Eastern Washington Steep Slope Research for

Management of Highway Stormwater

By

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To the Faculty of Washington State University:

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ABSTRACT

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Highway embankments can provide an ideal location for integrating low impact development (LID) stormwater best management practices (BMPs) into a highway setting, specifically sheet flow BMPs such as vegetated filter strips (VFS) and dispersion. However, the design criterion at Washington State Department of Transportation (WSDOT) limits the embankment slope to 15% maximum. A possible justification for this limit is steeper slopes could concentrate flow, reducing the effectiveness of the BMP, and encouraging channelized flow that can erode the embankment.

This design criterion can present a challenge to WSDOT since highway embankments can be constructed, without vehicle safety barriers, on slopes as steep as 33% and when VFS or dispersion are required on slopes greater than 15%, embankments need to be flattened and the roadway footprint expanded. This may result in the additional right of way (ROW) acquisition as well as additional construction and ecological costs from the expanded embankment.

While studies have shown that VFS and dispersion areas can successfully meet runoff treatment and flow control goals on 33% slopes, limited research was found that evaluated the site characteristics that support stable embankments (without erosion) located at steeper slopes.

In an effort to evaluate a design criteria, for both VFS and dispersion, that aligns with the 33% highway embankment limit, 45 sites in Eastern Washington were inventoried to determine the specific site characteristics that contribute to concentration of highway runoff on slopes steeper than 15%. Based a statistical analysis the embankment slope alone was not considered statistically significant to erosion severity compared to other site characteristics. Instead, low vegetation coverage and a high percentage of sand had the strongest correlation to erosion severity. In addition, empirical observations at the sites noted conditions at the edge of pavement (EOP) can also encourage channelized flows.

Based on these findings, a modified design criteria for VFS and dispersion BMPs is recommended allowing embankment slopes up to of 33% when vegetation can be established, taking into consideration the soil characteristics. In addition, level spreaders may allow for dispersed flows regardless of the conditions at the EOP.

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Dedication

This thesis is dedicated to my husband Thomas Brasch, our children Annabelle, Wilken, and Samuel, and my parents, Ken and Cheryl Navickis. Their combined support, understanding, and patients were essential to the completion of this project.

CHAPTER 1: INTRODUCTION

1.1 Stormwater Policy History

Managing stormwater runoff from highways, to protect the environment, became a priority for Washington State Department of Transportation (WSDOT) since the 1987 amendment to the Clean Water Act which expanded the National Point Discharge Elimination System (NPDES) permit program to include stormwater discharges from highways. This amendment required the use of structural devices or managerial best management practices (BMPs) to the maximum extent practicable to meet stormwater management requirements. In response to these and state requirements, WSDOT developed the Highway Runoff Manual (HRM) which contains the design and maintenance guidelines for BMPs that meet the runoff treatment (reduce pollutant loads and concentrations) and flow control (maintain natural runoff volumes and flow rates) requirements of the NPDES permit (WAC173-270; WSDOT, 1995; WSDOT, 2008a). The term BMPs quickly became a catch all term to describe every operational and structural practice for stormwater management, however they do not equally compensate for the various aspects of the altered hydrology and use of the many BMPs is dependent on site conditions and local or regional standard practices (NCHRP, 2006).

In response to these concerns, the concept of Low Impact Development (LID) was formalized by a set of standards developed by Prince George's Counties Department of Environmental Resources in the late 1990's, with the goal of providing an innovative approach to stormwater management that minimize impacts to the environment by considering the individual site characteristics and integrating practices it into the landscape (DER, 1999). While many techniques support LID, approaches suited for a highway setting can include; using the benefits of all the hydrological processes, managing the increased stormwater discharges as close to the source as possible, and maintain natural vegetation by limiting the areas of disturbance (Haselbach, 2011). Agencies such as Washington State Department of Ecology (Ecology) have recognized the benefits of LID and in response to the Pollution Control Hearing's Board ruling, will likely require LID to the maximum extent feasible when some state municipal NPDES stormwater permits are renewed (WSDOE, 2009). While many of the recognized BMPs have various levels of LID characteristics, with future regulations anticipated, there is a priority on using the most appropriate BMPs for a project site.

1.2 Vegetated Filter Strips and Dispersion Defined

Highway embankments can provide an ideal location for integrating low impact development (LID) stormwater best management practices (BMPs) into a highway setting, specifically sheet flow BMPs such as vegetated filter strips (VFS) and dispersion. These BMPs are considered LID approaches to stormwater management by being located immediately adjacent to the highway (pollution source) and maximize the hydrological cycle by reducing or dispersing runoff over a contiguous sloped vegetated area (Schooler, 2010; Winston, 2010). Figure 1.1 shows a picture of the two BMPs, followed by a brief description, and summary of the BMPs design criteria in Table 1.1.

Figure 1.1 Typical Vegetated Filter Strip and Dispersion Area
Source: (WSDOT, 2008a)

Vegetated Filter Strip (VFS), also known as Filter Strip, Riparian Buffer, and Vegetated Buffer, are effective at providing runoff treatment of total suspended solids (TSS) when highway runoff sheet flows through vegetation where velocities are slowed, in turn trapping sediment and other pollutants. While some flow control is provided through evaporation, vegetation uptake and transpiration, and infiltration, since these BMPs are generally located at sites with limited area or low saturated hydraulic conductivity (K_{sat}), it is assumed that most of the volume of stormwater will be conveyed to the downstream end of the BMP and if required another BMP is used for flow control (WSDOT, 2008a).

Dispersion, is an abbreviated term that will be used in this paper to represent both Natural or Engineering Dispersion. The difference between the two is engineered dispersion represents an area that has been modified to meet the design criteria and natural dispersion represents sites that meet the design criteria without modification. Dispersion is located at sites with a large areas compared to VFS or where K_{sat} is high, either of these site conditions allow all the stormwater to disperse within the limits of the BMP area and meet flow control requirements. Since runoff infiltrates into the existing soils and through vegetation root zones, dispersion is effective at pollutant-removal of TSS, metals, oils, and phosphorus (WSDOT, 2008a).

