0.004	1.0277	0.1094	0.9223	11
3 - Swale main channel	0.004	1.4733	0.1275	1.3498	9
4 - Swale main channel	0.004	1.9009	0.1389	1.766	7
5 - Swale main channel	0.004	2.317	0.1803	2.1407	8

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2473	0	0	0.2473	0
2 - Swale Side Slope	0.2473	0	0	0.2473	0
3 - Swale Side Slope	0.2473	0	0	0.2473	0
4 - Swale Side Slope	0.2473	0	0	0.2473	0
5 - Swale Side Slope	0.2473	0	0	0.2473	0
1 - Swale main channel	0.0018	0.2473	0.1913	0.0578	77
2 - Swale main channel	0.0018	0.3051	0.2328	0.0741	76
3 - Swale main channel	0.0018	0.3214	0.2435	0.0797	75
4 - Swale main channel	0.0018	0.327	0.2465	0.0823	75
5 - Swale main channel	0.0018	0.3296	0.2489	0.0825	75

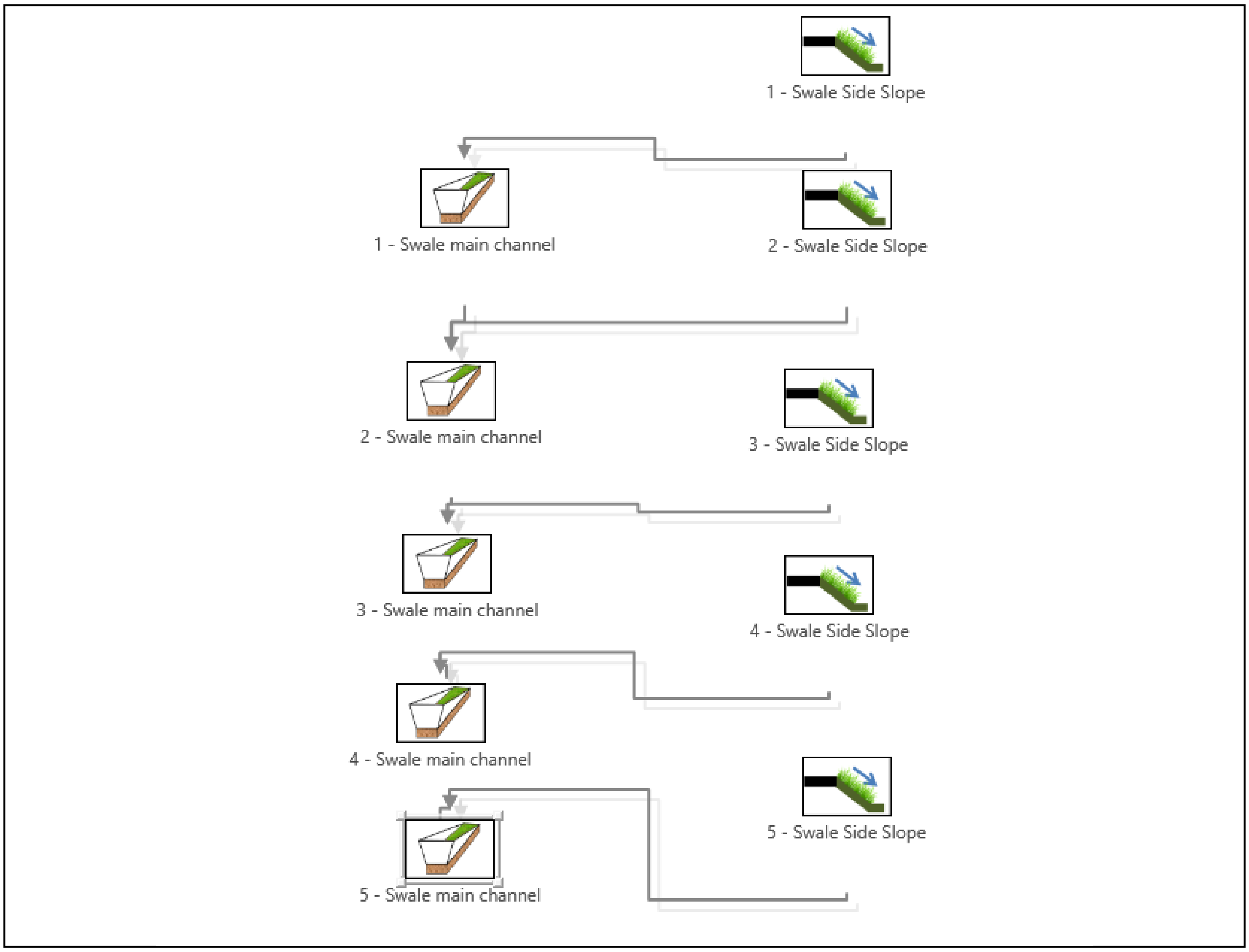
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2023	0	0	0.2023	0
2 - Swale Side Slope	0.2023	0	0	0.2023	0
3 - Swale Side Slope	0.2023	0	0	0.2023	0
4 - Swale Side Slope	0.2023	0	0	0.2023	0
5 - Swale Side Slope	0.2023	0	0	0.2023	0
1 - Swale main channel	0.0015	0.2023	0.0288	0.175	14
2 - Swale main channel	0.0015	0.3773	0.0402	0.3386	11
3 - Swale main channel	0.0015	0.5409	0.0468	0.4956	9
4 - Swale main channel	0.0015	0.6979	0.051	0.6484	7
5 - Swale main channel	0.0015	0.8507	0.0662	0.786	8

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	81.68	0	0	81.68	0
2 - Swale Side Slope	81.68	0	0	81.68	0
3 - Swale Side Slope	81.68	0	0	81.68	0
4 - Swale Side Slope	81.68	0	0	81.68	0
5 - Swale Side Slope	81.68	0	0	81.68	0
1 - Swale main channel	0.6	81.68	59.67	22.61	73
2 - Swale main channel	0.6	104.29	74.88	30.01	71
3 - Swale main channel	0.6	111.69	79.46	32.83	71
4 - Swale main channel	0.6	114.51	80.96	34.15	70
5 - Swale main channel	0.6	115.83	82.07	34.36	70

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 3 - New Road - 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56701
Annual Rainfall (inches):	22.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.97				0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.94				1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.97				0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.94				1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	8226	ft^3
Percent volume removed towards performance goal	**100**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.7752	acre-ft
Annual runoff volume removed by BMPs:	3.7738	acre-ft
Percent annual runoff volume removed:	**100**	**%**
Post development annual particulate P load:	1.694	lbs
Annual particulate P removed by BMPs:	1.694	lbs
Post development annual dissolved P load:	1.386	lbs
Annual dissolved P removed by BMPs:	1.386	lbs
Percent annual total phosphorus removed:	**100**	**%**
Post development annual TSS load:	559.6	lbs
Annual TSS removed by BMPs:	559.6	lbs
Percent annual TSS removed:	**100**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	36	1645	36	1609	2
2 - Swale Side Slope	36	1645	36	1609	2
3 - Swale Side Slope	36	1645	36	1609	2
4 - Swale Side Slope	36	1645	36	1609	2
5 - Swale Side Slope	36	1645	36	1609	2
1 - Swale main channel	4585	1609	1609	0	100
2 - Swale main channel	4585	1609	1609	0	100
3 - Swale main channel	4585	1609	1609	0	100
4 - Swale main channel	4585	1609	1609	0	100
5 - Swale main channel	4585	1609	1609	0	100

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7486	0	0.1418	0.6068	19
2 - Swale Side Slope	0.7486	0	0.1418	0.6068	19
3 - Swale Side Slope	0.7486	0	0.1418	0.6068	19
4 - Swale Side Slope	0.7486	0	0.1418	0.6068	19
5 - Swale Side Slope	0.7486	0	0.1418	0.6068	19
1 - Swale main channel	0.0065	0.6068	0.6118	0.0014999999	100
2 - Swale main channel	0.0065	0.6083	0.6133	0.0014999999	100
3 - Swale main channel	0.0065	0.6083	0.6133	0.0014999999	100
4 - Swale main channel	0.0065	0.6083	0.6133	0.0014999999	100
5 - Swale main channel	0.0065	0.6083	0.6133	0.0014999999	100

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.336	0	0.0636	0.2724	19
2 - Swale Side Slope	0.336	0	0.0636	0.2724	19
3 - Swale Side Slope	0.336	0	0.0636	0.2724	19
4 - Swale Side Slope	0.336	0	0.0636	0.2724	19
5 - Swale Side Slope	0.336	0	0.0636	0.2724	19
1 - Swale main channel	0.0029	0.2724	0.2751	0.0002	100
2 - Swale main channel	0.0029	0.2726	0.2753	0.0002	100
3 - Swale main channel	0.0029	0.2726	0.2753	0.0002	100
4 - Swale main channel	0.0029	0.2726	0.2753	0.0002	100
5 - Swale main channel	0.0029	0.2726	0.2753	0.0002	100

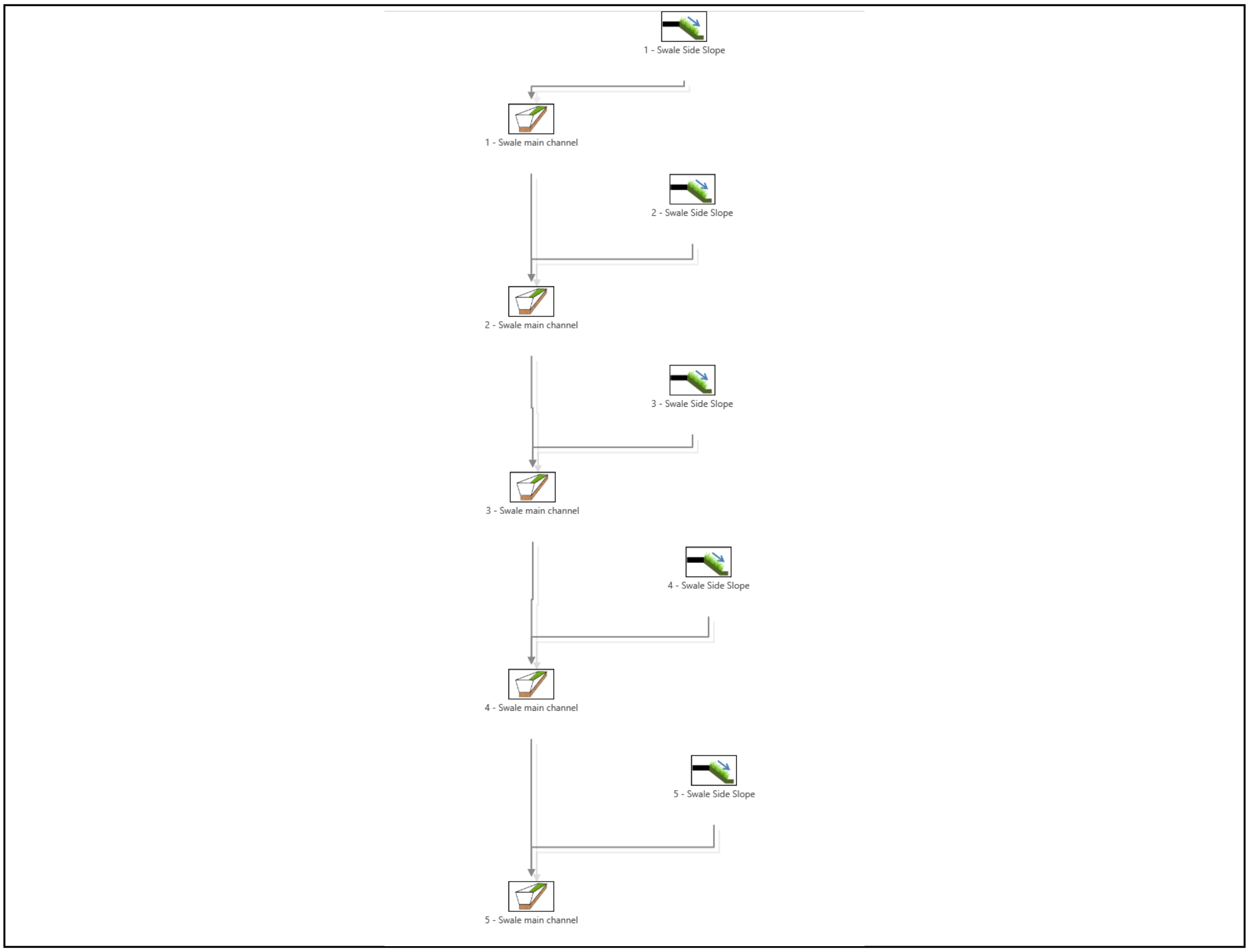
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2749	0	0.0521	0.2228	19
2 - Swale Side Slope	0.2749	0	0.0521	0.2228	19
3 - Swale Side Slope	0.2749	0	0.0521	0.2228	19
4 - Swale Side Slope	0.2749	0	0.0521	0.2228	19
5 - Swale Side Slope	0.2749	0	0.0521	0.2228	19
1 - Swale main channel	0.0024	0.2228	0.2247	0.0005	100
2 - Swale main channel	0.0024	0.2233	0.2252	0.0005	100
3 - Swale main channel	0.0024	0.2233	0.2252	0.0005	100
4 - Swale main channel	0.0024	0.2233	0.2252	0.0005	100
5 - Swale main channel	0.0024	0.2233	0.2252	0.0005	100

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	110.97	0	21.02	89.95	19
2 - Swale Side Slope	110.97	0	21.02	89.95	19
3 - Swale Side Slope	110.97	0	21.02	89.95	19
4 - Swale Side Slope	110.97	0	21.02	89.95	19
5 - Swale Side Slope	110.97	0	21.02	89.95	19
1 - Swale main channel	0.96	89.95	90.84	0.0699999999	100
2 - Swale main channel	0.96	90.02	90.91	0.0699999999	100
3 - Swale main channel	0.96	90.02	90.91	0.0699999999	100
4 - Swale main channel	0.96	90.02	90.91	0.0699999999	100
5 - Swale main channel	0.96	90.02	90.91	0.0699999999	100

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 3 - New Road - 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12’ lane, 5’ shoulder, 4:1 side slope, 4’ swale depth, 8’ bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56701
Annual Rainfall (inches):	22.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.97			0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.94			1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.97			0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.94			1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	5097	ft^3
Percent volume removed towards performance goal	**62**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.9529	acre-ft
Annual runoff volume removed by BMPs:	3.4281	acre-ft
Percent annual runoff volume removed:	**87**	**%**
Post development annual particulate P load:	1.774	lbs
Annual particulate P removed by BMPs:	1.731	lbs
Post development annual dissolved P load:	1.452	lbs
Annual dissolved P removed by BMPs:	1.259	lbs
Percent annual total phosphorus removed:	**93**	**%**
Post development annual TSS load:	586	lbs
Annual TSS removed by BMPs:	568.9	lbs
Percent annual TSS removed:	**97**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	17	1645	17	1628	1
2 - Swale Side Slope	17	1645	17	1628	1
3 - Swale Side Slope	17	1645	17	1628	1
4 - Swale Side Slope	17	1645	17	1628	1
5 - Swale Side Slope	17	1645	17	1628	1
1 - Swale main channel	805	1628	805	823	49
2 - Swale main channel	918	2452	918	1534	37
3 - Swale main channel	1028	3162	1028	2134	33
4 - Swale main channel	1101	3762	1101	2661	29
5 - Swale main channel	1160	4289	1160	3129	27

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7809	0	0.0363	0.7446	5
2 - Swale Side Slope	0.7809	0	0.0363	0.7446	5
3 - Swale Side Slope	0.7809	0	0.0363	0.7446	5
4 - Swale Side Slope	0.7809	0	0.0363	0.7446	5
5 - Swale Side Slope	0.7809	0	0.0363	0.7446	5
1 - Swale main channel	0.0097	0.7446	0.5295	0.2248	70
2 - Swale main channel	0.0097	0.9694	0.6351	0.344	65
3 - Swale main channel	0.0097	1.0886	0.6598	0.4385	60
4 - Swale main channel	0.0097	1.183	0.6761	0.5166	57
5 - Swale main channel	0.0097	1.2612	0.7461	0.5248	59

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3505	0	0.0163	0.3342	5
2 - Swale Side Slope	0.3505	0	0.0163	0.3342	5
3 - Swale Side Slope	0.3505	0	0.0163	0.3342	5
4 - Swale Side Slope	0.3505	0	0.0163	0.3342	5
5 - Swale Side Slope	0.3505	0	0.0163	0.3342	5
1 - Swale main channel	0.0043	0.3342	0.3113	0.0272	92
2 - Swale main channel	0.0043	0.3614	0.331	0.0347	91
3 - Swale main channel	0.0043	0.3689	0.333	0.0402	89
4 - Swale main channel	0.0043	0.3744	0.3344	0.0443	88
5 - Swale main channel	0.0043	0.3785	0.3401	0.0427	89

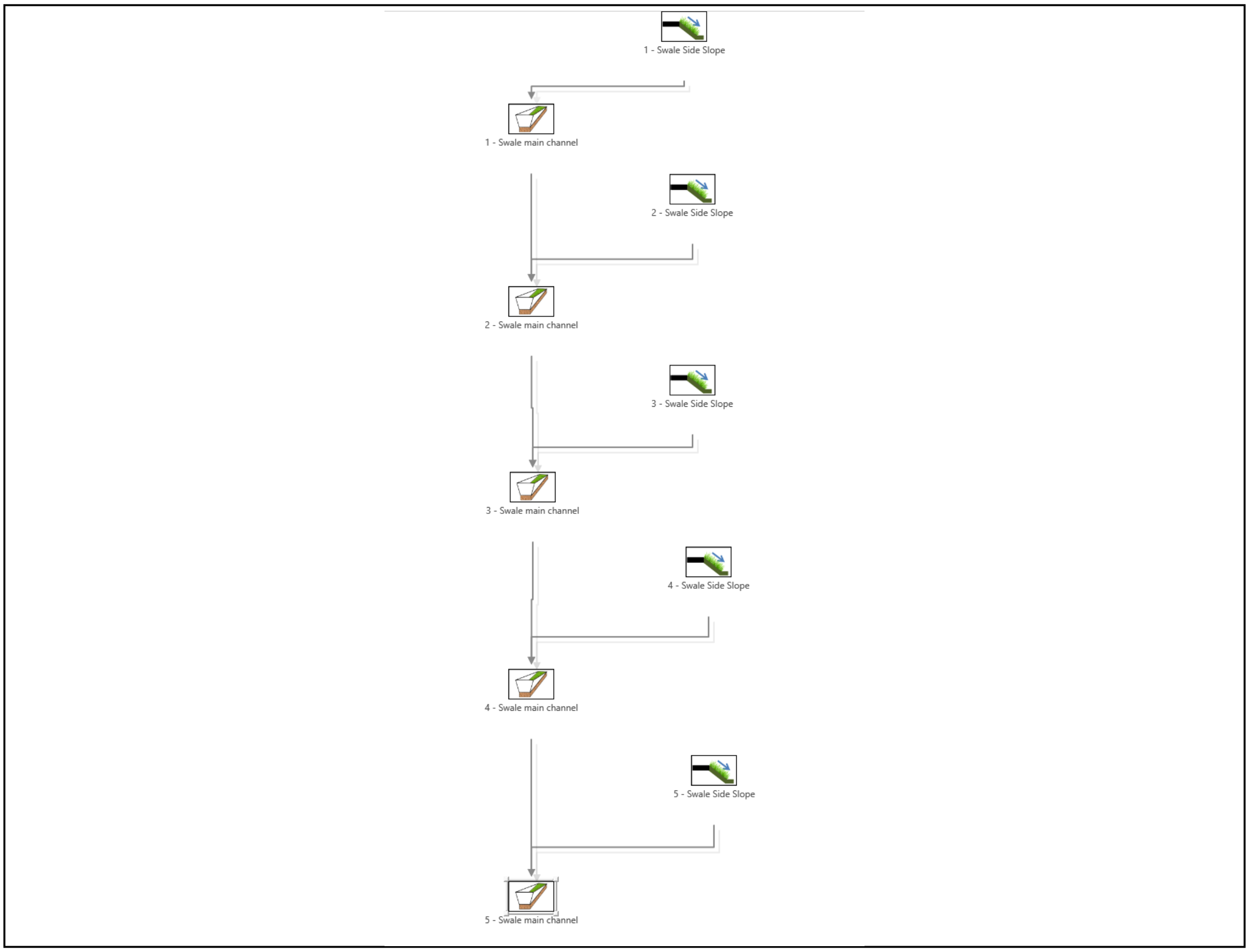
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2867	0	0.0133	0.2734	5
2 - Swale Side Slope	0.2867	0	0.0133	0.2734	5
3 - Swale Side Slope	0.2867	0	0.0133	0.2734	5
4 - Swale Side Slope	0.2867	0	0.0133	0.2734	5
5 - Swale Side Slope	0.2867	0	0.0133	0.2734	5
1 - Swale main channel	0.0036	0.2734	0.1945	0.0825	70
2 - Swale main channel	0.0036	0.3559	0.2332	0.1263	65
3 - Swale main channel	0.0036	0.3997	0.2423	0.161	60
4 - Swale main channel	0.0036	0.4344	0.2483	0.1897	57
5 - Swale main channel	0.0036	0.4631	0.274	0.1927	59