Table 1.1 Summary of VFS and Dispersion Design Criteria

	HRM (WSDOT, 2008a)	
BMP	**Vegetative Filter Strip (VFS)**	**Natural and Engineered Dispersion**
Effectiveness	Runoff Treatment[1]	Runoff Treatment and Flow Control
Target Pollutants	TSS	TSS, Metals, Phosphorus, Oil Control
Pollutant Removal Mechanism	Vegetation slows runoff velocities, traps sediment and other pollutants. Soil provides some infiltration and biologic uptake.	Infiltration into the existing soils, through vegetation root zones; evaporation; uptake and transpiration from vegetation.
Infiltration Considered	No	Yes
Max. Contributing Flow Path Length	150' sheet flow	
Level Spreader	1' flow spreader	Engineer Dispersion
Roadway Grade (G)	2%	5%
Super Elevation (e)	5%	8%
Max. Slope Limit (S_e)	15% max	15% max

1. While some VFS design criterions allow credit for the infiltration capacity of the soil, the current WSDOT design criterion does not.

1.3 Problem Statement

Currently, roadway embankments constructed as a VFS or dispersion are constrained to a 15% slope or flatter per the WSDOT HRM. This design criterion can present a challenge to WSDOT since highway embankments can be constructed, without vehicle safety barrier, on slopes as steep as 33%, which would otherwise be an ideal location for VFS and dispersion (WSDOT, 2009b). But currently when the standard highway embankment slope designs are steeper than a 15%, in order to fit these BMPs, the embankments would need to be flattened and the roadway footprint expanded. This may result in additional right of way (ROW) acquisition and construction costs as well as additional ecological impacts to established native vegetation or environmentally sensitive areas. To keep highway construction cost down and ecological impacts to a minimum, it is desirable to have the design criteria for VFS and dispersion align with the range of slopes for highway embankments that may not require vehicle safety barriers. In addition, this modification would allow VFS and dispersion to be used in more locations and provide additional options for WSDOT to meet the anticipated LID NPDES stormwater permit requirements.

Maximizing the construction locations for VFS and dispersion, can also support current maintenance management and safety practices of the roadside area which consists of the area outside the highway travel lanes. This area is maintained to for many reasons, but specific to this research includes: maintain a clear visual area (sight distance) and to support recovery of an errant vehicle, enhancing the natural scenic quality, and reducing the spread of noxious weeds. Various practices are used to support these goals particularly the establishing desirable species of vegetation along the embankment to prevent the seeding of noxious weeds and inhibit the establishment of woody shrubs that can interfere with the required sight distance (WSDOT, 1997; WSDOT, 2009b). Desirable species of vegetation includes indigenous grasses, also an approved material for both VFS and dispersion (WSDOT, 2008a; WSDOT, 2009b; Lucey, 2011). With many state DOTs required to trim their budgets due to a reduction in income generated from fuel taxes amid an economic recession and a shift toward more fuel efficient vehicles, it is necessary to develop more strategies to further reduce cost (Lucey, 2011). One way to achieve this goal is to maximizing the use of VFS and dispersion on highway embankments in areas that may already be vegetated as part of the roadside maintenance plan.

A change in the slope limit for VFS or dispersion requires a modification to the HRM, which defines how WSDOT meets some of its NPDES stormwater permit requirements, and any change to the HRM requires approval from the permitting authority, Washington State Department of Ecology (WSDOT, 2008a). In order for Ecology to approve modifications to the VFS design criteria, it is necessary to demonstrate steeper slopes can maintain sheet flow, a critical function of both VFS and dispersion. In an effort to evaluate the stability of a steeper slope limit, Ecology has recommended an inventory of existing vegetated embankment slopes and site characteristics be conducted in Eastern Washington to determine if a pattern can be observed that support sheet flow on steeper slopes. Since a current justification for the 15% slope is based on concerns that concentrated flow could cause erosion, it has been proposed that the effectiveness of an embankment to maintain sheet flow be characterized based on the presence or lack of erosion along the slope as well as any observations of runoff pooling or sediment buildup at the bottom or toe of the embankment (O'Brien, 2006).

CHAPTER 2: LITERATURE SEARCH

The literature search first focuses on understanding the history of the existing design guidance for VFS and justification for the 15% slope limit, described in Section 2.1. Then, Section 2.2 presents a summary of background research and indicates the starting place for this study. Next, research that supports VFS and dispersion slopes as steep at 33% will be considered in Section 2.3. The practices and research that support Stable Embankment Design will be reviewed in section 2.4. Finally, Section 2.5 provides an overview of the research objectives.

2.1 History of Design Guidance

First used for treatment of runoff from agricultural applications, VFS quickly evolved into BMPs for urban development (EPA, 2010). Since then multiple research documents have been pubished and used as the basis to define design requirements for VFS. For WSDOT applications, based on a review of correspondence between Ecology and WSDOT along with general literature review, it appears the original VFS design guidance was based on a biofiltration swale research project conducted for Ecology by the former Municipality of Metropolitan Seattle Water Pollution (MMS) now known as the King County Department of Natural Resources and Parks (Oldham, 2006). The MMS study was performed to determine pollutant removal effectiveness of swales with the goal of providing design guidance for both biofiltration swales and VFS (MMS, 1992). The only recommendations from the MMS study currently in the HRM is a 9 minute residence time, that is 9 minutes of stormwater contact time traveling through the length of the VFS to allow removal of TSS, and recommendations for a Manning's n value. The MMS study did not included any final recommendation for VFS maximum slope limits. However when WSDOT published the first HRM in 1995, the design guidance included a 15% slope limit and is still referenced as support for technical guidance including in the FHWA Fact Sheet for Filter Strips (FHWA, 2007).

The current 15% maximum slope limit in the 2008 HRM is the same limit used by other Northwest Governmental Agencies, with the justification that steep slopes could encourage concentrated flow (Ecology, 2005; ODOT, 2008; WSDOT, 2008a; King County, 2009). Despite a detailed literature search for the source of this limit, none were found, however some literature has indicated safety concerns as another possible justification. A 2002 swale study performed in Texas, monitored biofiltration swales located in the highway median for 4 years with the goal of recommending design guidance for VFSs and swales. In the final recommendation, embankment slopes used as part of a biofiltration swale were limited to 15% and the justification was safety (Barrett, 2005). The Federal Highway Adminstration (FHWA) also notes safety as the justification for a 25% slope limit when using embankments as part of roadside or median channel as defined in Hydraulic Engineering Circular (HEC) 22 (HEC 22. 2009). In both the Texas study and the HEC, the embankment functions the same as VFS and dispersion in that highway runoff sheet flows from the edge of pavement through vegetation.

The 15% to 25% embankment limit is within the range of slope limits allowed for WSDOT roadways and which is based on the maximum allowable recoverable slope for an errant vehicle. Generally, slopes 25% or flatter are considered recoverable depending on site factors such as speed, traffic volumes, and the roadside geometry (WSDOT, 2009b). Recoverable slopes are defined as a slope that a motorist may safely retain or regain control of a errant vehicle by slowing or stopping. Slopes between 25%-33%, are considered traversable but non- recoverable meaning the errant vehicle could continue to the toe of the embankment and further recover on a slope flatter than 25% at the bottom (FHWA, 2007). Slopes steeper than 33% may require some type of traffic barrier to safely redirect errant vehicles away from the embankment (WSDOT, 2009b). The Texas Roadway Design Manual has the same 10%-33% range of slope limits as WSDOT, however 15% is listed as preferred which may account for the Texas study recommending 15% for safety.

2.2 Background of Research

If the current VFS and dispersion slope limit was based on safety concerns and not BMP performance, it is possible that the limit could be modified to align with the highway roadside design standards. Previous research which may also support this modication was presented in a Natural Disperion study conducted in Washington by Washington State University (WSU) in 2004. The intent of the WSU study was to evaluate the relationship between site characteristics and the length of dispersion necessary to meet flow control (infiltration) requirements on highway embankment. The study recommended an equation that could predict Disperion length based on measureable site specific factors including the roadway width, saturated hydraulic conductivity, and rain fall intensity. Further recommendations were based on observations during the research and included; increasing the slope limit from 15% to 33% and testing the saturated hydraulic conductivity of an existing embankment using a direct measurement method such as the the Guelph Permameter (Yonge, 2005).

While Ecology did approve modification to the dispersion design criteria including use of the equation to predict dispersion length and direct measure of the K_{sat} with the Guelph Permeameter, increasing the slope limit was not part of those modifications. Instead, Ecology requested an detailed study of the effect of runoff on various embankment slopes, soil types, and rainfall intensity was warranted prior to approving an increase in the 15% slope limit (O'brien, 2006). This request is the starting place for the research described in this paper.

2.3 Current Similar Research

The body of research found on VFS, that supports slopes steeper than 15%, focuses on meeting the stormwater obiligations of the NPDES municipal stormwater permit for runoff treatment and/or flow control. One of the larger studies was conducted by CALTrans on Vegetative Buffers. The study had a similar approach and objectives to this research project, including devoloping an inventory of site characteristics from mulitple locations in the state to support modification to the design criteria. The study was conducted over two years at 23 sites and focused on the effectiveness of existing vegetated embankments designed following roadway standards. These results were compared to studies performed on sites designed as Vegetative Buffers and found similar runoff treatment performance between the vegetated embankments and Vegetative Buffers. In addition, a minimum 65% vegetation coverage was observed to prevent flows from channeling and causing erosion, however a decrease in pollutant removal (i.e., runoff treatment) was noted when vegetation coverage dropped below 80% (CALTRANS, 2003). These findings are similar to a Kansas VFS study that noted a decline in pollutant removal when vegetation coverage dropped below 70% (Ebihara, 2009).

The embankment slope did not appear to be a factor in the CALTrans study as sites with 33% and 50% slopes were as effective at runoff treatment as sites with flatter slopes. The CALTrans findings were combined with a similar study performed in Austin Texas on vegetated medians, and based on the two studies a 30% slope limit was recommended for Vegetated Buffer Strips. The Texas study indicated that while steeper slopes were effective at meeting runoff treatment goals, the 30% limit was to prevent concentrated flows that could lead to erosion (Barrett, 2005).

CALTrans and Texas had consistent findings to a study performed by Ohio University that investigated pollutant removal effectiveness from artificial highway runoff on a 4 foot by 14 foot prototype vegetated biofilter designed at 12.5%, 25%, and 45% slopes. The pollutants tested were typical of NPDES municipal stormwater requirements at WSDOT including; total and dissolved metals, TSS and oil and grease. The study found the vegetated biofilter had consistent runoff treatment performance at all three slopes for both medium and high concentrated flows, except oil removal for 45% slopes which was approximately 50% (Mitchell, 2011). A summary of the design criteria and research sites in the aforementioned studies is given in Table 1.2.

Table 1.2 Comparison of Literature Review Research and Design Criteria's

	HRM 1995	HRM 2008	MMS 1992	HEC 22	Barrett 2005	Young 2005	CALTrans 2003	Mitchell 2011
Slope Limit	15%	15%	None	25%	15%	33%	25%	45%
Slope Limit Justification	Sheet Flow	Sheet Flow	N/A	Safety	Safety	Research	Research	Research
Width Analysis	10'	9 min Res. Time	9 min Res. Time	NC	NC	Equation Developed	5 min Res. Time	NC
Vegetation Coverage	Dense	Dense	Dense	NC	80%	NC	80%	Dense
Erosion Observed	N/A	N/A	NC	N/A	NC	NC	Yes	NC

NC – No Comment N/A – Not Applicable.

2.4 Stable Embankment Design

Only studies performed by CalTrans and Texas included field observations and/or recommended preventative actions to reduce the occurrence of concentrated runoff, specifically using a minimum 65% vegetation cover and limiting the slope to 30% (TXDOT, 2009; WSDOT, 2003). A common stable embankment design practice uses vegetation cover and root systems to protect soils from erosion by; reducing the impact of raindrops, dissipating energy from highway runoff, and increasing the structural integrity of the soil via the root system (Forman, 2003; FAO, 1986; Lucey, 2011; OMAFRA, 2010). In addition to using vegetation to prevent flows from concentrating, some VFS and dispersion designs include a level spreader to disperse flows along the embankment and dissipate energy from highway runoff (Dillaha, 1986; Ecology, 2005; IDEQ, 2005; ODOT, 2008; King County, 2009; Winston, 2010; CALTrans, 2002). Level spreader designs vary, but a majority of the roadside designs consist of a gravel area between the highway pavement and vegetated area to slow runoff velocities and allow for the required contact time and pollutant removal effectiveness (King County, 2009).

While little research was found on the specific site factors that could contribute to concentrated flows on VFS and dispersion, extensive research has been performed on the cause and prevention of erosion. This study does not seek to prove what causes erosion, but rather consider how specific site characteristics, related to the design criteria for VFS and dispersion, could contribute to erosion specifically on slopes steeper than 15%. The purpose of this section is to consider erosion research and principles for stable slope design to assist in generating a list of site characteristics that can be used in evaluating and validating the final recommendations.

The current design and construction standards for highway embankments are based on research that focused on designing and constructing a stable slope (WSDOT, 2009b; WSDOT, 2010e; WSDOT, 2011). A primary concern with stable embankments is preventing erosion, which is essentially the wearing a way of soil particles or aggregates and can cause the collapse of the stream banks, pollute receiving waters, or compromise the structural integrity of the highway pavement due to slope instability (Carlton, 1991; Wynn, 2007). Studies have shown that erosion can be predicted when the shear stress from runoff exceeds the critical shear of the soil material. Where the critical shear stress of the soil is the stress at which soil detachment begins or the condition that initiates soil detachment and is a function of geotechnical properties and the site characteristics (Higgins, 1988; Conduto, 2001; Hilldale, 2001; Smith, 2005).