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	115.76	0	5.38	110.38	5
2 - Swale Side Slope	115.76	0	5.38	110.38	5
3 - Swale Side Slope	115.76	0	5.38	110.38	5
4 - Swale Side Slope	115.76	0	5.38	110.38	5
5 - Swale Side Slope	115.76	0	5.38	110.38	5
1 - Swale main channel	1.44	110.38	101.16	10.66	90
2 - Swale main channel	1.44	121.04	108.71	13.77	89
3 - Swale main channel	1.44	124.15	109.55	16.04	87
4 - Swale main channel	1.44	126.42	110.14	17.72	86
5 - Swale main channel	1.44	128.1	112.42	17.12	87

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 3 - New Road - 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56701
Annual Rainfall (inches):	22.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.97		0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.94		1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.97		0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.94		1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	4049	ft^3
Percent volume removed towards performance goal	**49**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.0336	acre-ft
Annual runoff volume removed by BMPs:	2.9717	acre-ft
Percent annual runoff volume removed:	**74**	**%**
Post development annual particulate P load:	1.81	lbs
Annual particulate P removed by BMPs:	1.744	lbs
Post development annual dissolved P load:	1.481	lbs
Annual dissolved P removed by BMPs:	1.091	lbs
Percent annual total phosphorus removed:	**86**	**%**
Post development annual TSS load:	598	lbs
Annual TSS removed by BMPs:	570.7	lbs
Percent annual TSS removed:	**95**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	7	1645	7	1638	0
2 - Swale Side Slope	7	1645	7	1638	0
3 - Swale Side Slope	7	1645	7	1638	0
4 - Swale Side Slope	7	1645	7	1638	0
5 - Swale Side Slope	7	1645	7	1638	0
1 - Swale main channel	595	1638	595	1043	36
2 - Swale main channel	733	2681	733	1948	27
3 - Swale main channel	834	3586	834	2752	23
4 - Swale main channel	895	4390	895	3495	20
5 - Swale main channel	956	5133	956	4176	19

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7938	0	0.014	0.7798	2
2 - Swale Side Slope	0.7938	0	0.014	0.7798	2
3 - Swale Side Slope	0.7938	0	0.014	0.7798	2
4 - Swale Side Slope	0.7938	0	0.014	0.7798	2
5 - Swale Side Slope	0.7938	0	0.014	0.7798	2
1 - Swale main channel	0.0129	0.7798	0.4296	0.3631	54
2 - Swale main channel	0.0129	1.1429	0.5217	0.6341	45
3 - Swale main channel	0.0129	1.414	0.5796	0.8473	41
4 - Swale main channel	0.0129	1.6271	0.6	1.04	37
5 - Swale main channel	0.0129	1.8198	0.7708	1.0619	42

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3563	0	0.0063	0.35	2
2 - Swale Side Slope	0.3563	0	0.0063	0.35	2
3 - Swale Side Slope	0.3563	0	0.0063	0.35	2
4 - Swale Side Slope	0.3563	0	0.0063	0.35	2
5 - Swale Side Slope	0.3563	0	0.0063	0.35	2
1 - Swale main channel	0.0058	0.35	0.3118	0.044	88
2 - Swale main channel	0.0058	0.394	0.3406	0.0592	85
3 - Swale main channel	0.0058	0.4092	0.3485	0.0665	84
4 - Swale main channel	0.0058	0.4165	0.35	0.0723	83
5 - Swale main channel	0.0058	0.4223	0.3611	0.067	84

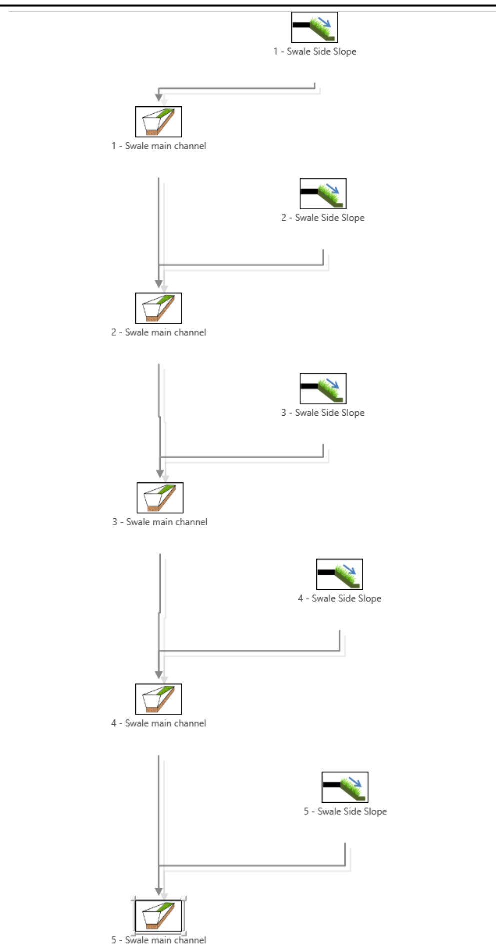
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2915	0	0.0051	0.2864	2
2 - Swale Side Slope	0.2915	0	0.0051	0.2864	2
3 - Swale Side Slope	0.2915	0	0.0051	0.2864	2
4 - Swale Side Slope	0.2915	0	0.0051	0.2864	2
5 - Swale Side Slope	0.2915	0	0.0051	0.2864	2
1 - Swale main channel	0.0047	0.2864	0.1578	0.1333	54
2 - Swale main channel	0.0047	0.4197	0.1916	0.2328	45
3 - Swale main channel	0.0047	0.5192	0.2128	0.3111	41
4 - Swale main channel	0.0047	0.5975	0.2203	0.3819	37
5 - Swale main channel	0.0047	0.6683	0.2831	0.3899	42

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	117.67	0	2.07	115.6	2
2 - Swale Side Slope	117.67	0	2.07	115.6	2
3 - Swale Side Slope	117.67	0	2.07	115.6	2
4 - Swale Side Slope	117.67	0	2.07	115.6	2
5 - Swale Side Slope	117.67	0	2.07	115.6	2
1 - Swale main channel	1.92	115.6	100.3	17.22	85
2 - Swale main channel	1.92	132.82	111.08	23.66	82
3 - Swale main channel	1.92	139.26	114.35	26.83	81
4 - Swale main channel	1.92	142.43	115.06	29.29	80
5 - Swale main channel	1.92	144.89	119.59	27.22	81

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 3 - New Road - 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 8' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56701
Annual Rainfall (inches):	22.2
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.97	0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.94	1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.97	0.97
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.94	1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.97

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	3842	ft^3
Percent volume removed towards performance goal	**47**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.1467	acre-ft
Annual runoff volume removed by BMPs:	1.536	acre-ft
Percent annual runoff volume removed:	**37**	**%**
Post development annual particulate P load:	1.861	lbs
Annual particulate P removed by BMPs:	1.748	lbs
Post development annual dissolved P load:	1.523	lbs
Annual dissolved P removed by BMPs:	0.564	lbs
Percent annual total phosphorus removed:	**68**	**%**
Post development annual TSS load:	614.7	lbs
Annual TSS removed by BMPs:	568.1	lbs
Percent annual TSS removed:	**92**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	2	1645	2	1643	0
2 - Swale Side Slope	2	1645	2	1643	0
3 - Swale Side Slope	2	1645	2	1643	0
4 - Swale Side Slope	2	1645	2	1643	0
5 - Swale Side Slope	2	1645	2	1643	0
1 - Swale main channel	573	1643	573	1071	35
2 - Swale main channel	703	2714	703	2011	26
3 - Swale main channel	786	3655	786	2868	22
4 - Swale main channel	860	4512	860	3651	19
5 - Swale main channel	911	5295	911	4384	17

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.8132	0	0.0031	0.8101	0
2 - Swale Side Slope	0.8132	0	0.0031	0.8101	0
3 - Swale Side Slope	0.8132	0	0.0031	0.8101	0
4 - Swale Side Slope	0.8132	0	0.0031	0.8101	0
5 - Swale Side Slope	0.8132	0	0.0031	0.8101	0
1 - Swale main channel	0.0162	0.81	0.1765	0.6497	21
2 - Swale main channel	0.0162	1.4597	0.261	1.2149	18
3 - Swale main channel	0.0162	2.0249	0.3157	1.7254	15
4 - Swale main channel	0.0162	2.5355	0.3587	2.193	14
5 - Swale main channel	0.0162	3.003	0.4084	2.6108	14

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.365	0	0.0014	0.3636	0
2 - Swale Side Slope	0.365	0	0.0014	0.3636	0
3 - Swale Side Slope	0.365	0	0.0014	0.3636	0
4 - Swale Side Slope	0.365	0	0.0014	0.3636	0
5 - Swale Side Slope	0.365	0	0.0014	0.3636	0
1 - Swale main channel	0.0072	0.3636	0.2921	0.0787	79
2 - Swale main channel	0.0072	0.4423	0.3496	0.0999	78
3 - Swale main channel	0.0072	0.4635	0.3633	0.1074	77
4 - Swale main channel	0.0072	0.471	0.3672	0.111	77
5 - Swale main channel	0.0072	0.4746	0.3693	0.1125	77

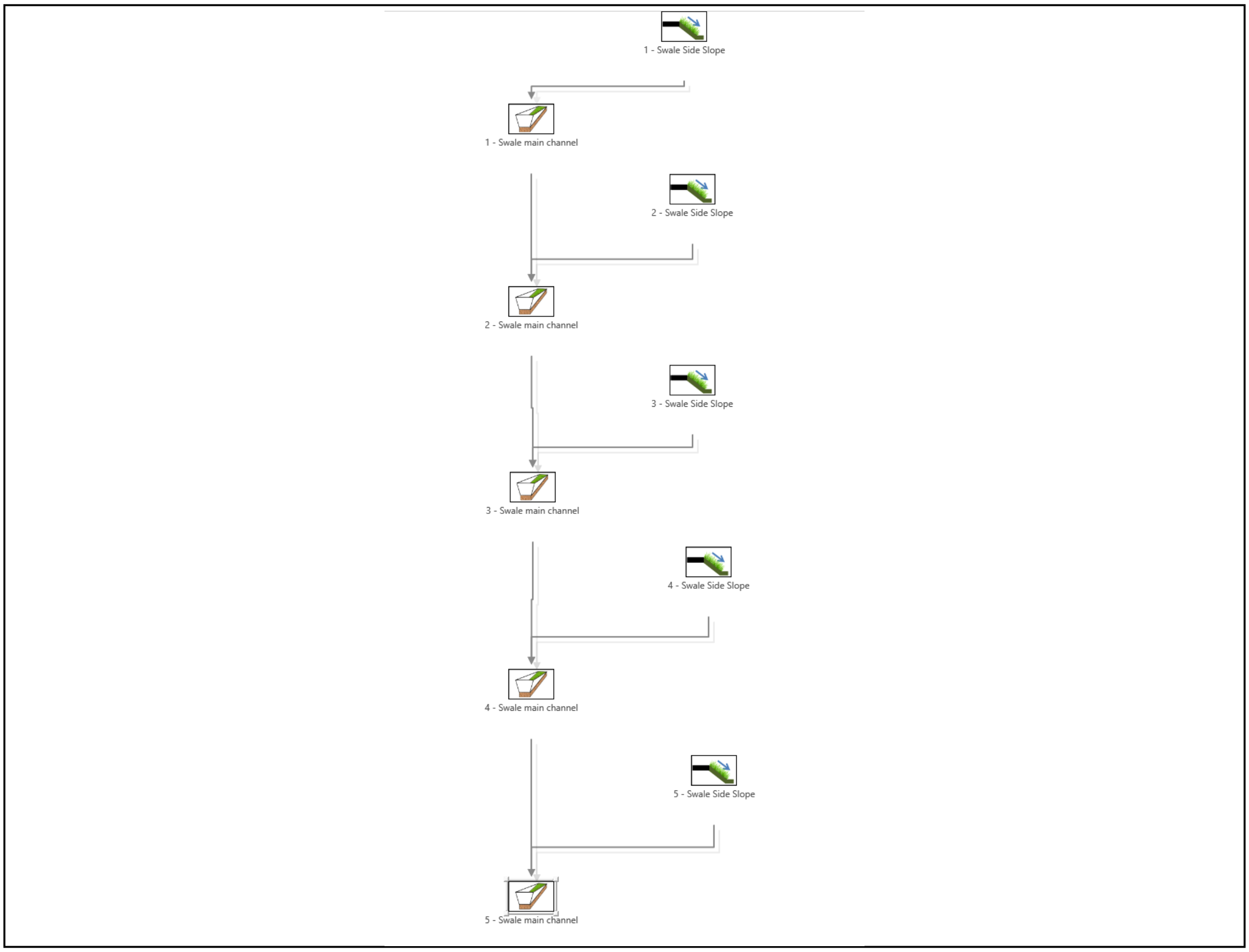
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2986	0	0.0012	0.2974	0
2 - Swale Side Slope	0.2986	0	0.0012	0.2974	0
3 - Swale Side Slope	0.2986	0	0.0012	0.2974	0
4 - Swale Side Slope	0.2986	0	0.0012	0.2974	0
5 - Swale Side Slope	0.2986	0	0.0012	0.2974	0
1 - Swale main channel	0.0059	0.2974	0.0648	0.2385	21
2 - Swale main channel	0.0059	0.5359	0.0958	0.446	18
3 - Swale main channel	0.0059	0.7434	0.1159	0.6334	15
4 - Swale main channel	0.0059	0.9308	0.1317	0.805	14
5 - Swale main channel	0.0059	1.1024	0.1499	0.9584	14

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	120.55	0	0.47	120.08	0
2 - Swale Side Slope	120.55	0	0.47	120.08	0
3 - Swale Side Slope	120.55	0	0.47	120.08	0
4 - Swale Side Slope	120.55	0	0.47	120.08	0
5 - Swale Side Slope	120.55	0	0.47	120.08	0
1 - Swale main channel	2.39	120.08	91.65	30.82	75
2 - Swale main channel	2.39	150.9	112.91	40.38	74
3 - Swale main channel	2.39	160.46	118.8	44.05	73
4 - Swale main channel	2.39	164.13	120.72	45.8	72
5 - Swale main channel	2.39	165.88	121.71	46.559999999	72

BMP Schematic



CASE STUDY 4, HSG A, EXISTING ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Existing Road 5280' long in 5 segments
User Name / Company Name:	
Date:	
Project Description:	5280' long, 5 Segments. Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 8.5' swale bottom width.
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56458
Annual Rainfall (inches):	26.4
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	1.03				1.03
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.455				1.455
				Impervious Area (acres)	1.695
				Total Area (acres)	4.18

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	1.03				1.03
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.455				1.455
				Impervious Area (acres)	1.695
				Total Area (acres)	4.18

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	6768	ft^3
Percent volume removed towards performance goal	**100**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.6612	acre-ft
Annual runoff volume removed by BMPs:	3.6597	acre-ft
Percent annual runoff volume removed:	**100**	**%**
Post development annual particulate P load:	1.643	lbs
Annual particulate P removed by BMPs:	1.643	lbs
Post development annual dissolved P load:	1.344	lbs
Annual dissolved P removed by BMPs:	1.344	lbs
Percent annual total phosphorus removed:	**100**	**%**
Post development annual TSS load:	542.7	lbs
Annual TSS removed by BMPs:	542.7	lbs
Percent annual TSS removed:	**100**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	22	1354	22	1331	2
2 - Swale Side Slope	22	1354	22	1331	2
3 - Swale Side Slope	27	1354	27	1326	2
4 - Swale Side Slope	22	1354	22	1331	2
5 - Swale Side Slope	22	1354	22	1331	2
1 - Swale main channel	3727	1331	1331	0	100
2 - Swale main channel	3727	1331	1331	0	100
3 - Swale main channel	3710	1326	1326	0	100
4 - Swale main channel	3727	1331	1331	0	100
5 - Swale main channel	3727	1331	1331	0	100

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7241	0	0.1028	0.6213	14
2 - Swale Side Slope	0.7241	0	0.1028	0.6213	14
3 - Swale Side Slope	0.7241	0	0.1246	0.5995	17
4 - Swale Side Slope	0.7241	0	0.1028	0.6213	14
5 - Swale Side Slope	0.7241	0	0.1028	0.6213	14
1 - Swale main channel	0.0082	0.6213	0.6279	0.0015999999	100
2 - Swale main channel	0.0082	0.6228	0.6294	0.0016000000	100
3 - Swale main channel	0.0082	0.601	0.6077	0.0014999999	100
4 - Swale main channel	0.0082	0.6228	0.6294	0.0016000000	100
5 - Swale main channel	0.0082	0.6228	0.6294	0.0016000000	100

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.325	0	0.0461	0.2789	14
2 - Swale Side Slope	0.325	0	0.0461	0.2789	14
3 - Swale Side Slope	0.325	0	0.0559	0.2691	17
4 - Swale Side Slope	0.325	0	0.0461	0.2789	14
5 - Swale Side Slope	0.325	0	0.0461	0.2789	14
1 - Swale main channel	0.0037	0.2789	0.2824	0.0002	100
2 - Swale main channel	0.0037	0.2791	0.2826	0.0002	100
3 - Swale main channel	0.0037	0.2693	0.2728	0.0002	100
4 - Swale main channel	0.0037	0.2791	0.2826	0.0002	100
5 - Swale main channel	0.0037	0.2791	0.2826	0.0002	100