2.5 Research Objectives

Based on the literature reviewed, it appears the current 15% slope limit for VFS and dispersion may have been based on safety concerns and not BMP research specific with respect to specific site characteristics that could contribute contribute to concentrated flows. Considering recent studies have demonstrated slopes up to 33% can be effective in meeting the obligations of the NPDES municipal stormwater permit for sheet flow dependent BMPs, it is possible the embankment slope limit could be increased if the site characteristics that can maintain sheet flow are identified. In seeking to justify embankment slopes steeper than 15%, this study will:

1. Develop an inventory of measured and empirical site characteristics on embankment slopes steeper than 15% at multiple locations in Eastern Washington.
2. Determine a pattern of site characteristics that maintain sheet flow.
3. Perform a shear stress analysis to evaluate the significance of these site characteristic to support stable embankment designs.
4. If warranted, recommend a modifications to the design criteria that will justify embankment slopes steeper than 15% and possibly, when applicable, up to the 33% highway design limit for traversable slopes.

CHAPTER 3: RESEARCH METHODS

The methods used to evaluate the site characteristics that contribute to or prevent erosion had three parts: 1) developing an inventory of site characteristics, 2) a statistical analysis, and 3) a shear stress analysis. An inventory of site characteristics, both measured and observed, was created by collecting and analyzing field data from forty-five sites across Eastern Washington as described in Section 3.1. Once the inventory was completed, a statistical analysis was performed to evaluate which measured site characteristics have the strongest correlation to erosion severity as described in Section 3.2. Finally, the significance of both the statistical analysis results, as well as empirical observations, to support stable embankments, will be evaluated using a shear stress analysis. The Shear Stress Analysis is described in Section 3.3.

3.1 Inventory of Site Characteristics

Site Selection and Description

Site characteristics were collected at Forty-five sites across Eastern Washington during the summer of 2007. Site selection was based on evaluating embankment slopes steeper than 15%, both with and without the presence of erosion. Another consideration in site selection was to develop an inventory that included a range of site characteristics representative of those found in eastern Washington such as: mean annual precipitation (MAP), soil types, and vegetation coverage. Safety of the field crew was also a priority specifically ensuring available turn-off area to park a vehicle and accessible highway conditions; as such most of the sites evaluated were located at sites in rural areas that experience less traffic. Because of safety concerns, at a few sites, some site characteristics were not collected. The locations of test sites and their erosive classification are noted in Figure 3.1 Erosion classification is further described in Appendix B.

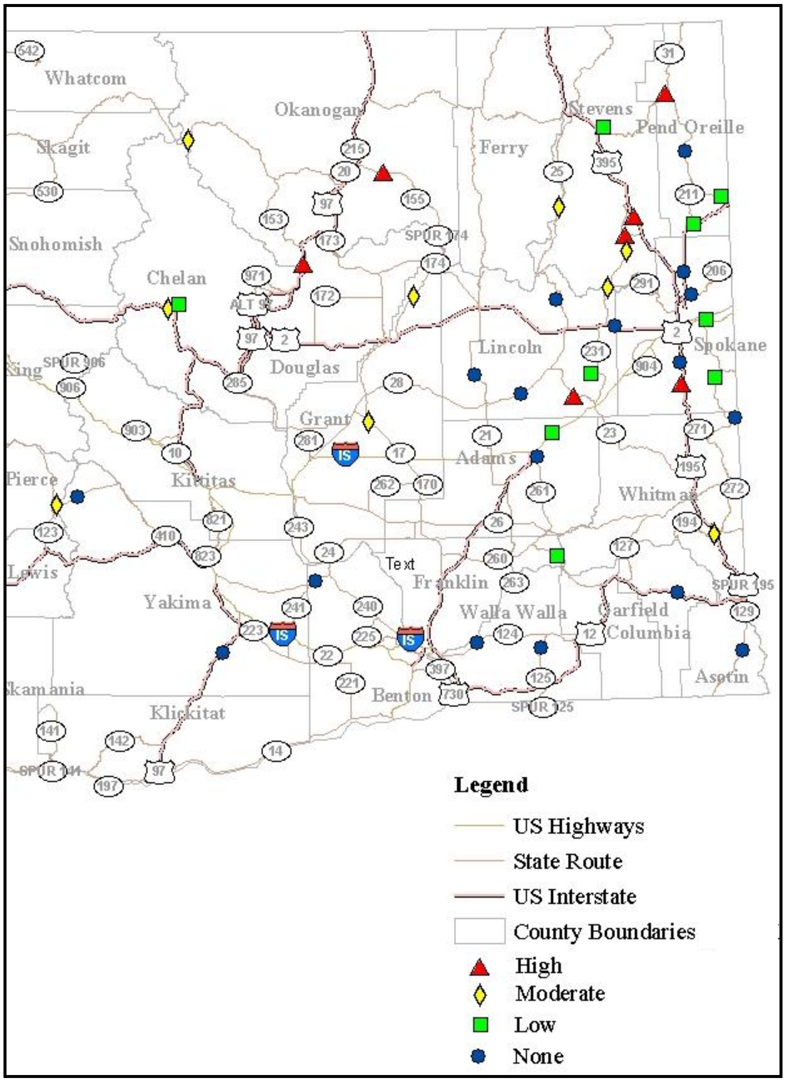

Figure 3.1 Location of Test Sites in eastern Washington

Given that the current design criteria for VFS and dispersion was first published in 1995 and revised as recently as 2006, most of the highway embankments in Washington were constructed prior to these more stringent requirements. Accordingly, the majority of sites inventoried represent existing vegetated embankments constructed in support of highway design standards and roadside maintenance practices. Since the current design limits and requirements for VFS and dispersion where exceeded or not required, these existing vegetative embankments represent applications that might support the proposed design modifications for steeper slopes.

Measure Site Characteristics

A list of the 14 measured site characteristics inventoried is summarized in Table 3.1, along with the representative nomenclature, definitions, and the range of values found over the forty-five sites evaluated. Figure 3.2 illustrates the typical location of these measured site characteristics and a complete inventory if the site characteristics for each site is located in Appendix A. Thirteen of the measured site characteristics represent most of the independent variables necessary to design VFS and dispersion BMPs and design a stable embankment as described below:

- <u>VFS</u> is designed to provide runoff treatment of highway runoff over the length of the embankment and is calculated assuming dense vegetation along the embankment using; width of pavement sloped toward the embankment, super elevation of the pavement, roadway grade, and precipitation depths.
- <u>Dispersion</u> is designed to provide both runoff treatment and flow control of highway runoff over the length of the embankment and is calculated assuming dense vegetation along the embankment using: width of pavement sloped toward the embankment, precipitation depths, and saturated hydraulic conductivity of the embankment soils.
- <u>Stable Embankment Design</u>, is described in detail in section 3.2, and generally includes verifying the critical shear stress of the embankment is greater than the shear stress applied from highway runoff. The site characteristics necessary to perform this analysis include; the width of pavement sloped toward the embankment, super elevation of the pavement, roadway grade, precipitation depths, the vegetation conditions along the embankment, and the embankment slope. Vegetation conditions

along the embankment were measured based on the approximate area of vegetation coverage as well as the distance from the edge of pavement (EOP) to the start of the consistent vegetation area. Geotechnical properties represent another essential variable necessary to determine the critical shear stress of the embankment and for this study were based on soil classification. However, since a numerical value is required to perform a statistical analysis, the soils at each site were broken down into three groups by mass percentage of: gravel, sand, and fines.

The fourteenth site characteristic measured was erosion which was classified into one of four categories at each site: none, low, moderate and high. Since erosion measures the effectiveness of an embankment to maintain sheet flow, this variable is considered a dependant to the other thirteen site characteristics. The actual methods followed to measure all the site characteristics are described in Appendix B.

Table 3.1 Summary of Inventory for Measured Site Characteristics

	Site Characteristics	Symbol	Definition	Tested Sites Ranges
Geometry	Width of Pavement (ft)	W_T	The horizontal width of pavement sloped toward the embankment.	12 - 56ft
	Roadway Grade (%)	G	The longitudinal incline of the pavement from the horizontal.	0.1% - 7%
	Super Elevation (%)	e	The lateral incline of the pavement from the horizontal.	0.5% - 9%
	Embankment Slope (%)	S_e	The incline of the embankment from the horizontal.	20% - 90%
Vegetation	Vegetation Coverage (%)	P_{VC}	The approximate area of vegetation coverage along the embankment.	0 -95%
	Distance from EOP to Vegetation (ft)	D_{EOP-V}	The distance from the edge of pavement (EOP) to the start of vegetation.	0 -20 ft
Erosion	Sites with Erosion	N/A	Erosion was classified as High, Moderate, or Low.	22
	Sites without Erosion	N/A	Sites without the observed presence of erosion were classified as None.	24
Precipitation	MAP (in)	N/A	Mean Annual Precipitation recorded for the site in inches.	7.4 - 63 in
	100 year 3 hour Precipitation (in)	$P_{100yr3hr}$	Precipitation depth for the short duration storm	1.1-1.45 in
Geotechnical Properties	Saturated Hydraulic Conductivity (in/hr)	K_{sat}	The saturated hydraulic conductivity measured for the embankment.	0.02 - 152[1] in/hr
	Percent Fines	N/A	The percentage of fines in the soil sample from the embankment.	3.9 - 84.8%
	Percent Sand	N/A	The percentage of sand in the soil sample from the embankment.	15.3 - 71.3%
	Percent Gravel	N/A	The percentage of gravel in the soil sample from the embankment.	0 - 75%

1. The saturated hydraulic conductivity (K_{sat}) measured at 152 in/hr represents a single test performed on well graded gravel soils and most likely an outlier since typical values for this soil classification are four times smaller (Lindeburg, 2006).

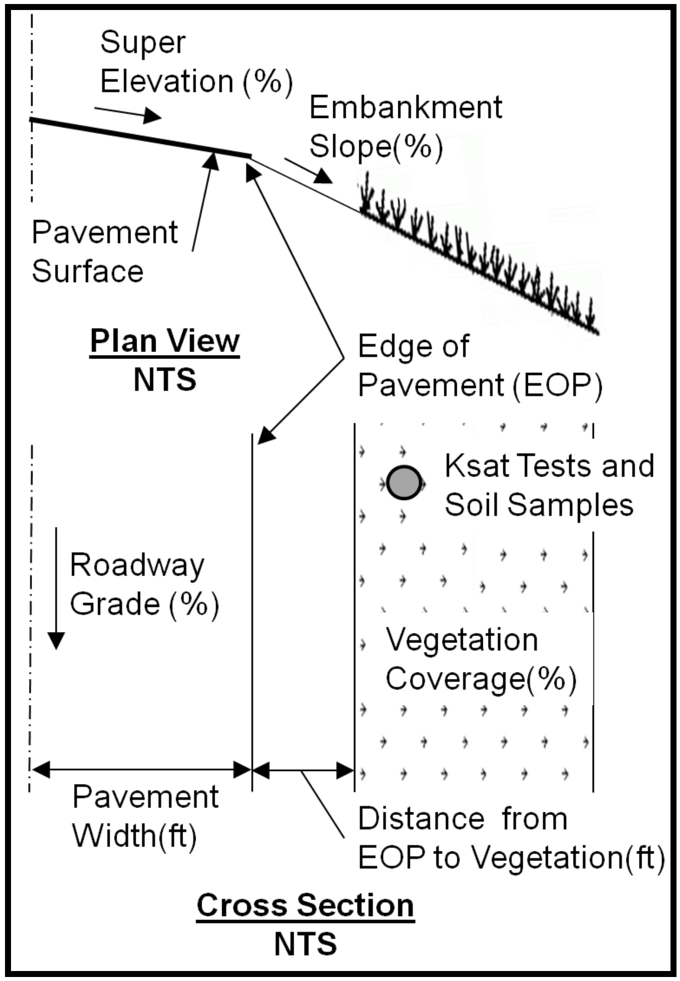

Figure 3.2 Locations of Measured Site Characteristics

Empirical Observations

Empirical observations represent visual observations documented and/or photographed at each site. The photographs have been included throughout this report to illustrate various site conditions. This section summarizes immeasurable site characteristics that visually appeared to encourage concentration of runoff and Appendix D contains a complete list organized by site.

- Pooling or Sediment Buildup – These observations were included in this study since the effectiveness of an embankment to maintain sheet flow was measured not only on evidence/absence of erosion but also on the presence of pooling or sediment buildup at the bottom or toe of the embankment. However, these conditions were not found to exist at any of the sites.