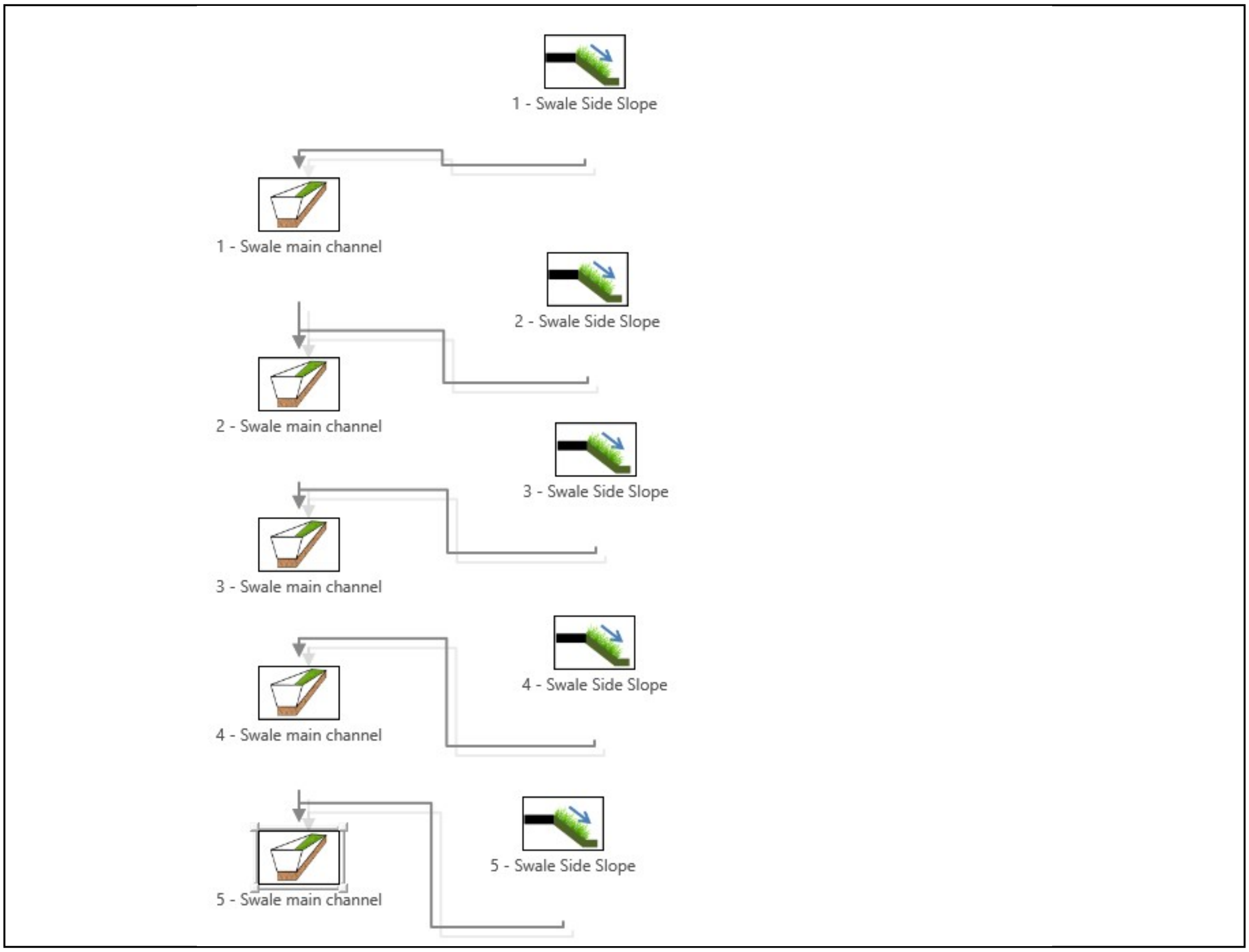
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2659	0	0.0377	0.2282	14
2 - Swale Side Slope	0.2659	0	0.0377	0.2282	14
3 - Swale Side Slope	0.2659	0	0.0458	0.2201	17
4 - Swale Side Slope	0.2659	0	0.0377	0.2282	14
5 - Swale Side Slope	0.2659	0	0.0377	0.2282	14
1 - Swale main channel	0.003	0.2282	0.2306	0.0006	100
2 - Swale main channel	0.003	0.2288	0.2312	0.0006	100
3 - Swale main channel	0.003	0.2207	0.2231	0.0006	100
4 - Swale main channel	0.003	0.2288	0.2312	0.0006	100
5 - Swale main channel	0.003	0.2288	0.2312	0.0006	100

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	107.34	0	15.24	92.1	14
2 - Swale Side Slope	107.34	0	15.24	92.1	14
3 - Swale Side Slope	107.34	0	18.48	88.86	17
4 - Swale Side Slope	107.34	0	15.24	92.1	14
5 - Swale Side Slope	107.34	0	15.24	92.1	14
1 - Swale main channel	1.21	92.1	93.24	0.0700000000	100
2 - Swale main channel	1.21	92.17	93.31	0.0700000000	100
3 - Swale main channel	1.21	88.93	90.07	0.0700000000	100
4 - Swale main channel	1.21	92.17	93.31	0.0700000000	100
5 - Swale main channel	1.21	92.17	93.31	0.0700000000	100

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Existing Road 5280' long in 5 segments
User Name / Company Name:	
Date:	
Project Description:	5280' long, 5 Segments. Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 8.5' swale bottom width.
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56458
Annual Rainfall (inches):	26.4
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		1.03			1.03
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.455			1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		4.18

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		1.03			1.03
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.455			1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		4.18

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	4363	ft^3
Percent volume removed towards performance goal	**64**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.8257	acre-ft
Annual runoff volume removed by BMPs:	3.2947	acre-ft
Percent annual runoff volume removed:	**86**	**%**
Post development annual particulate P load:	1.717	lbs
Annual particulate P removed by BMPs:	1.673	lbs
Post development annual dissolved P load:	1.405	lbs
Annual dissolved P removed by BMPs:	1.21	lbs
Percent annual total phosphorus removed:	**92**	**%**
Post development annual TSS load:	567.1	lbs
Annual TSS removed by BMPs:	549.3	lbs
Percent annual TSS removed:	**97**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	6	1354	6	1347	0
2 - Swale Side Slope	6	1354	6	1347	0
3 - Swale Side Slope	11	1354	11	1342	1
4 - Swale Side Slope	6	1354	6	1347	0
5 - Swale Side Slope	6	1354	6	1347	0
1 - Swale main channel	712	1347	712	635	53
2 - Swale main channel	803	1982	803	1179	41
3 - Swale main channel	877	2522	877	1644	35
4 - Swale main channel	944	2991	944	2048	32
5 - Swale main channel	989	3395	989	2405	29

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7529	0	0.016	0.7369	2
2 - Swale Side Slope	0.7529	0	0.016	0.7369	2
3 - Swale Side Slope	0.7529	0	0.0278	0.7251	4
4 - Swale Side Slope	0.7529	0	0.016	0.7369	2
5 - Swale Side Slope	0.7529	0	0.016	0.7369	2
1 - Swale main channel	0.0122	0.7369	0.5393	0.2098	72
2 - Swale main channel	0.0122	0.9467	0.6429	0.316	67
3 - Swale main channel	0.0122	1.0411	0.6558	0.3975	62
4 - Swale main channel	0.0122	1.1345	0.6758	0.4709	59
5 - Swale main channel	0.0122	1.2078	0.689	0.531	56

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3379	0	0.0072	0.3307	2
2 - Swale Side Slope	0.3379	0	0.0072	0.3307	2
3 - Swale Side Slope	0.3379	0	0.0125	0.3254	4
4 - Swale Side Slope	0.3379	0	0.0072	0.3307	2
5 - Swale Side Slope	0.3379	0	0.0072	0.3307	2
1 - Swale main channel	0.0055	0.3307	0.3108	0.0254	92
2 - Swale main channel	0.0055	0.3561	0.3294	0.0322	91
3 - Swale main channel	0.0055	0.3576	0.3261	0.037	90
4 - Swale main channel	0.0055	0.3677	0.3318	0.0414	89
5 - Swale main channel	0.0055	0.3721	0.3332	0.0444	88

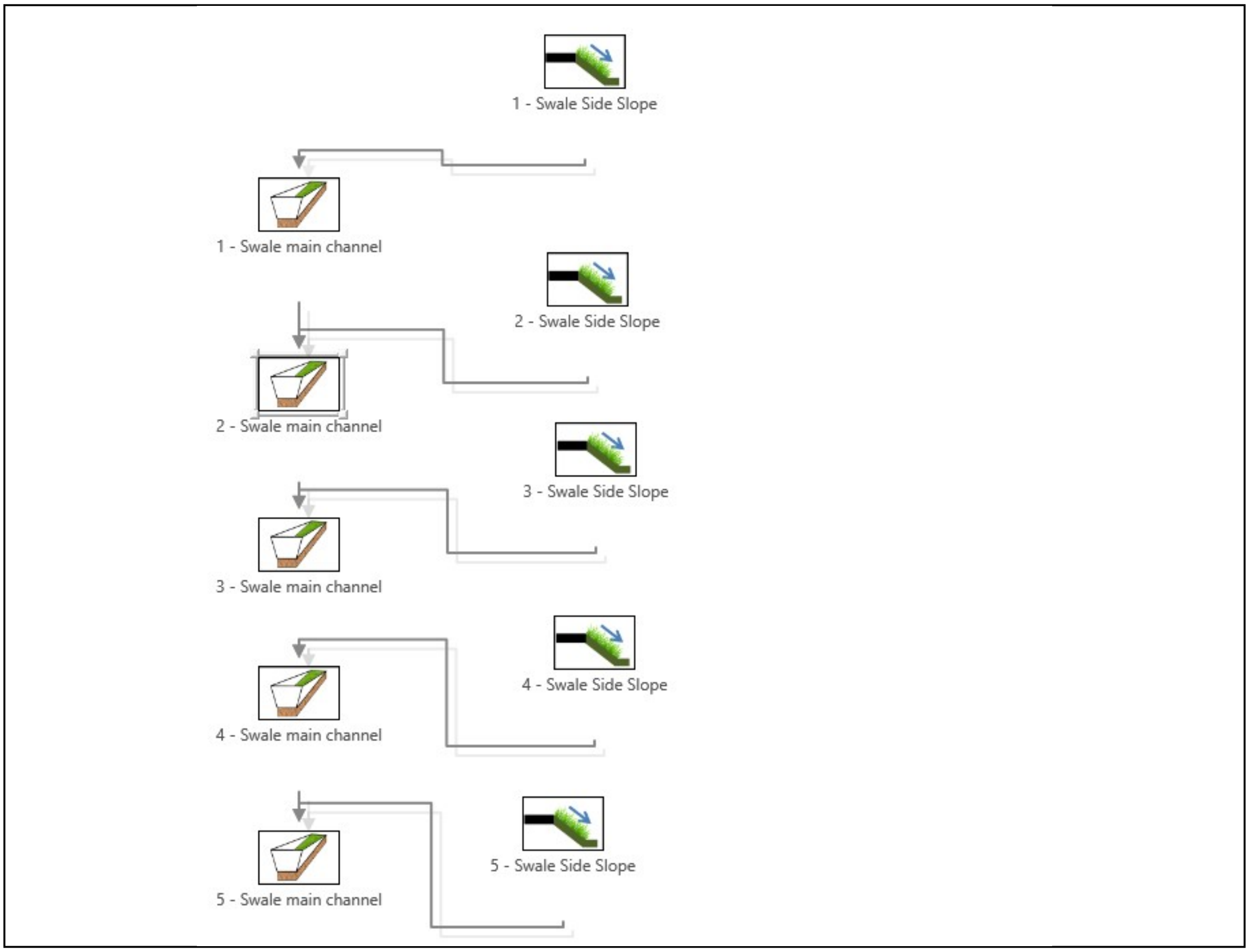
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2765	0	0.0059	0.2706	2
2 - Swale Side Slope	0.2765	0	0.0059	0.2706	2
3 - Swale Side Slope	0.2765	0	0.0102	0.2663	4
4 - Swale Side Slope	0.2765	0	0.0059	0.2706	2
5 - Swale Side Slope	0.2765	0	0.0059	0.2706	2
1 - Swale main channel	0.0045	0.2706	0.1981	0.077	72
2 - Swale main channel	0.0045	0.3476	0.2361	0.116	67
3 - Swale main channel	0.0045	0.3823	0.2408	0.146	62
4 - Swale main channel	0.0045	0.4166	0.2482	0.1729	59
5 - Swale main channel	0.0045	0.4435	0.253	0.195	56

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	111.61	0	2.37	109.24	2
2 - Swale Side Slope	111.61	0	2.37	109.24	2
3 - Swale Side Slope	111.61	0	4.13	107.48	4
4 - Swale Side Slope	111.61	0	2.37	109.24	2
5 - Swale Side Slope	111.61	0	2.37	109.24	2
1 - Swale main channel	1.81	109.24	101.1	9.95	91
2 - Swale main channel	1.81	119.19	108.24	12.76	89
3 - Swale main channel	1.81	120.24	107.31	14.74	88
4 - Swale main channel	1.81	123.98	109.26	16.53	87
5 - Swale main channel	1.81	125.77	109.81	17.77	86

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Existing Road 5280' long in 5 segments
User Name / Company Name:	
Date:	
Project Description:	5280' long, 5 Segments. Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 8.5' swale bottom width.
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56458
Annual Rainfall (inches):	26.4
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			1.03		1.03
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.455		1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		4.18

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			1.03		1.03
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.455		1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		4.18

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	3456	ft^3
Percent volume removed towards performance goal	**51**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.9037	acre-ft
Annual runoff volume removed by BMPs:	2.9135	acre-ft
Percent annual runoff volume removed:	**75**	**%**
Post development annual particulate P load:	1.752	lbs
Annual particulate P removed by BMPs:	1.688	lbs
Post development annual dissolved P load:	1.433	lbs
Annual dissolved P removed by BMPs:	1.07	lbs
Percent annual total phosphorus removed:	**87**	**%**
Post development annual TSS load:	578.7	lbs
Annual TSS removed by BMPs:	552.7	lbs
Percent annual TSS removed:	**96**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1354	0	1354	0
2 - Swale Side Slope	0	1354	0	1354	0
3 - Swale Side Slope	4	1354	4	1350	0
4 - Swale Side Slope	0	1354	0	1354	0
5 - Swale Side Slope	0	1354	0	1354	0
1 - Swale main channel	519	1354	519	835	38
2 - Swale main channel	628	2188	628	1561	29
3 - Swale main channel	717	2911	717	2194	25
4 - Swale main channel	774	3547	774	2774	22
5 - Swale main channel	816	4127	816	3312	20

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7644	0	0	0.7644	0
2 - Swale Side Slope	0.7644	0	0	0.7644	0
3 - Swale Side Slope	0.7644	0	0.0081	0.7563	1
4 - Swale Side Slope	0.7644	0	0	0.7644	0
5 - Swale Side Slope	0.7644	0	0	0.7644	0
1 - Swale main channel	0.0163	0.7644	0.4338	0.3469	56
2 - Swale main channel	0.0163	1.1113	0.5224	0.6052	46
3 - Swale main channel	0.0163	1.3615	0.5827	0.7951	42
4 - Swale main channel	0.0163	1.5596	0.6046	0.9713	38
5 - Swale main channel	0.0163	1.7357	0.7618	0.9902	43

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3431	0	0	0.3431	0
2 - Swale Side Slope	0.3431	0	0	0.3431	0
3 - Swale Side Slope	0.3431	0	0.0036	0.3395	1
4 - Swale Side Slope	0.3431	0	0	0.3431	0
5 - Swale Side Slope	0.3431	0	0	0.3431	0
1 - Swale main channel	0.0073	0.3431	0.3084	0.042	88
2 - Swale main channel	0.0073	0.3851	0.3355	0.0569	86
3 - Swale main channel	0.0073	0.3964	0.3408	0.0629	84
4 - Swale main channel	0.0073	0.406	0.3445	0.0688	83
5 - Swale main channel	0.0073	0.4119	0.3552	0.064	85

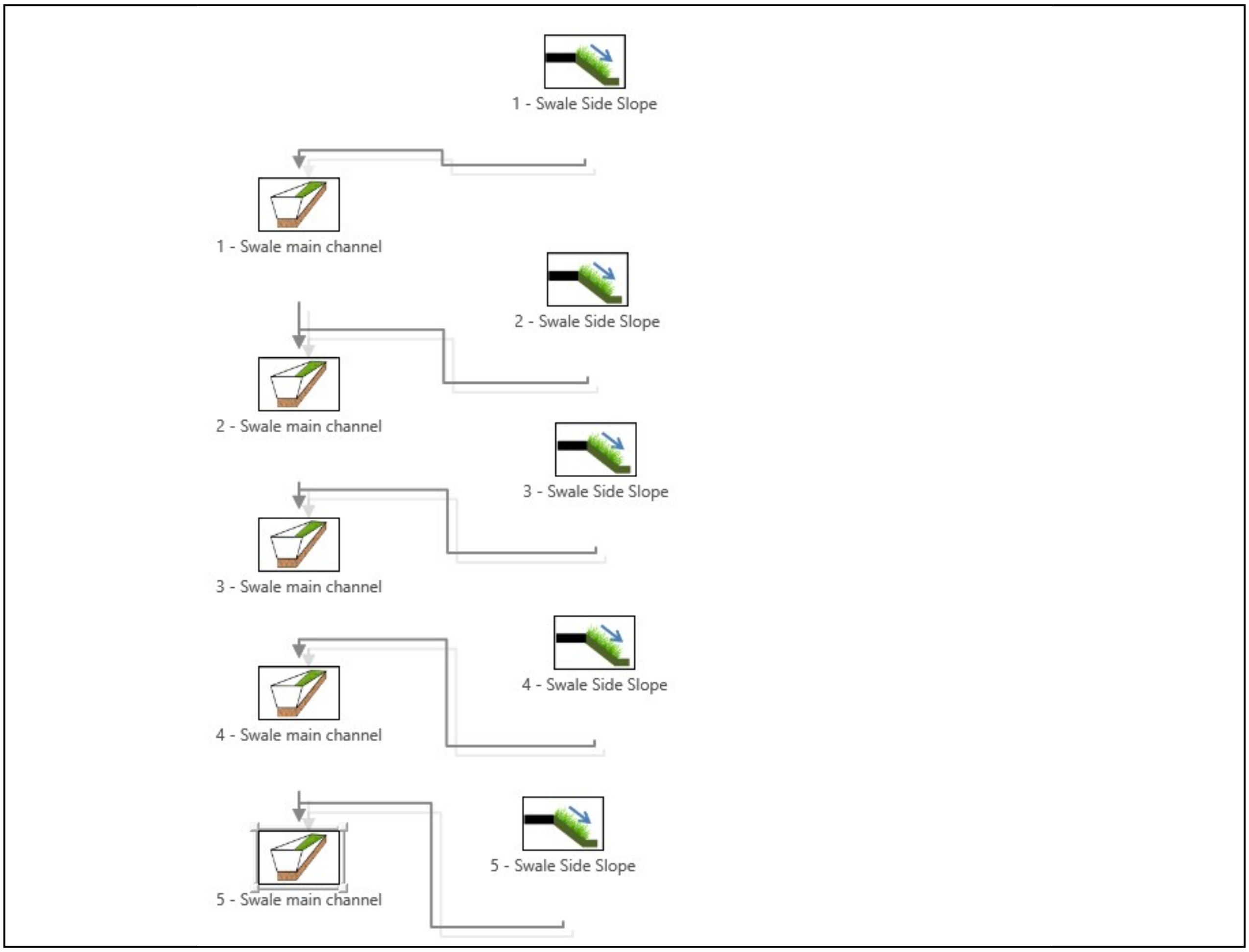
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2807	0	0	0.2807	0
2 - Swale Side Slope	0.2807	0	0	0.2807	0
3 - Swale Side Slope	0.2807	0	0.003	0.2777	1
4 - Swale Side Slope	0.2807	0	0	0.2807	0
5 - Swale Side Slope	0.2807	0	0	0.2807	0
1 - Swale main channel	0.006	0.2807	0.1593	0.1274	56
2 - Swale main channel	0.006	0.4081	0.1919	0.2222	46
3 - Swale main channel	0.006	0.4999	0.2139	0.292	42
4 - Swale main channel	0.006	0.5727	0.222	0.3567	38
5 - Swale main channel	0.006	0.6374	0.2798	0.3636	43

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	113.32	0	0	113.32	0
2 - Swale Side Slope	113.32	0	0	113.32	0
3 - Swale Side Slope	113.32	0	1.2	112.12	1
4 - Swale Side Slope	113.32	0	0	113.32	0
5 - Swale Side Slope	113.32	0	0	113.32	0
1 - Swale main channel	2.42	113.32	99.28	16.46	86
2 - Swale main channel	2.42	129.78	109.5	22.7	83
3 - Swale main channel	2.42	134.82	111.9	25.339999999	82
4 - Swale main channel	2.42	138.66	113.25	27.829999999	80
5 - Swale main channel	2.42	141.15	117.6	25.969999999	82