- Condition of the EOP - Cracks or other imperfections at the EOP that appeared to encourage runoff to concentrate and in some cases may be causing erosion were recorded. Figure 3.2 shows a crack at the EOP at site 195-21.3 LT (left) and imperfections at the EOP at site 155-70.8 RT (right). Conditions like these were noted at 5 of the 25 sites with erosion and only 2 of the sites without erosion.

Figure 3.2 Cracks at EOP at (left) and Imperfections at EOP (right)

- EOP and Embankment Interface – Evidence of flow channelizing in streamlets between the EOP and embankment interface is shown in Figure 3.3 at Sites 23-52.1RT (left) and 292-0.8-RT (right). These conditions were observed at 10 of the 25 sites with erosion and only 1 site without erosion.

Figure 3.3 EOP and Embankment Interface Channels

- Level Spreaders – A one foot gravel level spreader is required between the EOP and VFS and/or Engineered Disperse areas however, since these requirements are predate than most of the highways, none were present at the sites tested. However, one low erosion site and one no erosion site had features that appeared to function as a level spreaders including; a tapered EOP from multiple pavement overlays and rumble strips at the edge of shoulder. The multiple overlays along the EOP were not visible in photographs however; these conditions are similar to a rolled shoulder used on WSDOT highways as depicted in Figure 3.4. The rumble strips were located at site 2EB-304.7 RT as depicted in Figure 3.4.

Figure 3.4 Rumble Strips (left) and A Rolled Shoulder (right)

- Guard Rail – Site conditions that required guard rail to redirect an errant vehicle away from the embankment can also encourage highway runoff to erode the embankment (WSDOT, 2010b). This condition can occur when runoff flows behind the guardrail or along a curb installed in conjunction with the guardrail creating concentrated flows that can cause erosion as depicted in Figure 3.5 shown at site 20-389.1 RT (left) and 155-70.8 RT (right). Of the 45 sites tested, 9 had guard rail. Of those sites, only 4 showed evidence of erosion.


Figure 3.5 Erosion from Channelized Flow at Guard Rails

Embankment Age

Soil erosion represents a natural process that progresses over time and evaluation of the embankment age along with the erosion severity may indicate which site characteristics can accelerate the process (WSDOT, 2003; NRCS, 2010). However, accurate determination of each embankment age was not possible. While WSDOT documents highway construction work on Right of Way (ROW) and As Built plan sheets, database records may not reflect current conditions or clearly indicate embankment construction activities. In addition, standard maintenance practices may also affect embankment conditions however; records of specific locations and details of these practices typically only include work performed under an Emergency Declaration (Blegen, 2011).

Instead the age of three randomly selected sites without erosion was estimated using both the statewide and eastern region data base. Based on the information available, the age of these embankments appears to range from 1 to 10 years at the time of testing as indicated in Table 3.2. While this small sample size does not necessarily provide a confident statistical representation of the sites, it appears the no erosion embankments included in this study may represent both new and established conditions.

Table 3.2 Estimated Age of Embankments

Site Identification	Estimated Age
206-2.6 LT	+10
20-412.8 RT	+1
20-356.7 RT	+5

3.2 Statistical Analysis

Statistical correlations were performed on the site characteristics listed in Table 3.1 using Minitab® Software version 16. The results of the analysis will indicate which of the measured site characteristics most closely correlate with erosion severity using both a correlation coefficient and a p-value.

The Pearson Correlation Coefficient Method was used to measure the strength and direction of a linear relationship between erosion severity and a site characteristic. The correlation coefficient (also known as r) can range between -1 and 1. The closer a correlation coefficient is to -1 or 1, the stronger the linear relationship between a site characteristic and erosion severity. Conversely the closer a correlation coefficient is to 0 the weaker the relationship. A negative correlation coefficient indicates that as a site characteristic tends to increase, erosion severity tends to decreases. Conversely, a positive correlation coefficient indicates, when a site characteristic increases erosion severity has a tendency to increase as well.

A p-value was also calculated and indicates which site characteristic(s) is statistically most significant to erosion severity compared to other site characteristics. A p-value of 5% or alpha = 0.05 is used to determine the level of significance. Site characteristic with a p-value less than 0.05 is considered statistically significant and a p-value above 0.05 indicates no relationship between erosion severity and a site characteristic. Any p-values less than 0.01 is considered highly significant, with the smallest p-value identified as the most statistically significant site characteristic compared to other site characteristics (Utts, 2004).

3.3 Shear Stress Analysis

The purpose of the shear stress analysis is to evaluate the statistical significance as well as any empirical observations, to support sheet flow along the embankment at slopes steeper than 15%. This will be done by applying the principles to design a stable embankment at the 45 sites in an attempt to predict when erosion may occur given the site conditions. A stable embankment requires the critical shear stress be greater than the applied highway runoff to prevent erosion from occurring, where the critical shear stress is the stress at which soil detachment begins or the condition that initiates soil detachment and can lead to erosion (Wynn, 2007). The critical shear stress of the embankment is a function of the soil properties, vegetation coverage, and the embankment slope. To represent the slope of the embankment, a critical flow rate will be calculated, which is the flow rate at which erosion can begin. Embankments will be considered stable when the applied highway flow rate is less than the critical flow rate.

This type of analysis generally assumes uniform distribution of the applied highway runoff from the contributing pavement area, which may not accurately represent the presence of EOP imperfection or guardrail flow which can contribute to concentrate runoff. Instead, worst case highway geometry and embankment conditions will be considered in an attempt to predict erosion. The shear stress analysis and equations described in this section were performed assuming the embankment was a very wide channel and following the process outlined in The

Design of Roadside Channels with Flexible Linings (FHWA, 2005). A summary of the analysis is located in Appendix F for each site and was performed using the following steps:

1. Calculate the Applied Highway Runoff Flow Rate (Q_{AHR})
2. Determine the Critical Shear Stress of Bare Ground (τ_{CBG}) based on the soil classifications.
3. Using both soil classification and the vegetation coverage along the embankment, calculating the Critical Shear Stress for Existing Embankment Conditions (τ_{CEC}).
4. Determine the Critical Flow Rate on Bare Ground (Q_{CBG}) considering the embankment slope and the critical shear stress of the bare ground.
5. Determine the Critical Flow Rate on the Existing Embankment Conditions (Q_{CEC}) considering the embankment slope and the critical shear stress of the existing embankment conditions.
6. Assuming a VFS was designed for the embankment; determine the Critical Shear Stress (τ_{VFS}) and Critical Flow Rate for VFS (Q_{CVFS}).
7. Performing a Stability Check for bare ground conditions, existing vegetated embankment condition, and assuming a VFS was designed for the embankment.

Determine the Applied Highway Runoff Flow Rate (Q_{AHR})

The applied highway runoff flow rate represents the design flow rate from highway runoff and is a function of the basin area and precipitation for a project site. The basin area analysis is described in the paragraph that follows. The flow rate was determined by performing a hydrologic analysis using the program StormShed 3G to generate a single event hydrograph using the Santa Barbara Urban Hydrograph (SBUH) method and was selected since it is the required method used to design most eastern Washington BMPs including VFS (WSDOT, 2008a). Since the contributing basin area and the precipitation varies depending on location, a hydrograph was generated at each test site to compute the flow rate of highway runoff using the 100 year 3 hour duration storms, and the results are summarized in Appendix B.

Calculate the Basin Area

The contributing basin area is used to estimate the flow rate of runoff and was calculated based on the width and length of the contributing pavement area using equation 3.1.

$$A = L_{CFP} x 1(ft) \qquad \textit{Eqn 3.1}$$

Runoff generally travels perpendicular to the contours from the crown or high point of the road to the EOP and down the embankment. Since the pavement surface and the embankment run parallel, it was assumed that 1-foot of highway runoff will travel over 1-foot of embankment area. The contributing area was computed on a per foot basis to represent this length (WSDOT, 2008a; CALTRANS, 2003). The width of the basin area was calculated based on the longest contributing flow path, which for sites with flatter roadway grades is about the same as the pavement width. However for sites with steeper grades, runoff travels more at a diagonal along the pavement as shown in Figure 3.6. The term *contributing flow length* is a hypothetical representation of the longest straight distance runoff could travel along the pavement. However, this is difficult to determine accurately from this research. For example, for the flow path to be straight, the highway geometry would have to remain a consistent along the flow path. However, field data was collected at a single location along the highway and the highway geometry beyond that is unknown. In addition, the super elevation in this research represents the weighted average of the shoulder and travel lanes and if the two differ, the actual flow path would not be straight as shown in Figure 3.6. Finally, as runoff sheet flows across the pavement the roughened surface of the pavement could cause runoff to be redirected and spread. For the shear stress analysis the longest hypothetical contributing flow path is an dependant variable based on independent highway geometry variables and is calculated using equation 3.2.

$$L_{CFP}\ (ft) = \frac{W}{\sin\left(\arctan\left(\frac{e}{G}\right)\right)} \qquad \textit{Eqn 3.2}$$

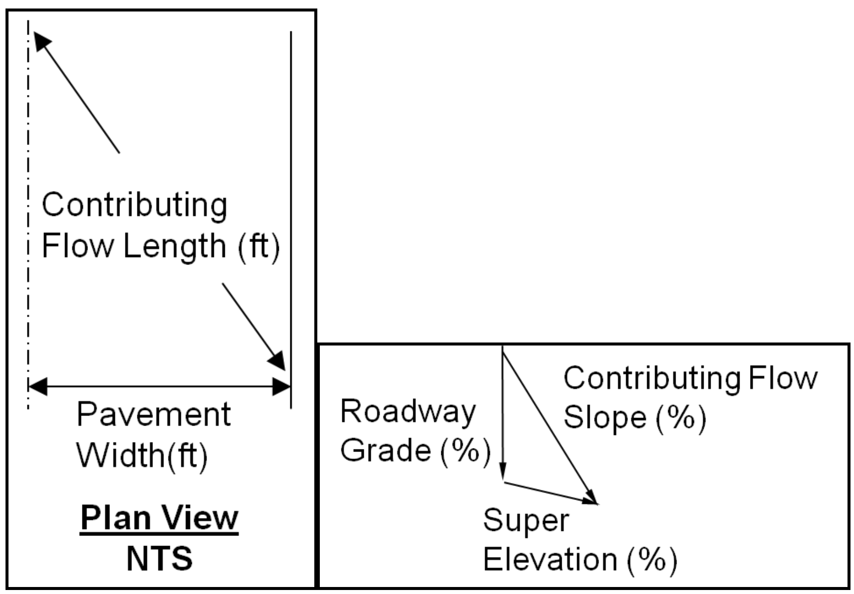

Figure 3.6 Contributing Flow Length and Slope

The slope of the contributing flow line is a measure of the pavement incline from the horizontal assumed to be straight as shown in Figure 3.15. This is also considered hypothetical for the same reason as described for the contributing flow path. The slope is calculated based on the super elevation and the roadway grade using equation 3.3 and also used to determine the flow rate.

$$S_{CFS} = (G^2 + e^2)^{0.5} \qquad \textit{Eqn 3.3}$$

Determine the Critical Shear Stress of Bare Ground (τ_{CBG})

The critical shear stress of bare soil represents the maximum shear stress that the embankment soils can accept before erosion occurs (FHWA, 2005). The critical shear stress or erodibility is a function of the particle size, cohesive strength, and soil density. For non-cohesive soils, such as gravelly or sandy soils, the erodibility is a function primarily of the particle size. For cohesive soils, such as fine grained silts and clays, the erodibility is generally a function of the cohesive strength and soil density. Accurately predicting the critical shear stress on an embankment requires knowledge of specific soil properties. As noted in Appendix B, only the distribution of soil size was collected. Furthermore, because of limited data, assumptions were made about the cohesive strength of fine grain properties to select a representative value for critical shear stress. The values shown in Table 3.3 are based on recommendation from HEC 15 and assume low compressibility for fine grain soils (as assumed in the soil classifications section (FHWA, 2005).

Table 3.3 Critical Shear Stress of Bare Ground (τ_{CBG})

Soil Description	**Soil Classification**	**Critical Shear Stress (lb/sqft)**
Well Graded Sand	SW	0.020
Silty Sands	SM	0.072
Inorganics Silts	ML	0.083
Clayey Silts	ML-CL	0.089
Sandy Clays	CL	0.095
Fine Gravel	GM	0.120
Gravel	GW	0.240

Calculate the Critical Shear Stress for Existing Embankment Conditions (τ_{CEC})

The critical shear for vegetated areas along the embankment is a function of both the shear stress of the bare ground, as well as the vegetated conditions. Vegetation can serve as an energy dissipater, slowly highway runoff velocities and increasing the critical shear stress of the embankment (calculated using Equation 3.4) (FHWA, 2005; Library Index, 2011).

$$\tau_{CEC} = \frac{\tau_{CBG}}{(1-C_{FG})}\left(\frac{n_c}{n_{bg}}\right)^2 \qquad \textit{Eqn 3.4}$$

The Mannings coefficients used in Equation 3.4 are summarized in Table 3.4. The bare ground coefficient (n_{BG}) was selected based highest percent of soil content (fines, sand, or gravel). Then a composite coefficient was calculated to represent the vegetation coverage on the embankment considering the percentage of bare ground and the percentage of vegetation coverage as shown in equation 3.5 (Sturm, 2010). The vegetation on most embankments was native grasses and weeds and is represented by coefficient for short prairie grasses.