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Existing Road 5280' long in 5 segments
User Name / Company Name:	
Date:	
Project Description:	5280' long, 5 Segments. Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 8.5' swale bottom width.
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56458
Annual Rainfall (inches):	26.4
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				1.03	1.03
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.455	1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		4.18

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				1.03	1.03
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.455	1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		4.18

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	3321	ft^3
Percent volume removed towards performance goal	**49**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.0105	acre-ft
Annual runoff volume removed by BMPs:	1.5295	acre-ft
Percent annual runoff volume removed:	**38**	**%**
Post development annual particulate P load:	1.8	lbs
Annual particulate P removed by BMPs:	1.692	lbs
Post development annual dissolved P load:	1.473	lbs
Annual dissolved P removed by BMPs:	0.562	lbs
Percent annual total phosphorus removed:	**69**	**%**
Post development annual TSS load:	594.5	lbs
Annual TSS removed by BMPs:	549.8	lbs
Percent annual TSS removed:	**92**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1354	0	1354	0
2 - Swale Side Slope	0	1354	0	1354	0
3 - Swale Side Slope	0	1354	0	1354	0
4 - Swale Side Slope	0	1354	0	1354	0
5 - Swale Side Slope	0	1354	0	1354	0
1 - Swale main channel	503	1354	503	850	37
2 - Swale main channel	607	2204	607	1597	28
3 - Swale main channel	684	2951	684	2267	23
4 - Swale main channel	740	3620	740	2880	20
5 - Swale main channel	786	4234	786	3447	19

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7817	0	0	0.7817	0
2 - Swale Side Slope	0.7817	0	0	0.7817	0
3 - Swale Side Slope	0.7817	0	0	0.7817	0
4 - Swale Side Slope	0.7817	0	0	0.7817	0
5 - Swale Side Slope	0.7817	0	0	0.7817	0
1 - Swale main channel	0.0204	0.7817	0.1778	0.6243	22
2 - Swale main channel	0.0204	1.406	0.2611	1.1653	18
3 - Swale main channel	0.0204	1.947	0.3209	1.6465	16
4 - Swale main channel	0.0204	2.4283	0.3617	2.087	15
5 - Swale main channel	0.0204	2.8687	0.4081	2.481	14

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3508	0	0	0.3508	0
2 - Swale Side Slope	0.3508	0	0	0.3508	0
3 - Swale Side Slope	0.3508	0	0	0.3508	0
4 - Swale Side Slope	0.3508	0	0	0.3508	0
5 - Swale Side Slope	0.3508	0	0	0.3508	0
1 - Swale main channel	0.0092	0.3508	0.2843	0.0757	79
2 - Swale main channel	0.0092	0.4265	0.3396	0.0961	78
3 - Swale main channel	0.0092	0.4469	0.353	0.1031	77
4 - Swale main channel	0.0092	0.4539	0.3565	0.1066	77
5 - Swale main channel	0.0092	0.4574	0.3584	0.1082	77

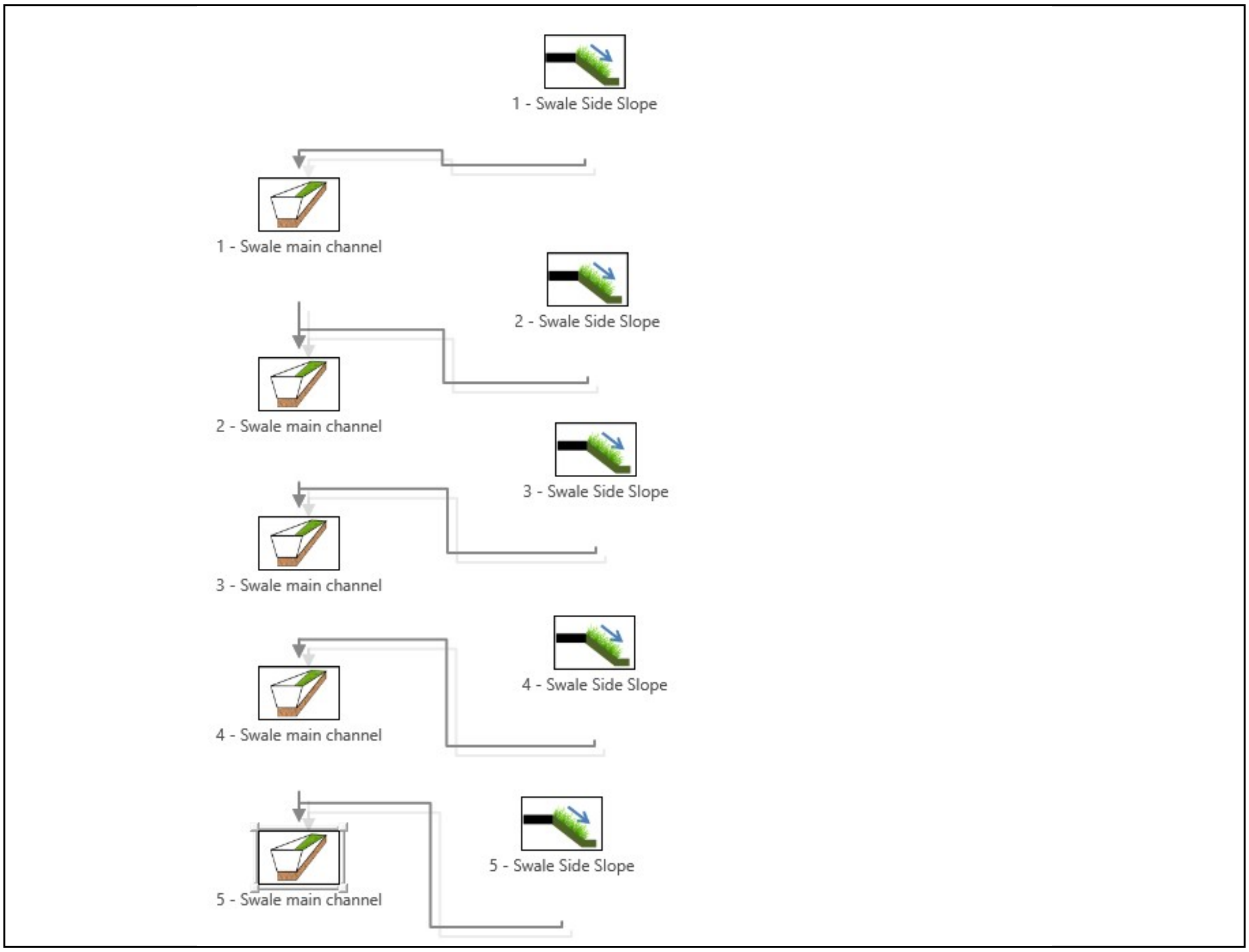
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.287	0	0	0.287	0
2 - Swale Side Slope	0.287	0	0	0.287	0
3 - Swale Side Slope	0.287	0	0	0.287	0
4 - Swale Side Slope	0.287	0	0	0.287	0
5 - Swale Side Slope	0.287	0	0	0.287	0
1 - Swale main channel	0.0075	0.287	0.0653	0.2292	22
2 - Swale main channel	0.0075	0.5162	0.0959	0.4278	18
3 - Swale main channel	0.0075	0.7148	0.1178	0.6045	16
4 - Swale main channel	0.0075	0.8915	0.1328	0.7662	15
5 - Swale main channel	0.0075	1.0532	0.1498	0.9109	14

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	115.88	0	0	115.88	0
2 - Swale Side Slope	115.88	0	0	115.88	0
3 - Swale Side Slope	115.88	0	0	115.88	0
4 - Swale Side Slope	115.88	0	0	115.88	0
5 - Swale Side Slope	115.88	0	0	115.88	0
1 - Swale main channel	3.02	115.88	89.29	29.61	75
2 - Swale main channel	3.02	145.49	109.69	38.82	74
3 - Swale main channel	3.02	154.7	115.48	42.24	73
4 - Swale main channel	3.02	158.12	117.19	43.95	73
5 - Swale main channel	3.02	159.83	118.1	44.75	73

BMP Schematic



CASE STUDY 4, HSG A, NEW ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Mod Case 4 - New Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 5:1 side slope, 4', swale depth, 10' bottom width.
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56458
Annual Rainfall (inches):	26.4
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	1.21				1.21
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	2.425				2.425
				Impervious Area (acres)	2.06
				Total Area (acres)	5.695

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	1.21				1.21
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	2.425				2.425
				Impervious Area (acres)	2.06
				Total Area (acres)	5.695

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	8226	ft^3
Percent volume removed towards performance goal	**100**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.643	acre-ft
Annual runoff volume removed by BMPs:	3.918	acre-ft
Percent annual runoff volume removed:	**84**	**%**
Post development annual particulate P load:	2.084	lbs
Annual particulate P removed by BMPs:	1.996	lbs
Post development annual dissolved P load:	1.705	lbs
Annual dissolved P removed by BMPs:	1.439	lbs
Percent annual total phosphorus removed:	**91**	**%**
Post development annual TSS load:	688.3	lbs
Annual TSS removed by BMPs:	654	lbs
Percent annual TSS removed:	**95**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	41	1645	41	1604	2
2 - Swale Side Slope	41	1645	41	1604	2
3 - Swale Side Slope	41	1645	41	1604	2
4 - Swale Side Slope	41	1645	41	1604	2
5 - Swale Side Slope	41	1645	41	1604	2
1 - Swale main channel	4034	1604	1604	0	100
2 - Swale main channel	4034	1604	1604	0	100
3 - Swale main channel	4034	1604	1604	0	100
4 - Swale main channel	4034	1604	1604	0	100
5 - Swale main channel	4034	1604	1604	0	100

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.919	0	0.2062	0.7128	22
2 - Swale Side Slope	0.919	0	0.2062	0.7128	22
3 - Swale Side Slope	0.919	0	0.2062	0.7128	22
4 - Swale Side Slope	0.919	0	0.2062	0.7128	22
5 - Swale Side Slope	0.919	0	0.2062	0.7128	22
1 - Swale main channel	0.0096	0.7128	0.7198	0.0026000000	100
2 - Swale main channel	0.0096	0.7154	0.7224	0.0026000000	100
3 - Swale main channel	0.0096	0.7155	0.7225	0.0026000000	100
4 - Swale main channel	0.0096	0.7155	0.7225	0.0026000000	100
5 - Swale main channel	0.0096	0.7155	0	0.7251	0

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4125	0	0.0926	0.3199	22
2 - Swale Side Slope	0.4125	0	0.0926	0.3199	22
3 - Swale Side Slope	0.4125	0	0.0926	0.3199	22
4 - Swale Side Slope	0.4125	0	0.0926	0.3199	22
5 - Swale Side Slope	0.4125	0	0.0926	0.3199	22
1 - Swale main channel	0.0043	0.3199	0.3239	0.0003	100
2 - Swale main channel	0.0043	0.3202	0.3242	0.0003	100
3 - Swale main channel	0.0043	0.3202	0.3242	0.0003	100
4 - Swale main channel	0.0043	0.3202	0.3242	0.0003	100
5 - Swale main channel	0.0043	0.3202	0.2369	0.0876	73

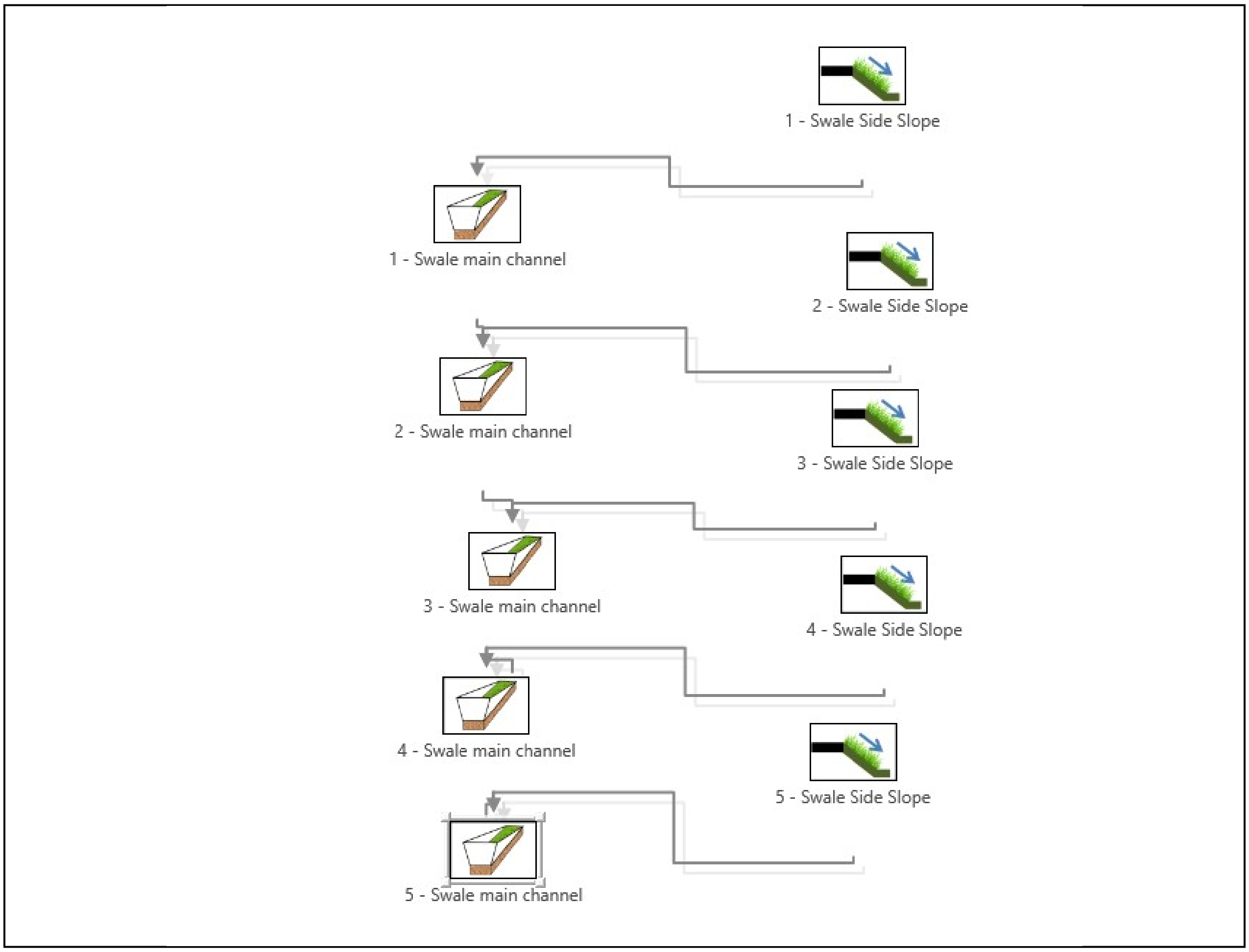
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3375	0	0.0757	0.2618	22
2 - Swale Side Slope	0.3375	0	0.0757	0.2618	22
3 - Swale Side Slope	0.3375	0	0.0757	0.2618	22
4 - Swale Side Slope	0.3375	0	0.0757	0.2618	22
5 - Swale Side Slope	0.3375	0	0.0757	0.2618	22
1 - Swale main channel	0.0035	0.2618	0.2643	0.001	100
2 - Swale main channel	0.0035	0.2628	0.2653	0.001	100
3 - Swale main channel	0.0035	0.2628	0.2653	0.001	100
4 - Swale main channel	0.0035	0.2628	0.2653	0.001	100
5 - Swale main channel	0.0035	0.2628	0	0.2663	0

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	136.24	0	30.57	105.67	22
2 - Swale Side Slope	136.24	0	30.57	105.67	22
3 - Swale Side Slope	136.24	0	30.57	105.67	22
4 - Swale Side Slope	136.24	0	30.57	105.67	22
5 - Swale Side Slope	136.24	0	30.57	105.67	22
1 - Swale main channel	1.42	105.67	106.97	0.1200000000	100
2 - Swale main channel	1.42	105.79	107.09	0.1200000000	100
3 - Swale main channel	1.42	105.79	107.09	0.1200000000	100
4 - Swale main channel	1.42	105.79	107.09	0.1200000000	100
5 - Swale main channel	1.42	105.79	72.9	34.310000000	68

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Mod Case 4 - New Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 5:1 side slope, 4', swale depth, 10' bottom width.
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56458
Annual Rainfall (inches):	26.4
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		1.21			1.21
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		2.425			2.425
			Impervious Area (acres)		2.06
			Total Area (acres)		5.695

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		1.21			1.21
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		2.425			2.425
			Impervious Area (acres)		2.06
			Total Area (acres)		5.695

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	5371	ft^3
Percent volume removed towards performance goal	**65**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.907	acre-ft
Annual runoff volume removed by BMPs:	4.2801	acre-ft
Percent annual runoff volume removed:	**87**	**%**
Post development annual particulate P load:	2.202	lbs
Annual particulate P removed by BMPs:	2.15	lbs
Post development annual dissolved P load:	1.802	lbs
Annual dissolved P removed by BMPs:	1.572	lbs
Percent annual total phosphorus removed:	**93**	**%**
Post development annual TSS load:	727.4	lbs
Annual TSS removed by BMPs:	706.5	lbs
Percent annual TSS removed:	**97**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	24	1645	24	1622	1
2 - Swale Side Slope	24	1645	24	1622	1
3 - Swale Side Slope	24	1645	24	1622	1
4 - Swale Side Slope	24	1645	24	1622	1
5 - Swale Side Slope	24	1645	24	1622	1
1 - Swale main channel	896	1622	896	725	55
2 - Swale main channel	981	2347	981	1366	42
3 - Swale main channel	1063	2988	1063	1925	36
4 - Swale main channel	1134	3546	1134	2413	32
5 - Swale main channel	1180	4034	1180	2854	29

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.967	0	0.0642	0.9028	7
2 - Swale Side Slope	0.967	0	0.0642	0.9028	7
3 - Swale Side Slope	0.967	0	0.0642	0.9028	7
4 - Swale Side Slope	0.967	0	0.0642	0.9028	7
5 - Swale Side Slope	0.967	0	0.0642	0.9028	7
1 - Swale main channel	0.0144	0.9028	0.6659	0.2513	73
2 - Swale main channel	0.0144	1.154	0.7889	0.3795	68
3 - Swale main channel	0.0144	1.2823	0.8032	0.4935	62
4 - Swale main channel	0.0144	1.3963	0.8277	0.583	59
5 - Swale main channel	0.0144	1.4858	0.8733	0.6269	58

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.434	0	0.0288	0.4052	7
2 - Swale Side Slope	0.434	0	0.0288	0.4052	7
3 - Swale Side Slope	0.434	0	0.0288	0.4052	7
4 - Swale Side Slope	0.434	0	0.0288	0.4052	7
5 - Swale Side Slope	0.434	0	0.0288	0.4052	7
1 - Swale main channel	0.0065	0.4052	0.3812	0.0305	93
2 - Swale main channel	0.0065	0.4357	0.4034	0.0388	91
3 - Swale main channel	0.0065	0.444	0.4042	0.0463	90
4 - Swale main channel	0.0065	0.4515	0.4069	0.0511	89
5 - Swale main channel	0.0065	0.4563	0.4106	0.0522	89

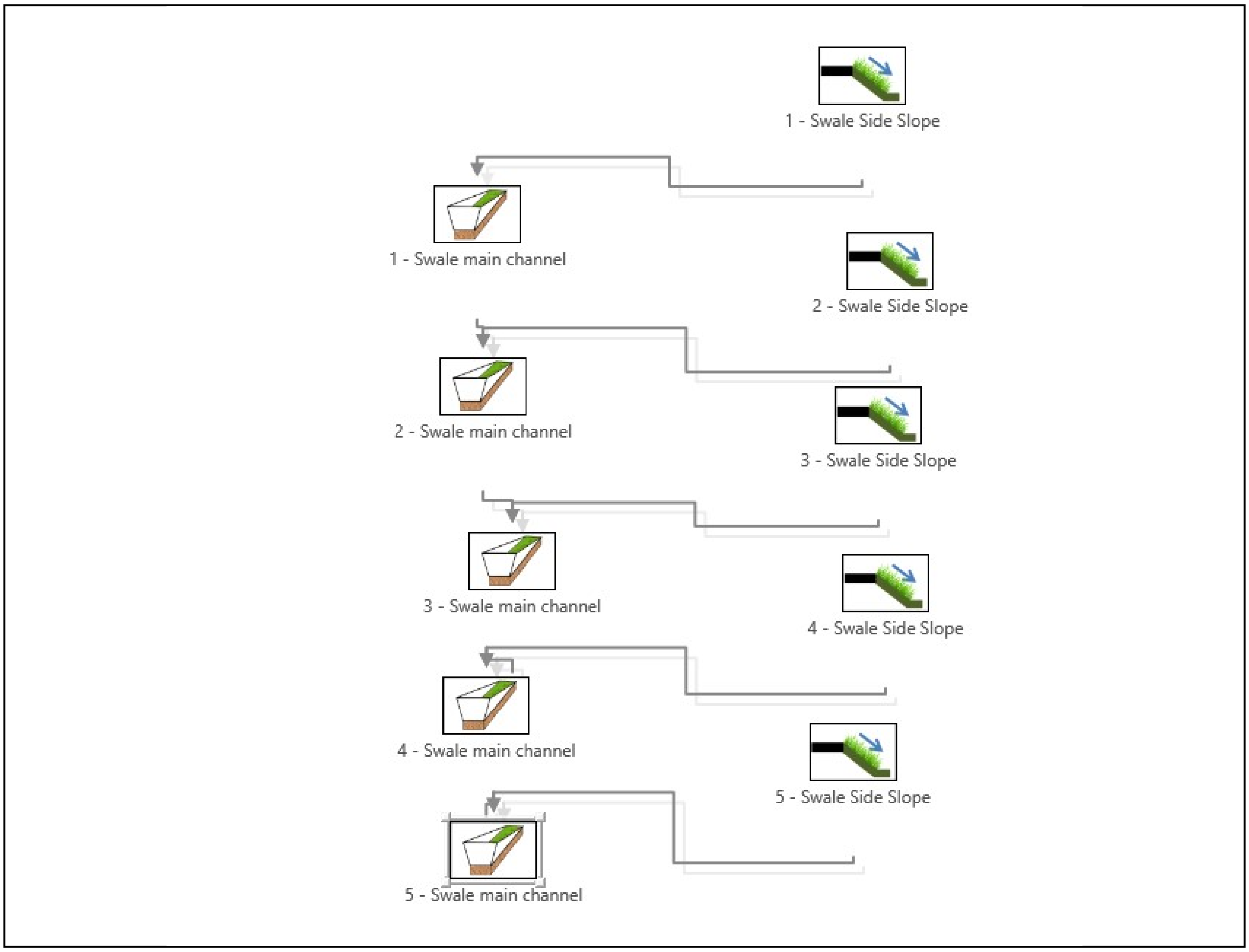
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3551	0	0.0236	0.3315	7
2 - Swale Side Slope	0.3551	0	0.0236	0.3315	7
3 - Swale Side Slope	0.3551	0	0.0236	0.3315	7
4 - Swale Side Slope	0.3551	0	0.0236	0.3315	7
5 - Swale Side Slope	0.3551	0	0.0236	0.3315	7
1 - Swale main channel	0.0053	0.3315	0.2445	0.0923	73
2 - Swale main channel	0.0053	0.4238	0.2897	0.1394	68
3 - Swale main channel	0.0053	0.4709	0.295	0.1812	62
4 - Swale main channel	0.0053	0.5127	0.3039	0.2141	59
5 - Swale main channel	0.0053	0.5456	0.3207	0.2302	58

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	143.35	0	9.52	133.83	7
2 - Swale Side Slope	143.35	0	9.52	133.83	7
3 - Swale Side Slope	143.35	0	9.52	133.83	7
4 - Swale Side Slope	143.35	0	9.52	133.83	7
5 - Swale Side Slope	143.35	0	9.52	133.83	7
1 - Swale main channel	2.13	133.83	124.04	11.92	91
2 - Swale main channel	2.13	145.75	132.51	15.369999999	90
3 - Swale main channel	2.13	149.2	132.9	18.429999999	88
4 - Swale main channel	2.13	152.26	133.97	20.419999999	87
5 - Swale main channel	2.13	154.25	135.47	20.909999999	87

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	New Road 5280' long in 5 segments
User Name / Company Name:	
Date:	
Project Description:	5280' long, 5 Segments. New Road: 12' lane, 5' shoulder, 5:1 side slope, 10' swale bottom width.
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56458
Annual Rainfall (inches):	26.4
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			1.2121		1.2121
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			2.42		2.42
			Impervious Area (acres)		2.06
			Total Area (acres)		5.6921

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			1.2121		1.2121
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			2.42		2.42
			Impervious Area (acres)		2.06
			Total Area (acres)		5.6921

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	4194	ft^3
Percent volume removed towards performance goal	**51**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.025	acre-ft
Annual runoff volume removed by BMPs:	3.5665	acre-ft
Percent annual runoff volume removed:	**71**	**%**
Post development annual particulate P load:	2.255	lbs
Annual particulate P removed by BMPs:	2.163	lbs
Post development annual dissolved P load:	1.845	lbs
Annual dissolved P removed by BMPs:	1.31	lbs
Percent annual total phosphorus removed:	**85**	**%**
Post development annual TSS load:	744.9	lbs
Annual TSS removed by BMPs:	707.5	lbs
Percent annual TSS removed:	**95**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	13	1645	13	1632	1
2 - Swale Side Slope	13	1645	13	1632	1
3 - Swale Side Slope	13	1645	13	1632	1
4 - Swale Side Slope	13	1645	13	1632	1
5 - Swale Side Slope	13	1645	13	1632	1
1 - Swale main channel	637	1632	637	995	39
2 - Swale main channel	756	2627	756	1871	29
3 - Swale main channel	856	3503	856	2647	24
4 - Swale main channel	917	4279	917	3361	21
5 - Swale main channel	962	4993	962	4032	19

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9858	0	0.0324	0.9534	3
2 - Swale Side Slope	0.9858	0	0.0324	0.9534	3
3 - Swale Side Slope	0.9858	0	0.0324	0.9534	3
4 - Swale Side Slope	0.9858	0	0.0324	0.9534	3
5 - Swale Side Slope	0.9858	0	0.0324	0.9534	3
1 - Swale main channel	0.0192	0.9534	0.5314	0.4412	55
2 - Swale main channel	0.0192	1.3946	0.6442	0.7696	46
3 - Swale main channel	0.0192	1.723	0.7048	1.0374	40
4 - Swale main channel	0.0192	1.9908	0.7357	1.2743	37
5 - Swale main channel	0.0192	2.2278	0.7885	1.4585	35

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4424	0	0.0145	0.4279	3
2 - Swale Side Slope	0.4424	0	0.0145	0.4279	3
3 - Swale Side Slope	0.4424	0	0.0145	0.4279	3
4 - Swale Side Slope	0.4424	0	0.0145	0.4279	3
5 - Swale Side Slope	0.4424	0	0.0145	0.4279	3
1 - Swale main channel	0.0086	0.4279	0.383	0.0535	88
2 - Swale main channel	0.0086	0.4814	0.418	0.072	85
3 - Swale main channel	0.0086	0.4999	0.4267	0.0818	84
4 - Swale main channel	0.0086	0.5097	0.4296	0.0887	83
5 - Swale main channel	0.0086	0.5166	0.4332	0.092	82

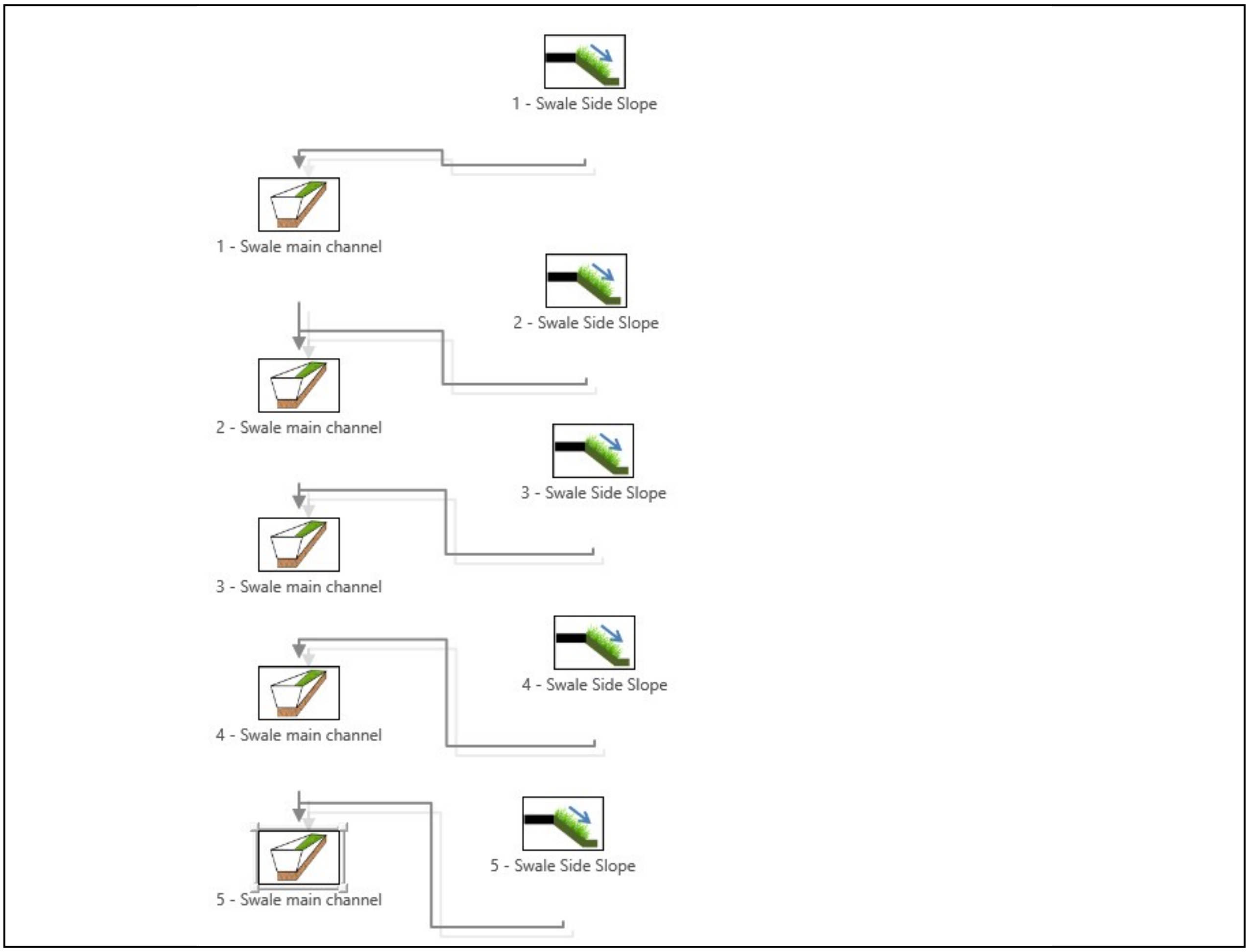
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.362	0	0.0119	0.3501	3
2 - Swale Side Slope	0.362	0	0.0119	0.3501	3
3 - Swale Side Slope	0.362	0	0.0119	0.3501	3
4 - Swale Side Slope	0.362	0	0.0119	0.3501	3
5 - Swale Side Slope	0.362	0	0.0119	0.3501	3
1 - Swale main channel	0.0071	0.3501	0.1952	0.162	55
2 - Swale main channel	0.0071	0.5121	0.2366	0.2826	46
3 - Swale main channel	0.0071	0.6327	0.2588	0.381	40
4 - Swale main channel	0.0071	0.7311	0.2702	0.468	37
5 - Swale main channel	0.0071	0.8181	0.2896	0.5356	35

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	146.14	0	4.8	141.34	3
2 - Swale Side Slope	146.14	0	4.8	141.34	3
3 - Swale Side Slope	146.14	0	4.8	141.34	3
4 - Swale Side Slope	146.14	0	4.8	141.34	3
5 - Swale Side Slope	146.14	0	4.8	141.34	3
1 - Swale main channel	2.85	141.34	123.26	20.93	85
2 - Swale main channel	2.85	162.27	136.36	28.759999999	83
3 - Swale main channel	2.85	170.1	139.99	32.959999999	81
4 - Swale main channel	2.85	174.3	141.21	35.939999999	80
5 - Swale main channel	2.85	177.28	142.72	37.409999999	79

BMP Schematic



CASE STUDY 4, HSG D, NEW ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Mod Case 4 - New Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 5:1 side slope, 4', swale depth, 10' bottom width.
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56458
Annual Rainfall (inches):	26.4
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				1.21	1.21
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				2.425	2.425
			Impervious Area (acres)		2.06
			Total Area (acres)		5.695

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				1.21	1.21
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				2.425	2.425
			Impervious Area (acres)		2.06
			Total Area (acres)		5.695

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	4132	ft^3
Percent volume removed towards performance goal	**50**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	5.195	acre-ft
Annual runoff volume removed by BMPs:	2.1212	acre-ft
Percent annual runoff volume removed:	**41**	**%**
Post development annual particulate P load:	2.332	lbs
Annual particulate P removed by BMPs:	2.198	lbs
Post development annual dissolved P load:	1.908	lbs
Annual dissolved P removed by BMPs:	0.779	lbs
Percent annual total phosphorus removed:	**70**	**%**
Post development annual TSS load:	770.1	lbs
Annual TSS removed by BMPs:	714.7	lbs
Percent annual TSS removed:	**93**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	7	1645	7	1638	0
2 - Swale Side Slope	7	1645	7	1638	0
3 - Swale Side Slope	7	1645	7	1638	0
4 - Swale Side Slope	7	1645	7	1638	0
5 - Swale Side Slope	7	1645	7	1638	0
1 - Swale main channel	643	1638	643	995	39
2 - Swale main channel	754	2632	754	1879	29
3 - Swale main channel	844	3516	844	2672	24
4 - Swale main channel	906	4310	906	3404	21
5 - Swale main channel	948	5042	948	4094	19

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	1.015	0	0.0164	0.9986	2
2 - Swale Side Slope	1.015	0	0.0164	0.9986	2
3 - Swale Side Slope	1.015	0	0.0164	0.9986	2
4 - Swale Side Slope	1.015	0	0.0164	0.9986	2
5 - Swale Side Slope	1.015	0	0.0164	0.9986	2
1 - Swale main channel	0.024	0.9987	0.2272	0.7955	22
2 - Swale main channel	0.024	1.7941	0.3346	1.4835	18
3 - Swale main channel	0.024	2.4822	0.4048	2.1014	16
4 - Swale main channel	0.024	3.1	0.4562	2.6678	15
5 - Swale main channel	0.024	3.6664	0.6165	3.0739	17

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4556	0	0.0073	0.4483	2
2 - Swale Side Slope	0.4556	0	0.0073	0.4483	2
3 - Swale Side Slope	0.4556	0	0.0073	0.4483	2
4 - Swale Side Slope	0.4556	0	0.0073	0.4483	2
5 - Swale Side Slope	0.4556	0	0.0073	0.4483	2
1 - Swale main channel	0.0108	0.4483	0.3627	0.0964	79
2 - Swale main channel	0.0108	0.5447	0.4331	0.1224	78
3 - Swale main channel	0.0108	0.5707	0.4499	0.1316	77
4 - Swale main channel	0.0108	0.5799	0.4545	0.1362	77
5 - Swale main channel	0.0108	0.5845	0.4614	0.1339	78

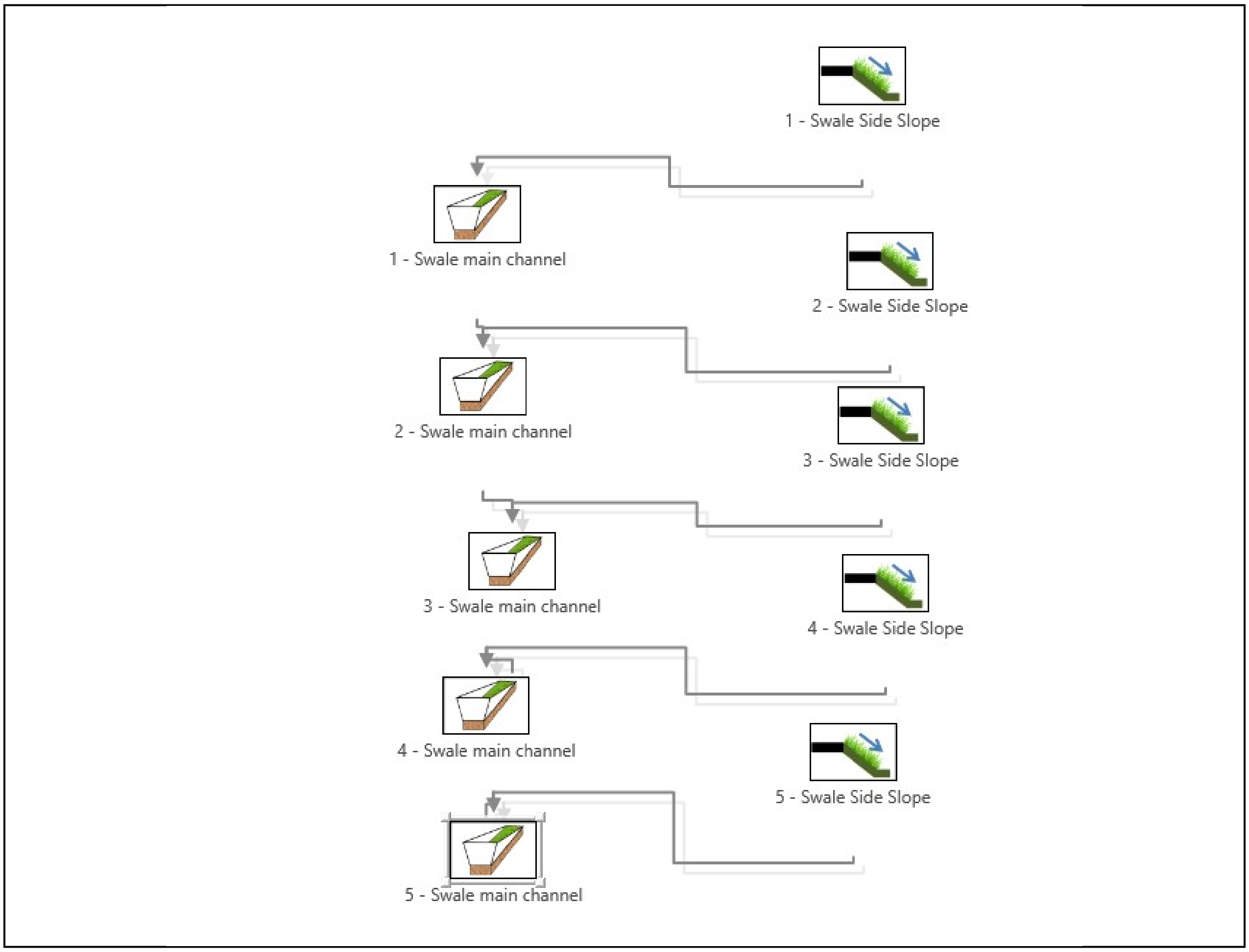
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3727	0	0.006	0.3667	2
2 - Swale Side Slope	0.3727	0	0.006	0.3667	2
3 - Swale Side Slope	0.3727	0	0.006	0.3667	2
4 - Swale Side Slope	0.3727	0	0.006	0.3667	2
5 - Swale Side Slope	0.3727	0	0.006	0.3667	2
1 - Swale main channel	0.0088	0.3667	0.0834	0.2921	22
2 - Swale main channel	0.0088	0.6588	0.1229	0.5447	18
3 - Swale main channel	0.0088	0.9114	0.1486	0.7716	16
4 - Swale main channel	0.0088	1.1383	0.1675	0.9796	15
5 - Swale main channel	0.0088	1.3463	0.2264	1.1287	17

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	150.47	0	2.43	148.04	2
2 - Swale Side Slope	150.47	0	2.43	148.04	2
3 - Swale Side Slope	150.47	0	2.43	148.04	2
4 - Swale Side Slope	150.47	0	2.43	148.04	2
5 - Swale Side Slope	150.47	0	2.43	148.04	2
1 - Swale main channel	3.55	148.04	113.86	37.73	75
2 - Swale main channel	3.55	185.77	139.89	49.43	74
3 - Swale main channel	3.55	197.47	147.08	53.94	73
4 - Swale main channel	3.55	201.98	149.37	56.16	73
5 - Swale main channel	3.55	204.2	152.38	55.37	73

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 5 - Existing Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12’ lane, 2’ shoulder, 3:1 side slope, 4’ swale depth, 2’ bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56395
Annual Rainfall (inches):	26.7
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.242				0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.455				1.455
				Impervious Area (acres)	1.695
				Total Area (acres)	3.392

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.242				0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.455				1.455
				Impervious Area (acres)	1.695
				Total Area (acres)	3.392

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	2615	ft^3
Percent volume removed towards performance goal	**39**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.6713	acre-ft
Annual runoff volume removed by BMPs:	3.0346	acre-ft
Percent annual runoff volume removed:	**83**	**%**
Post development annual particulate P load:	1.648	lbs
Annual particulate P removed by BMPs:	1.601	lbs
Post development annual dissolved P load:	1.348	lbs
Annual dissolved P removed by BMPs:	1.114	lbs
Percent annual total phosphorus removed:	**91**	**%**
Post development annual TSS load:	544.2	lbs
Annual TSS removed by BMPs:	525.1	lbs
Percent annual TSS removed:	**96**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	22	1354	22	1331	2
2 - Swale Side Slope	22	1354	22	1331	2
3 - Swale Side Slope	22	1354	22	1331	2
4 - Swale Side Slope	22	1354	22	1331	2
5 - Swale Side Slope	22	1354	22	1331	2
1 - Swale main channel	349	1331	349	983	26
2 - Swale main channel	435	2314	435	1879	19
3 - Swale main channel	520	3211	520	2691	16
4 - Swale main channel	579	4023	579	3444	14
5 - Swale main channel	622	4775	622	4153	13

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7323	0	0.1039	0.6284	14
2 - Swale Side Slope	0.7323	0	0.1039	0.6284	14
3 - Swale Side Slope	0.7323	0	0.1039	0.6284	14
4 - Swale Side Slope	0.7323	0	0.1039	0.6284	14
5 - Swale Side Slope	0.7323	0	0.1039	0.6284	14
1 - Swale main channel	0.0019	0.6284	0.429	0.2013	68
2 - Swale main channel	0.0019	0.8297	0.4824	0.3492	58
3 - Swale main channel	0.0019	0.9776	0.5165	0.463	53
4 - Swale main channel	0.0019	1.0914	0.5369	0.5564	49
5 - Swale main channel	0.0019	1.1848	0.55	0.6367	46

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3287	0	0.0467	0.282	14
2 - Swale Side Slope	0.3287	0	0.0467	0.282	14
3 - Swale Side Slope	0.3287	0	0.0467	0.282	14
4 - Swale Side Slope	0.3287	0	0.0467	0.282	14
5 - Swale Side Slope	0.3287	0	0.0467	0.282	14
1 - Swale main channel	0.0009	0.282	0.2585	0.0244	91
2 - Swale main channel	0.0009	0.3064	0.2725	0.0348	89
3 - Swale main channel	0.0009	0.3168	0.2772	0.0405	87
4 - Swale main channel	0.0009	0.3225	0.279	0.0444	86
5 - Swale main channel	0.0009	0.3264	0.2799	0.0474	86

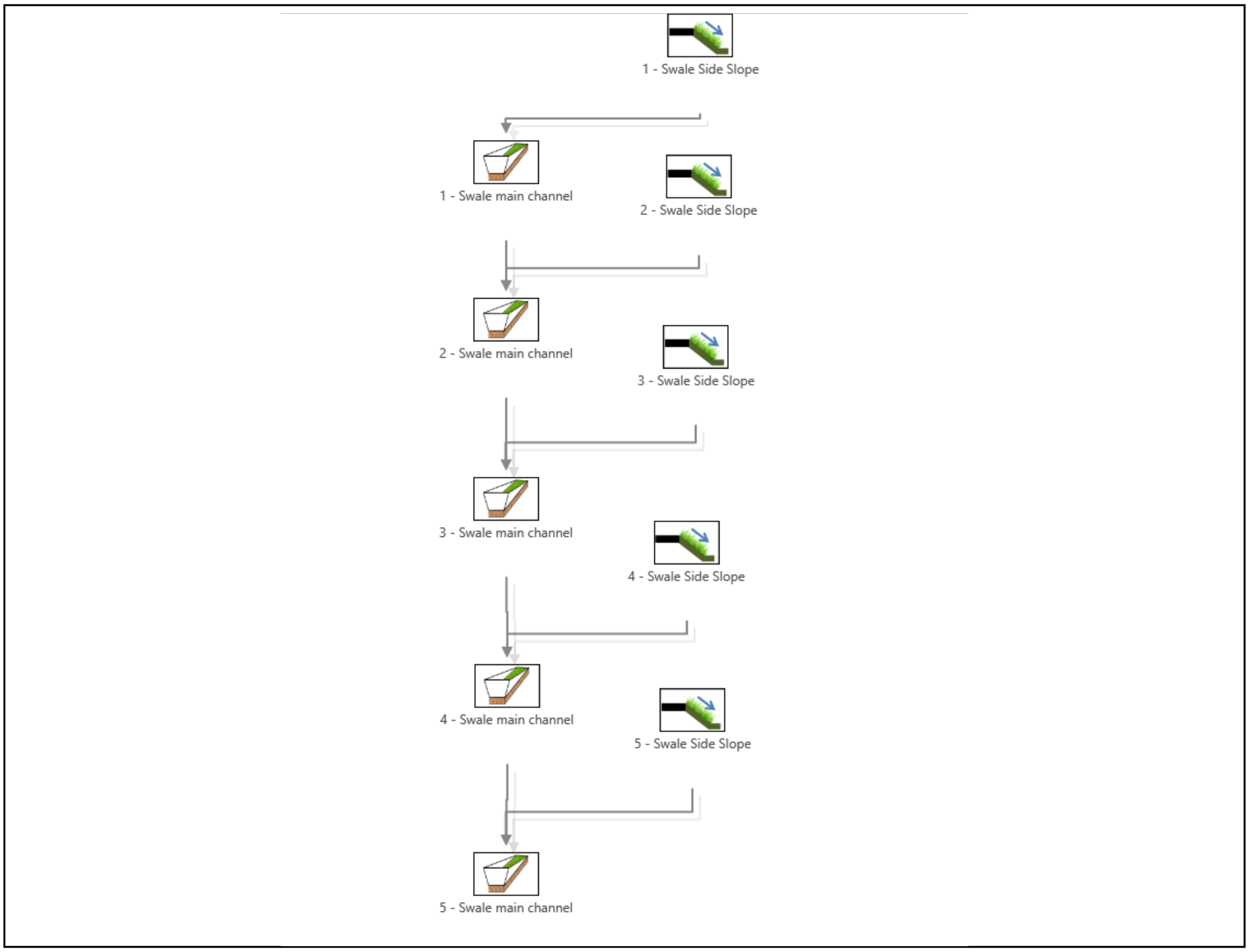
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2689	0	0.0382	0.2307	14
2 - Swale Side Slope	0.2689	0	0.0382	0.2307	14
3 - Swale Side Slope	0.2689	0	0.0382	0.2307	14
4 - Swale Side Slope	0.2689	0	0.0382	0.2307	14
5 - Swale Side Slope	0.2689	0	0.0382	0.2307	14
1 - Swale main channel	0.0007	0.2307	0.1575	0.0739	68
2 - Swale main channel	0.0007	0.3046	0.1771	0.1282	58
3 - Swale main channel	0.0007	0.3589	0.1896	0.17	53
4 - Swale main channel	0.0007	0.4007	0.1971	0.2043	49
5 - Swale main channel	0.0007	0.435	0.202	0.2337	46

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	108.56	0	15.41	93.15	14
2 - Swale Side Slope	108.56	0	15.41	93.15	14
3 - Swale Side Slope	108.56	0	15.41	93.15	14
4 - Swale Side Slope	108.56	0	15.41	93.15	14
5 - Swale Side Slope	108.56	0	15.41	93.15	14
1 - Swale main channel	0.29	93.15	83.89	9.5500000000	90
2 - Swale main channel	0.29	102.7	89.15	13.84	87
3 - Swale main channel	0.29	106.99	91.05	16.23	85
4 - Swale main channel	0.29	109.38	91.81	17.86	84
5 - Swale main channel	0.29	111.01	92.19	19.110000000	83

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 5 - Existing Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56395
Annual Rainfall (inches):	26.7
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.242			0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.455			1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.242			0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.455			1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	2178	ft^3
Percent volume removed towards performance goal	**32**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.8218	acre-ft
Annual runoff volume removed by BMPs:	2.4176	acre-ft
Percent annual runoff volume removed:	**63**	**%**
Post development annual particulate P load:	1.715	lbs
Annual particulate P removed by BMPs:	1.635	lbs
Post development annual dissolved P load:	1.403	lbs
Annual dissolved P removed by BMPs:	0.888	lbs
Percent annual total phosphorus removed:	**81**	**%**
Post development annual TSS load:	566.5	lbs
Annual TSS removed by BMPs:	533.7	lbs
Percent annual TSS removed:	**94**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	6	1354	6	1347	0
2 - Swale Side Slope	6	1354	6	1347	0
3 - Swale Side Slope	6	1354	6	1347	0
4 - Swale Side Slope	6	1354	6	1347	0
5 - Swale Side Slope	6	1354	6	1347	0
1 - Swale main channel	292	1347	292	1055	22
2 - Swale main channel	389	2403	389	2014	16
3 - Swale main channel	451	3361	451	2910	13
4 - Swale main channel	490	4257	490	3767	12
5 - Swale main channel	523	5114	523	4590	10

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7615	0	0.0161	0.7454	2
2 - Swale Side Slope	0.7615	0	0.0161	0.7454	2
3 - Swale Side Slope	0.7615	0	0.0161	0.7454	2
4 - Swale Side Slope	0.7615	0	0.0161	0.7454	2
5 - Swale Side Slope	0.7615	0	0.0161	0.7454	2
1 - Swale main channel	0.0029	0.7453	0.3336	0.4146	45
2 - Swale main channel	0.0029	1.1599	0.4499	0.7129	39
3 - Swale main channel	0.0029	1.4582	0.4922	0.9689	34
4 - Swale main channel	0.0029	1.7142	0.5187	1.1984	30
5 - Swale main channel	0.0029	1.9437	0.5424	1.4042	28

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3417	0	0.0072	0.3345	2
2 - Swale Side Slope	0.3417	0	0.0072	0.3345	2
3 - Swale Side Slope	0.3417	0	0.0072	0.3345	2
4 - Swale Side Slope	0.3417	0	0.0072	0.3345	2
5 - Swale Side Slope	0.3417	0	0.0072	0.3345	2
1 - Swale main channel	0.0013	0.3345	0.2856	0.0502	85
2 - Swale main channel	0.0013	0.3847	0.3221	0.0639	83
3 - Swale main channel	0.0013	0.3984	0.3281	0.0716	82
4 - Swale main channel	0.0013	0.4061	0.3306	0.0768	81
5 - Swale main channel	0.0013	0.4113	0.3322	0.0804	81

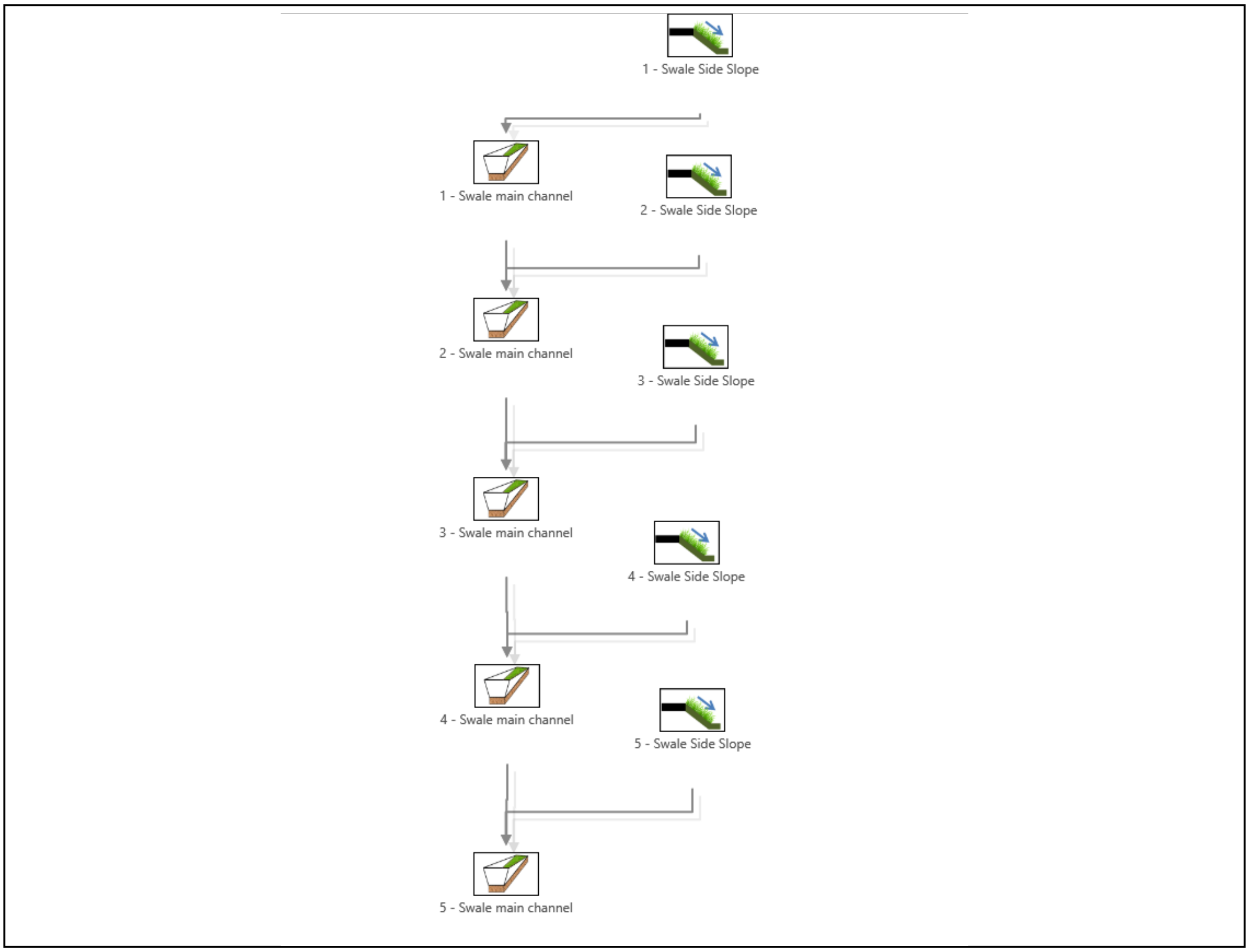
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2796	0	0.0059	0.2737	2
2 - Swale Side Slope	0.2796	0	0.0059	0.2737	2
3 - Swale Side Slope	0.2796	0	0.0059	0.2737	2
4 - Swale Side Slope	0.2796	0	0.0059	0.2737	2
5 - Swale Side Slope	0.2796	0	0.0059	0.2737	2
1 - Swale main channel	0.0011	0.2737	0.1225	0.1523	45
2 - Swale main channel	0.0011	0.426	0.1653	0.2618	39
3 - Swale main channel	0.0011	0.5355	0.1808	0.3558	34
4 - Swale main channel	0.0011	0.6295	0.1905	0.4401	30
5 - Swale main channel	0.0011	0.7138	0.1992	0.5157	28

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	112.88	0	2.39	110.49	2
2 - Swale Side Slope	112.88	0	2.39	110.49	2
3 - Swale Side Slope	112.88	0	2.39	110.49	2
4 - Swale Side Slope	112.88	0	2.39	110.49	2
5 - Swale Side Slope	112.88	0	2.39	110.49	2
1 - Swale main channel	0.43	110.49	91.25	19.67	82
2 - Swale main channel	0.43	130.16	104.97	25.62	80
3 - Swale main channel	0.43	136.11	107.57	28.97	79
4 - Swale main channel	0.43	139.46	108.65	31.24	78
5 - Swale main channel	0.43	141.73	109.34	32.82	77

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 5 - Existing Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12' lane, 2' shoulder, 3:1 side slope, 4' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56395
Annual Rainfall (inches):	26.7
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.242		0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.455		1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.242		0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.455		1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	1558	ft^3
Percent volume removed towards performance goal	**23**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.8849	acre-ft
Annual runoff volume removed by BMPs:	1.6721	acre-ft
Percent annual runoff volume removed:	**43**	**%**
Post development annual particulate P load:	1.744	lbs
Annual particulate P removed by BMPs:	1.64	lbs
Post development annual dissolved P load:	1.426	lbs
Annual dissolved P removed by BMPs:	0.614	lbs
Percent annual total phosphorus removed:	**71**	**%**
Post development annual TSS load:	575.9	lbs
Annual TSS removed by BMPs:	533.3	lbs
Percent annual TSS removed:	**93**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1354	0	1354	0
2 - Swale Side Slope	0	1354	0	1354	0
3 - Swale Side Slope	0	1354	0	1354	0
4 - Swale Side Slope	0	1354	0	1354	0
5 - Swale Side Slope	0	1354	0	1354	0
1 - Swale main channel	230	1354	230	1123	17
2 - Swale main channel	297	2477	297	2180	12
3 - Swale main channel	326	3534	326	3208	9
4 - Swale main channel	346	4561	346	4216	8
5 - Swale main channel	359	5569	359	5211	6

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7731	0	0	0.7731	0
2 - Swale Side Slope	0.7731	0	0	0.7731	0
3 - Swale Side Slope	0.7731	0	0	0.7731	0
4 - Swale Side Slope	0.7731	0	0	0.7731	0
5 - Swale Side Slope	0.7731	0	0	0.7731	0
1 - Swale main channel	0.0039	0.7731	0.2542	0.5228	33
2 - Swale main channel	0.0039	1.2959	0.3202	0.9796	25
3 - Swale main channel	0.0039	1.7526	0.3515	1.405	20
4 - Swale main channel	0.0039	2.1781	0.3684	1.8136	17
5 - Swale main channel	0.0039	2.5866	0.3777	2.2128	15

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.347	0	0	0.347	0
2 - Swale Side Slope	0.347	0	0	0.347	0
3 - Swale Side Slope	0.347	0	0	0.347	0
4 - Swale Side Slope	0.347	0	0	0.347	0
5 - Swale Side Slope	0.347	0	0	0.347	0
1 - Swale main channel	0.0017	0.347	0.2854	0.0633	82
2 - Swale main channel	0.0017	0.4103	0.3282	0.0838	80
3 - Swale main channel	0.0017	0.4308	0.3391	0.0934	78
4 - Swale main channel	0.0017	0.4404	0.3429	0.0992	78
5 - Swale main channel	0.0017	0.4462	0.3446	0.1033	77

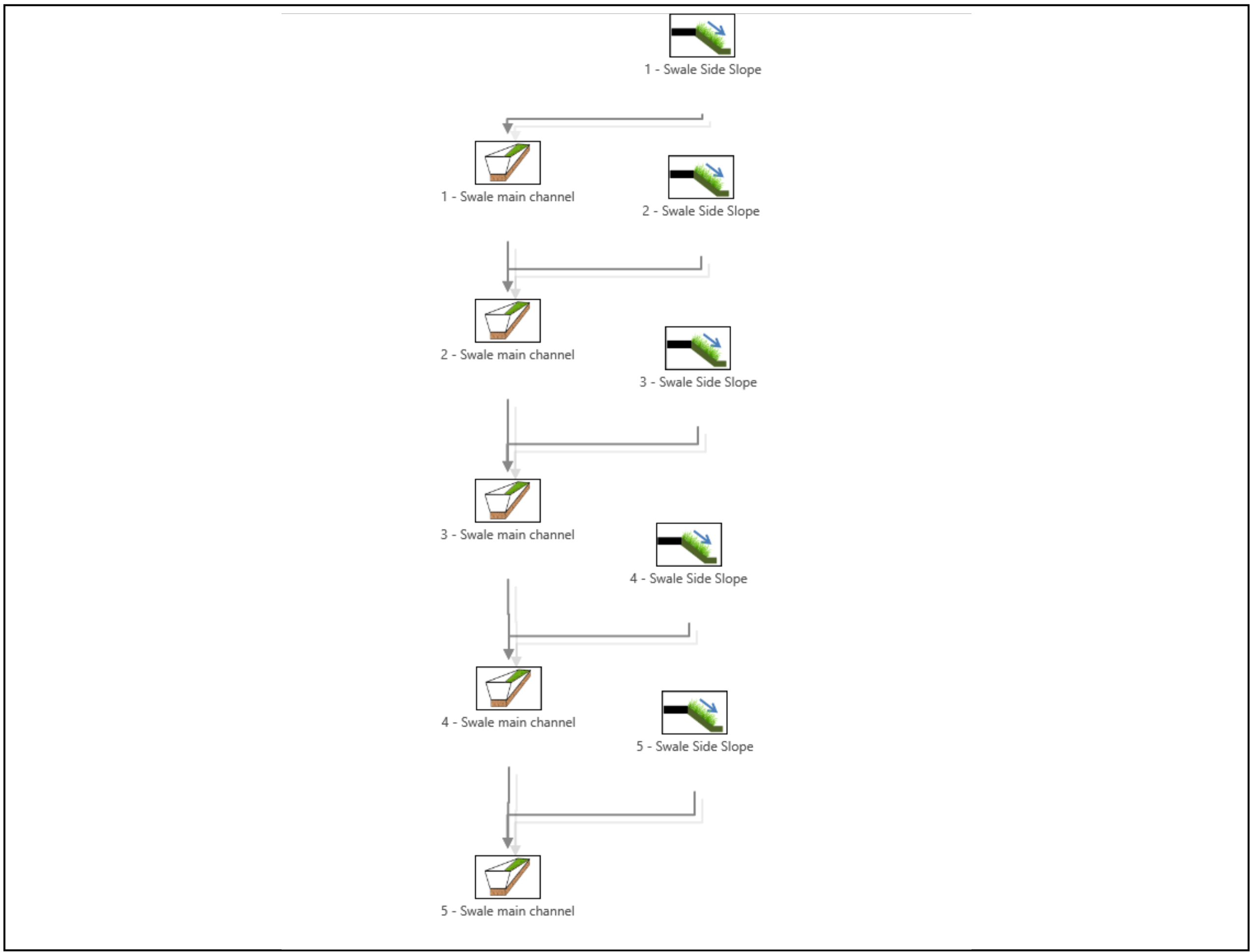
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2839	0	0	0.2839	0
2 - Swale Side Slope	0.2839	0	0	0.2839	0
3 - Swale Side Slope	0.2839	0	0	0.2839	0
4 - Swale Side Slope	0.2839	0	0	0.2839	0
5 - Swale Side Slope	0.2839	0	0	0.2839	0
1 - Swale main channel	0.0014	0.2839	0.0933	0.192	33
2 - Swale main channel	0.0014	0.4759	0.1176	0.3597	25
3 - Swale main channel	0.0014	0.6436	0.1291	0.5159	20
4 - Swale main channel	0.0014	0.7998	0.1353	0.6659	17
5 - Swale main channel	0.0014	0.9498	0.1387	0.8125	15

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	114.61	0	0	114.61	0
2 - Swale Side Slope	114.61	0	0	114.61	0
3 - Swale Side Slope	114.61	0	0	114.61	0
4 - Swale Side Slope	114.61	0	0	114.61	0
5 - Swale Side Slope	114.61	0	0	114.61	0
1 - Swale main channel	0.57	114.61	90.38	24.8	78
2 - Swale main channel	0.57	139.41	106.22	33.76	76
3 - Swale main channel	0.57	148.37	110.82	38.12	74
4 - Swale main channel	0.57	152.73	112.53	40.77	73
5 - Swale main channel	0.57	155.38	113.32	42.63	73

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Case 5 - Existing Road - 5 Segments
User Name / Company Name:	
Date:	
Project Description:	Existing Road: 12’ lane, 2’ shoulder, 3:1 side slope, 4’ swale depth, 2’ bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56395
Annual Rainfall (inches):	26.7
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.242	0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.455	1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.242	0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.455	1.455
			Impervious Area (acres)		1.695
			Total Area (acres)		3.392

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	6768	ft3
Volume removed by BMPs towards performance goal:	1225	ft^3
Percent volume removed towards performance goal	**18**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	3.9772	acre-ft
Annual runoff volume removed by BMPs:	0.6547	acre-ft
Percent annual runoff volume removed:	**16**	**%**
Post development annual particulate P load:	1.785	lbs
Annual particulate P removed by BMPs:	1.661	lbs
Post development annual dissolved P load:	1.46	lbs
Annual dissolved P removed by BMPs:	0.24	lbs
Percent annual total phosphorus removed:	**59**	**%**
Post development annual TSS load:	589.6	lbs
Annual TSS removed by BMPs:	538	lbs
Percent annual TSS removed:	**91**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	0	1354	0	1354	0
2 - Swale Side Slope	0	1354	0	1354	0
3 - Swale Side Slope	0	1354	0	1354	0
4 - Swale Side Slope	0	1354	0	1354	0
5 - Swale Side Slope	0	1354	0	1354	0
1 - Swale main channel	203	1354	203	1150	15
2 - Swale main channel	242	2504	242	2262	10
3 - Swale main channel	260	3616	260	3355	7
4 - Swale main channel	263	4709	263	4445	6
5 - Swale main channel	255	5799	255	5544	4

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.7906	0	0	0.7906	0
2 - Swale Side Slope	0.7906	0	0	0.7906	0
3 - Swale Side Slope	0.7906	0	0	0.7906	0
4 - Swale Side Slope	0.7906	0	0	0.7906	0
5 - Swale Side Slope	0.7906	0	0	0.7906	0
1 - Swale main channel	0.0048	0.7906	0.095	0.7004	12
2 - Swale main channel	0.0048	1.491	0.1262	1.3696	8
3 - Swale main channel	0.0048	2.1602	0.1415	2.0235	7
4 - Swale main channel	0.0048	2.8142	0.1468	2.6722	5
5 - Swale main channel	0.0048	3.4628	0.1452	3.3224	4

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3548	0	0	0.3548	0
2 - Swale Side Slope	0.3548	0	0	0.3548	0
3 - Swale Side Slope	0.3548	0	0	0.3548	0
4 - Swale Side Slope	0.3548	0	0	0.3548	0
5 - Swale Side Slope	0.3548	0	0	0.3548	0
1 - Swale main channel	0.0022	0.3548	0.2721	0.0849	76
2 - Swale main channel	0.0022	0.4397	0.3327	0.1092	75
3 - Swale main channel	0.0022	0.464	0.3486	0.1176	75
4 - Swale main channel	0.0022	0.4724	0.3531	0.1215	74
5 - Swale main channel	0.0022	0.4763	0.3547	0.1238	74

Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.2903	0	0	0.2903	0
2 - Swale Side Slope	0.2903	0	0	0.2903	0
3 - Swale Side Slope	0.2903	0	0	0.2903	0
4 - Swale Side Slope	0.2903	0	0	0.2903	0
5 - Swale Side Slope	0.2903	0	0	0.2903	0
1 - Swale main channel	0.0018	0.2903	0.0349	0.2572	12
2 - Swale main channel	0.0018	0.5475	0.0464	0.5029	8
3 - Swale main channel	0.0018	0.7932	0.0519	0.7431	7
4 - Swale main channel	0.0018	1.0334	0.0539	0.9813	5
5 - Swale main channel	0.0018	1.2716	0.0533	1.2201	4

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	117.2	0	0	117.2	0
2 - Swale Side Slope	117.2	0	0	117.2	0
3 - Swale Side Slope	117.2	0	0	117.2	0
4 - Swale Side Slope	117.2	0	0	117.2	0
5 - Swale Side Slope	117.2	0	0	117.2	0
1 - Swale main channel	0.72	117.2	84.69	33.23	72
2 - Swale main channel	0.72	150.43	106.86	44.29	71
3 - Swale main channel	0.72	161.49	113.69	48.52	70
4 - Swale main channel	0.72	165.72	115.95	50.49	70
5 - Swale main channel	0.72	167.69	116.77	51.64	69

BMP Schematic

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Mod Case 5 - New Road - 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56395
Annual Rainfall (inches):	26.7
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.242				0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.94				1.94
				Impervious Area (acres)	2.06
				Total Area (acres)	4.242

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land	0.242				0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed	1.94				1.94
				Impervious Area (acres)	2.06
				Total Area (acres)	4.242

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	2870	ft^3
Percent volume removed towards performance goal	**35**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.5113	acre-ft
Annual runoff volume removed by BMPs:	3.0348	acre-ft
Percent annual runoff volume removed:	**67**	**%**
Post development annual particulate P load:	2.025	lbs
Annual particulate P removed by BMPs:	1.92	lbs
Post development annual dissolved P load:	1.657	lbs
Annual dissolved P removed by BMPs:	1.114	lbs
Percent annual total phosphorus removed:	**82**	**%**
Post development annual TSS load:	668.8	lbs
Annual TSS removed by BMPs:	626.4	lbs
Percent annual TSS removed:	**94**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	34	1645	34	1611	2
2 - Swale Side Slope	34	1645	34	1611	2
3 - Swale Side Slope	34	1645	34	1611	2
4 - Swale Side Slope	34	1645	34	1611	2
5 - Swale Side Slope	34	1645	34	1611	2
1 - Swale main channel	368	1611	368	1242	23
2 - Swale main channel	480	2853	480	2373	17
3 - Swale main channel	565	3984	565	3418	14
4 - Swale main channel	623	5029	623	4407	12
5 - Swale main channel	661	6017	661	5356	11

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9003	0	0.1637	0.7366	18
2 - Swale Side Slope	0.9003	0	0.1637	0.7366	18
3 - Swale Side Slope	0.9003	0	0.1637	0.7366	18
4 - Swale Side Slope	0.9003	0	0.1637	0.7366	18
5 - Swale Side Slope	0.9003	0	0.1637	0.7366	18
1 - Swale main channel	0.0019	0.7366	0.4743	0.2642	64
2 - Swale main channel	0.0019	1.0008	0.5425	0.4602	54
3 - Swale main channel	0.0019	1.1968	0.5865	0.6122	49
4 - Swale main channel	0.0019	1.3488	0.6128	0.7379	45
5 - Swale main channel	0.0019	1.4746	0	1.4765	0

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4041	0	0.0735	0.3306	18
2 - Swale Side Slope	0.4041	0	0.0735	0.3306	18
3 - Swale Side Slope	0.4041	0	0.0735	0.3306	18
4 - Swale Side Slope	0.4041	0	0.0735	0.3306	18
5 - Swale Side Slope	0.4041	0	0.0735	0.3306	18
1 - Swale main channel	0.0009	0.3306	0.2995	0.032	90
2 - Swale main channel	0.0009	0.3626	0.3185	0.045	88
3 - Swale main channel	0.0009	0.3756	0.3246	0.0519	86
4 - Swale main channel	0.0009	0.3825	0.3268	0.0566	85
5 - Swale main channel	0.0009	0.3872	0.2833	0.1048	73

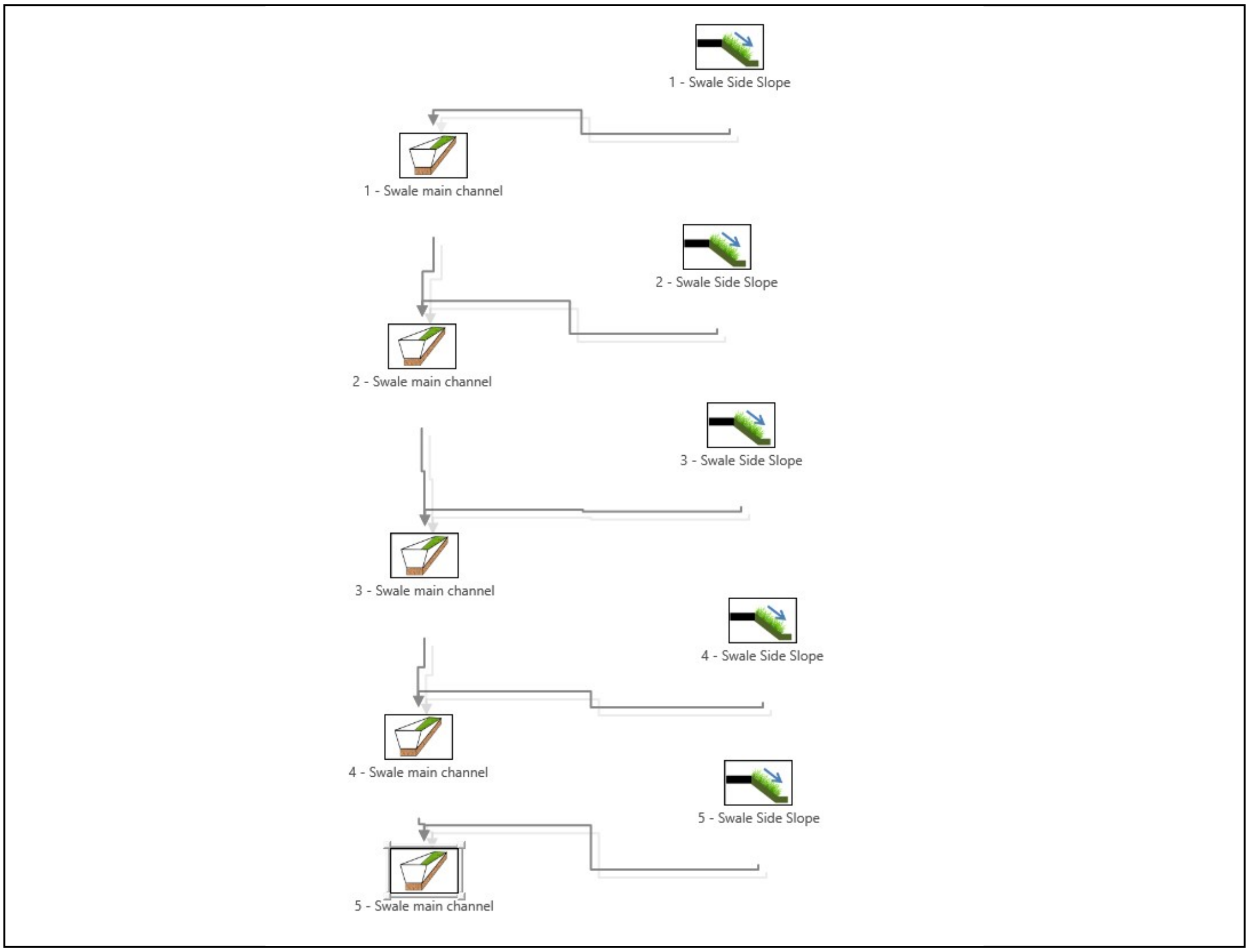
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3306	0	0.0601	0.2705	18
2 - Swale Side Slope	0.3306	0	0.0601	0.2705	18
3 - Swale Side Slope	0.3306	0	0.0601	0.2705	18
4 - Swale Side Slope	0.3306	0	0.0601	0.2705	18
5 - Swale Side Slope	0.3306	0	0.0601	0.2705	18
1 - Swale main channel	0.0007	0.2705	0.1742	0.097	64
2 - Swale main channel	0.0007	0.3675	0.1992	0.169	54
3 - Swale main channel	0.0007	0.4395	0.2154	0.2248	49
4 - Swale main channel	0.0007	0.4953	0.225	0.271	45
5 - Swale main channel	0.0007	0.5415	0	0.5422	0

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	133.46	0	24.27	109.19	18
2 - Swale Side Slope	133.46	0	24.27	109.19	18
3 - Swale Side Slope	133.46	0	24.27	109.19	18
4 - Swale Side Slope	133.46	0	24.27	109.19	18
5 - Swale Side Slope	133.46	0	24.27	109.19	18
1 - Swale main channel	0.29	109.19	96.95	12.53	89
2 - Swale main channel	0.29	121.72	104.09	17.92	85
3 - Swale main channel	0.29	127.11	106.58	20.820000000	84
4 - Swale main channel	0.29	130.01	107.52	22.78	83
5 - Swale main channel	0.29	131.97	89.94	42.320000000	68

BMP Schematic



Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Mod Case 5 - New Road - 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12’ lane, 5’ shoulder, 4:1 side slope, 4’ swale depth, 2’ bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56395
Annual Rainfall (inches):	26.7
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.242			0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.94			1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.242

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land		0.242			0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed		1.94			1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.242

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	2376	ft^3
Percent volume removed towards performance goal	**29**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.7104	acre-ft
Annual runoff volume removed by BMPs:	2.838	acre-ft
Percent annual runoff volume removed:	**60**	**%**
Post development annual particulate P load:	2.114	lbs
Annual particulate P removed by BMPs:	2.012	lbs
Post development annual dissolved P load:	1.73	lbs
Annual dissolved P removed by BMPs:	1.042	lbs
Percent annual total phosphorus removed:	**79**	**%**
Post development annual TSS load:	698.3	lbs
Annual TSS removed by BMPs:	656.3	lbs
Percent annual TSS removed:	**94**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	15	1645	15	1630	1
2 - Swale Side Slope	15	1645	15	1630	1
3 - Swale Side Slope	15	1645	15	1630	1
4 - Swale Side Slope	15	1645	15	1630	1
5 - Swale Side Slope	15	1645	15	1630	1
1 - Swale main channel	320	1630	320	1310	20
2 - Swale main channel	424	2940	424	2516	14
3 - Swale main channel	481	4146	481	3665	12
4 - Swale main channel	524	5294	524	4770	10
5 - Swale main channel	551	6400	551	5849	9

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9392	0	0.0397	0.8995	4
2 - Swale Side Slope	0.9392	0	0.0397	0.8995	4
3 - Swale Side Slope	0.9392	0	0.0397	0.8995	4
4 - Swale Side Slope	0.9392	0	0.0397	0.8995	4
5 - Swale Side Slope	0.9392	0	0.0397	0.8995	4
1 - Swale main channel	0.0029	0.8995	0.3764	0.526	42
2 - Swale main channel	0.0029	1.4255	0.5081	0.9203	36
3 - Swale main channel	0.0029	1.8199	0.5571	1.2657	31
4 - Swale main channel	0.0029	2.1652	0.5924	1.5757	27
5 - Swale main channel	0.0029	2.4752	0.6057	1.8724	24

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4215	0	0.0178	0.4037	4
2 - Swale Side Slope	0.4215	0	0.0178	0.4037	4
3 - Swale Side Slope	0.4215	0	0.0178	0.4037	4
4 - Swale Side Slope	0.4215	0	0.0178	0.4037	4
5 - Swale Side Slope	0.4215	0	0.0178	0.4037	4
1 - Swale main channel	0.0013	0.4037	0.3413	0.0637	84
2 - Swale main channel	0.0013	0.4674	0.3872	0.0815	83
3 - Swale main channel	0.0013	0.4852	0.3953	0.0912	81
4 - Swale main channel	0.0013	0.4949	0.3988	0.0974	80
5 - Swale main channel	0.0013	0.5011	0.3999	0.1025	80

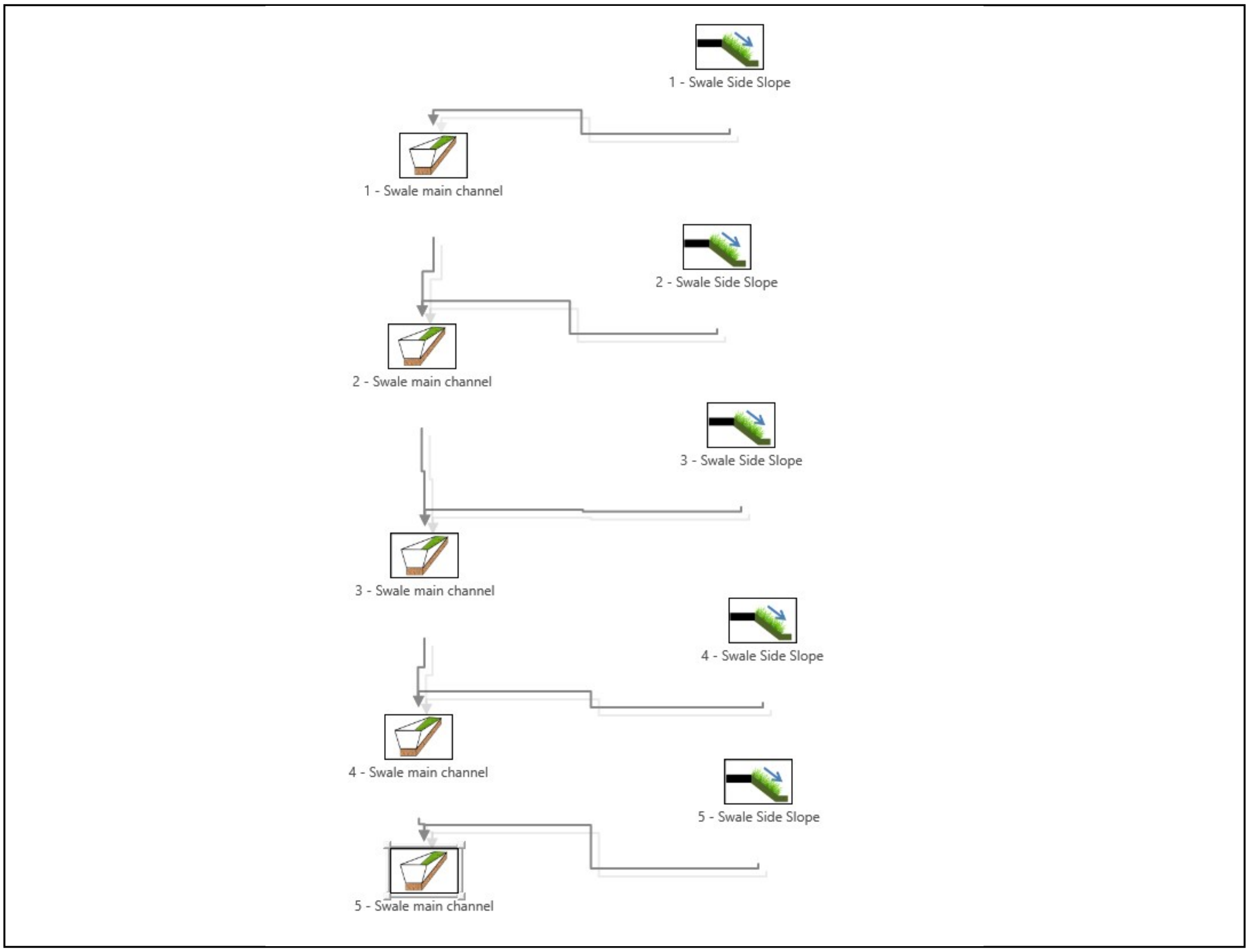
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3449	0	0.0146	0.3303	4
2 - Swale Side Slope	0.3449	0	0.0146	0.3303	4
3 - Swale Side Slope	0.3449	0	0.0146	0.3303	4
4 - Swale Side Slope	0.3449	0	0.0146	0.3303	4
5 - Swale Side Slope	0.3449	0	0.0146	0.3303	4
1 - Swale main channel	0.0011	0.3303	0.1382	0.1932	42
2 - Swale main channel	0.0011	0.5235	0.1866	0.338	36
3 - Swale main channel	0.0011	0.6683	0.2046	0.4648	31
4 - Swale main channel	0.0011	0.7951	0.2175	0.5787	27
5 - Swale main channel	0.0011	0.909	0.2224	0.6877	24

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	139.22	0	5.88	133.34	4
2 - Swale Side Slope	139.22	0	5.88	133.34	4
3 - Swale Side Slope	139.22	0	5.88	133.34	4
4 - Swale Side Slope	139.22	0	5.88	133.34	4
5 - Swale Side Slope	139.22	0	5.88	133.34	4
1 - Swale main channel	0.43	133.34	108.82	24.95	81
2 - Swale main channel	0.43	158.29	126	32.72	79
3 - Swale main channel	0.43	166.06	129.5	36.99	78
4 - Swale main channel	0.43	170.33	131.05	39.71	77
5 - Swale main channel	0.43	173.05	131.54	41.940000000	76

BMP Schematic



CASE STUDY 5, HSG C, NEW ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Mod Case 5 - New Road - 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12' lane, 5' shoulder, 4:1 side slope, 4' swale depth, 2' bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56395
Annual Rainfall (inches):	26.7
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.242		0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.94		1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.242

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land			0.242		0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed			1.94		1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.242

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	1641	ft^3
Percent volume removed towards performance goal	**20**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.7929	acre-ft
Annual runoff volume removed by BMPs:	2.0718	acre-ft
Percent annual runoff volume removed:	**43**	**%**
Post development annual particulate P load:	2.151	lbs
Annual particulate P removed by BMPs:	2.029	lbs
Post development annual dissolved P load:	1.76	lbs
Annual dissolved P removed by BMPs:	0.761	lbs
Percent annual total phosphorus removed:	**71**	**%**
Post development annual TSS load:	710.5	lbs
Annual TSS removed by BMPs:	660.1	lbs
Percent annual TSS removed:	**93**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	6	1645	6	1639	0
2 - Swale Side Slope	6	1645	6	1639	0
3 - Swale Side Slope	6	1645	6	1639	0
4 - Swale Side Slope	6	1645	6	1639	0
5 - Swale Side Slope	6	1645	6	1639	0
1 - Swale main channel	251	1639	251	1388	15
2 - Swale main channel	309	3027	309	2719	10
3 - Swale main channel	340	4358	340	4018	8
4 - Swale main channel	355	5657	355	5302	6
5 - Swale main channel	356	6941	356	6585	5

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.9547	0	0.0138	0.9409	1
2 - Swale Side Slope	0.9547	0	0.0138	0.9409	1
3 - Swale Side Slope	0.9547	0	0.0138	0.9409	1
4 - Swale Side Slope	0.9547	0	0.0138	0.9409	1
5 - Swale Side Slope	0.9547	0	0.0138	0.9409	1
1 - Swale main channel	0.0039	0.9409	0.2827	0.6621	30
2 - Swale main channel	0.0039	1.603	0.3511	1.2558	22
3 - Swale main channel	0.0039	2.1967	0.3817	1.8189	17
4 - Swale main channel	0.0039	2.7598	0.395	2.3687	14
5 - Swale main channel	0.0039	3.3096	0.5923	2.7212	18

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4285	0	0.0062	0.4223	1
2 - Swale Side Slope	0.4285	0	0.0062	0.4223	1
3 - Swale Side Slope	0.4285	0	0.0062	0.4223	1
4 - Swale Side Slope	0.4285	0	0.0062	0.4223	1
5 - Swale Side Slope	0.4285	0	0.0062	0.4223	1
1 - Swale main channel	0.0017	0.4223	0.3438	0.0802	81
2 - Swale main channel	0.0017	0.5025	0.3978	0.1064	79
3 - Swale main channel	0.0017	0.5287	0.412	0.1184	78
4 - Swale main channel	0.0017	0.5407	0.4169	0.1255	77
5 - Swale main channel	0.0017	0.5478	0.4277	0.1218	78

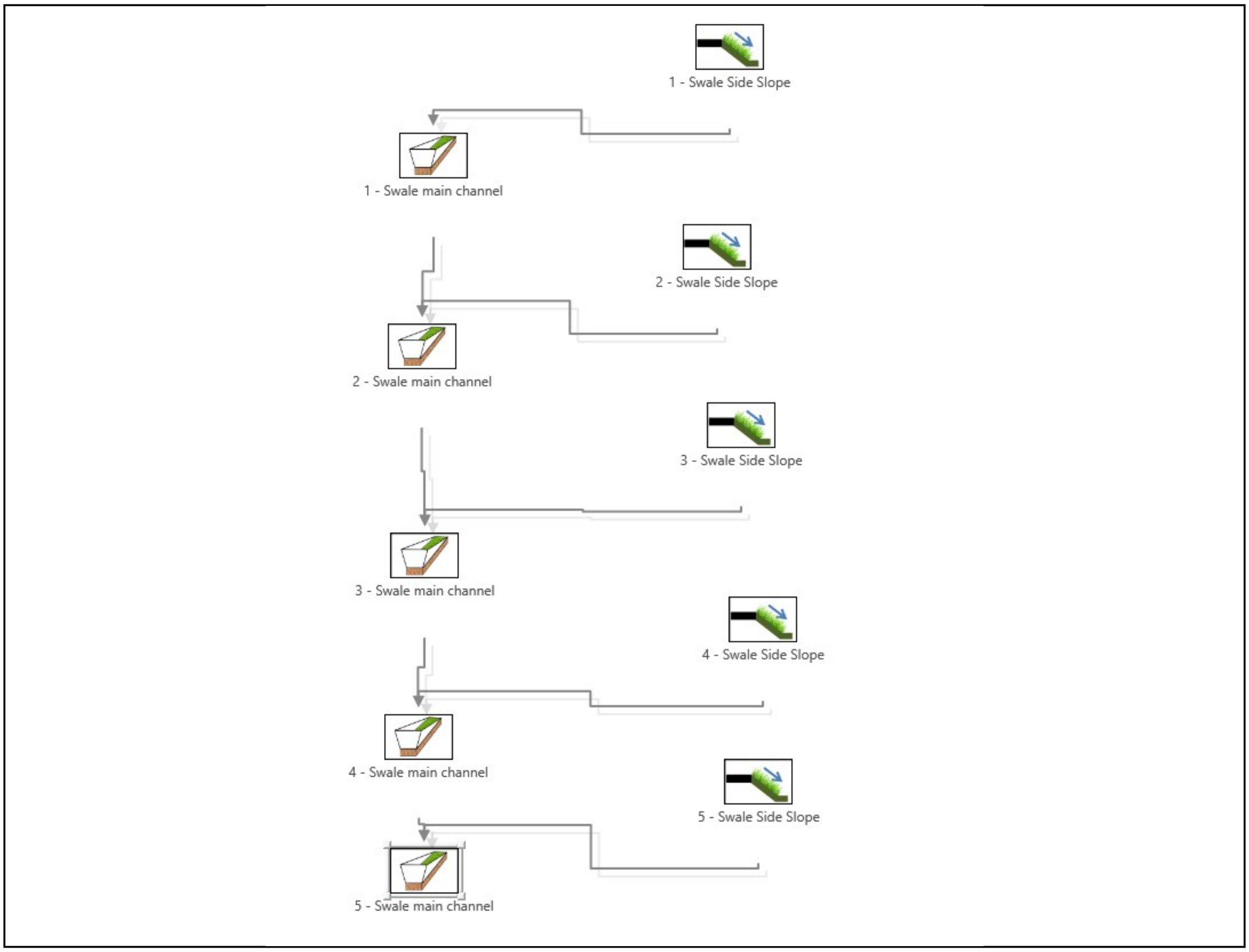
Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3506	0	0.0051	0.3455	1
2 - Swale Side Slope	0.3506	0	0.0051	0.3455	1
3 - Swale Side Slope	0.3506	0	0.0051	0.3455	1
4 - Swale Side Slope	0.3506	0	0.0051	0.3455	1
5 - Swale Side Slope	0.3506	0	0.0051	0.3455	1
1 - Swale main channel	0.0014	0.3455	0.1038	0.2431	30
2 - Swale main channel	0.0014	0.5886	0.1289	0.4611	22
3 - Swale main channel	0.0014	0.8066	0.1401	0.6679	17
4 - Swale main channel	0.0014	1.0134	0.145	0.8698	14
5 - Swale main channel	0.0014	1.2153	0.2175	0.9992	18

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	141.53	0	2.05	139.48	1
2 - Swale Side Slope	141.53	0	2.05	139.48	1
3 - Swale Side Slope	141.53	0	2.05	139.48	1
4 - Swale Side Slope	141.53	0	2.05	139.48	1
5 - Swale Side Slope	141.53	0	2.05	139.48	1
1 - Swale main channel	0.57	139.48	108.64	31.41	78
2 - Swale main channel	0.57	170.89	128.58	42.88	75
3 - Swale main channel	0.57	182.36	134.55	48.379999999	74
4 - Swale main channel	0.57	187.86	136.75	51.679999999	73
5 - Swale main channel	0.57	191.16	141.34	50.389999999	74

BMP Schematic



CASE STUDY 5, HSG D, NEW ROAD

Project Information

Calculator Version:	Version 3: January 2017
Project Name:	Mod Case 5 - New Road - 5 segments
User Name / Company Name:	
Date:	
Project Description:	New Road: 12’ lane, 5’ shoulder, 4:1 side slope, 4’ swale depth, 2’ bottom width
Construction Permit?:	Yes

Site Information

Retention Requirement (inches):	1.1
Site's Zip Code:	56395
Annual Rainfall (inches):	26.7
Phosphorus EMC (mg/l):	0.3
TSS EMC (mg/l):	54.5

Total Site Area

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.242	0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.94	1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.242

Site Areas Routed to BMPs

Land Cover	A Soils (acres)	B Soils (acres)	C Soils (acres)	D Soils (acres)	Total (acres)
Forest/Open Space - Undisturbed, protected forest/open space or reforested land				0.242	0.242
Managed Turf - disturbed, graded for yards or other turf to be mowed/managed				1.94	1.94
			Impervious Area (acres)		2.06
			Total Area (acres)		4.242

Summary Information

Performance Goal Requirement

Performance goal volume retention requirement:	8226	ft3
Volume removed by BMPs towards performance goal:	1221	ft^3
Percent volume removed towards performance goal	**15**	**%**

Annual Volume and Pollutant Load Reductions

Post development annual runoff volume	4.9143	acre-ft
Annual runoff volume removed by BMPs:	0.7445	acre-ft
Percent annual runoff volume removed:	**15**	**%**
Post development annual particulate P load:	2.206	lbs
Annual particulate P removed by BMPs:	2.053	lbs
Post development annual dissolved P load:	1.804	lbs
Annual dissolved P removed by BMPs:	0.273	lbs
Percent annual total phosphorus removed:	**58**	**%**
Post development annual TSS load:	728.5	lbs
Annual TSS removed by BMPs:	664.8	lbs
Percent annual TSS removed:	**91**	**%**

BMP Summary

Performance Goal Summary

BMP Name	BMP Volume Capacity (ft3)	Volume Recieved (ft3)	Volume Retained (ft3)	Volume Outflow (ft3)	Percent Retained (%)
1 - Swale Side Slope	1	1645	1	1644	0
2 - Swale Side Slope	1	1645	1	1644	0
3 - Swale Side Slope	1	1645	1	1644	0
4 - Swale Side Slope	1	1645	1	1644	0
5 - Swale Side Slope	1	1645	1	1644	0
1 - Swale main channel	218	1644	218	1426	13
2 - Swale main channel	253	3071	253	2817	8
3 - Swale main channel	263	4462	263	4199	6
4 - Swale main channel	253	5844	253	5591	4
5 - Swale main channel	231	7235	231	7004	3

Annual Volume Summary

BMP Name	Volume From Direct Watershed (acre-ft)	Volume From Upstream BMPs (acre-ft)	Volume Retained (acre-ft)	Volume outflow (acre-ft)	Percent Retained (%)
1 - Swale Side Slope	0.978	0	0.0014	0.9766	0
2 - Swale Side Slope	0.978	0	0.0014	0.9766	0
3 - Swale Side Slope	0.978	0	0.0014	0.9766	0
4 - Swale Side Slope	0.978	0	0.0014	0.9766	0
5 - Swale Side Slope	0.978	0	0.0014	0.9766	0
1 - Swale main channel	0.0048	0.9767	0.1062	0.8753	11
2 - Swale main channel	0.0048	1.852	0.1368	1.72	7
3 - Swale main channel	0.0048	2.6968	0.1477	2.5539	5
4 - Swale main channel	0.0048	3.5306	0.146	3.3894	4
5 - Swale main channel	0.0048	4.3661	0.201	4.1699	5

Particulate Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.4389	0	0.0006	0.4383	0
2 - Swale Side Slope	0.4389	0	0.0006	0.4383	0
3 - Swale Side Slope	0.4389	0	0.0006	0.4383	0
4 - Swale Side Slope	0.4389	0	0.0006	0.4383	0
5 - Swale Side Slope	0.4389	0	0.0006	0.4383	0
1 - Swale main channel	0.0022	0.4383	0.3344	0.1061	76
2 - Swale main channel	0.0022	0.5444	0.4099	0.1367	75
3 - Swale main channel	0.0022	0.575	0.4299	0.1473	74
4 - Swale main channel	0.0022	0.5856	0.4356	0.1522	74
5 - Swale main channel	0.0022	0.5905	0.44	0.1527	74

Dissolved Phosphorus Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	0.3591	0	0.0005	0.3586	0
2 - Swale Side Slope	0.3591	0	0.0005	0.3586	0
3 - Swale Side Slope	0.3591	0	0.0005	0.3586	0
4 - Swale Side Slope	0.3591	0	0.0005	0.3586	0
5 - Swale Side Slope	0.3591	0	0.0005	0.3586	0
1 - Swale main channel	0.0018	0.3586	0.039	0.3214	11
2 - Swale main channel	0.0018	0.68	0.0502	0.6316	7
3 - Swale main channel	0.0018	0.9902	0.0542	0.9378	5
4 - Swale main channel	0.0018	1.2964	0.0536	1.2446	4
5 - Swale main channel	0.0018	1.6032	0.0738	1.5312	5

TSS Summary

BMP Name	Load From Direct Watershed (lbs)	Load From Upstream BMPs (lbs)	Load Retained (lbs)	Outflow Load (lbs)	Percent Retained (%)
1 - Swale Side Slope	144.98	0	0.2	144.78	0
2 - Swale Side Slope	144.98	0	0.2	144.78	0
3 - Swale Side Slope	144.98	0	0.2	144.78	0
4 - Swale Side Slope	144.98	0	0.2	144.78	0
5 - Swale Side Slope	144.98	0	0.2	144.78	0
1 - Swale main channel	0.72	144.78	103.98	41.52	71
2 - Swale main channel	0.72	186.3	131.58	55.44	70
3 - Swale main channel	0.72	200.22	140.15	60.79	70
4 - Swale main channel	0.72	205.57	143	63.29	69
5 - Swale main channel	0.72	208.07	145.05	63.74	69

BMP Schematic