Table 3.4 Mannings n Coefficients

Ground Cover	**Mannings n**
Pavement	0.011
Bare Ground	
Fines	0.016
Sand	0.02
Gravel	0.025
Short Prairie Grass	0.15
Composite for embankments with both bare ground and vegetation coverage	Varies Between 0.016-0.15
Dense Vegetation	0.20

Source: (WSDOT, 2008a)

$$n_c = \left(P_V\left(n_v - n_{bg}\right)^{1.5} + (1 - P_V)n_{bg}{}^{1.5}\right)^{0.67} \qquad \textbf{\textit{Eqn 3.5}}$$

Determine the Critical Flow Rate on the Embankment (Q_{CBG}, Q_{CEC}, Q_{CVFS})

The critical flow rate on the embankment represents the maximum applied highway runoff flow rate the embankment can accept without eroding and is a function of the critical shear stress calculated from Table 3.3 and equation 3.4 and is proportional to the slope of the embankment as shown in Equation 3.6. To consider the affect of the embankment slopes, which ranged from 20-90%, a relationship relating the critical shear stress from Equation 3.6 to the embankment slope was developed using Manning's Equation shown as Equation 3.7. The resulting Equation 3.8 was used to determine the critical flow rate for a 1-foot wide area (based on the basin area analysis). The critical flow rate was calculated for bare ground conditions to represent the sites that had a distance from the EOP to vegetation and then with consideration for the vegetation along the embankment. The process was repeated assuming the embankment was designed as a VFS, using the Manning's coefficient for dense vegetation noted in Table 3.4.

$$\tau = \gamma d S_e \qquad \textbf{\textit{Eqn 3.6}}$$

$$Q = \frac{1.49\sqrt{S_e}(d)^{1.67}}{n_c} \qquad \textbf{\textit{Eqn 3.7}}$$

$$Q_{CEC} = \frac{1.49\sqrt{S_e}}{n_c}\left(\frac{\tau_{CEC}}{\gamma S_e}\right)^{1.67} \qquad \textbf{\textit{Eqn 3.8}}$$

Stability Check

The stability of the embankment can be predicted by comparing the Applied Highway Flow Rate to the applicable Critical Flow Rate for the Embankment. When the applied flow rate is greater than the critical flow rate, the embankment is considered unstable indicating that the applied flow rate could initiate the motion of soil particles and cause erosion. The stability check was completed three times, first considering the critical flow rate of the bare soil only, second considering the critical flow rate of the vegetated area on the embankment, and third assuming the embankment was designed as a VFS using the HRM design guidelines. In each case if the design flow rate was greater than the critical flow rate, the embankment was noted as 'Fail' to indicate a possible unstable condition from erosion. The stability criterion is summarized as follows:

If $Q_{AHR} > Q_{CBG}$, *embankment could fail in the bare ground areas*

If $Q_{AHR} > Q_{CEC}$, *embankment could fail in existing vegetated areas*

If $Q_{AHR} > Q_{CVFS}$, *embankment could fail designed as a VFS using dense vegetation*

CHAPTER 4: RESULTS AND DISCUSSION

This section provides a summary of the results and discussion for the; Statistical Analysis in Section 4.1, Empirical Observations in Section 4.2, and the Shear Analysis in Section 4.3. Finally, verification of the results of this study will be evaluated by applying the observations to embankment slopes less than 40% to determine if erosion can be predicted and is described in Section 4.4.

4.1 Statistical Analysis Results and Discussion

The primary objective of this study was to evaluate the specific site characteristics that contribute to erosion with the objective of developing modified design criteria for VFS and dispersion that supports stable slopes steeper than 15% and possibly, when applicable, up to the 33% highway design limit. In support of this objective a statistical analysis was performed to determine which of the 13 independant site characteristics, summerized in Table 3.1, had the strongest correlation to the dependant variable erosion severity. The results of the statistical analysis are summarized in Table 4.1, with the correlation coefficient (r) on top and the p-value on the bottom. A discussion of results for the embankment slope, along with the site characteristics that had a strong correlation to erosion severity, has been included in this section along with box plots and tables of the basic statistics. The box plots provide a visual representation of the spread of data by erosion classification and are further described in Appendix G. Other site characteristics that were not considered statistically significant are also summarized in Appendix G.

Table 4.1 Summary of Statistical Analysis

	Erosion Severity	**W_T (ft)**	**e (%)**	**G (%)**	**S_e (%)**	**P_{VC} (%)**	**$D_{EOP\text{-}V}$ (ft)**	**MAP (in)**	**$P_{100\ yr3hr}$ (in)**	**Fines (%)**	**Gravel (%)**	**Sand (%)**
W_T (ft)	0.012 0.940											
e (%)	0.064 0.676	0.540 0.000										
G (%)	0.258 0.088	-0.025 0.869	-0.024 0.877									
S_e (%)	0.207 0.172	-0.320 0.032	-0.103 0.499	0.194 0.201								
P_{VC} (%)	-0.559 0.000	-0.001 0.997	-0.111 0.469	-0.182 0.231	-0.263 0.081							
$D_{EOP\text{-}V}$ (ft)	0.189 0.215	-0.031 0.839	-0.080 0.602	-0.088 0.567	-0.069 0.651	-0.343 0.021						
MAP (in)	0.053 0.728	0.294 0.050	0.422 0.004	0.035 0.822	0.110 0.473	-0.140 0.358	-0.235 0.120					
$P_{100yr3hr}$ (in)	0.213 0.160	0.220 0.147	0.374 0.011	0.138 0.364	0.105 0.492	-0.505 0.000	-0.001 0.996	0.652 0.000				
Fines (%)	-0.205 0.181	-0.089 0.567	-0.225 0.143	-0.286 0.060	-0.136 0.379	0.641 0.000	-0.086 0.577	-0.260 0.088	-0.568 0.000			
Gravel (%)	-0.063 0.682	0.068 0.662	0.161 0.297	0.042 0.789	-0.063 0.682	-0.301 0.047	0.032 0.835	0.062 0.689	0.214 0.164	-0.722 0.000		
Sand (%)	0.363 0.015	0.057 0.712	0.156 0.311	0.370 0.013	0.263 0.085	-0.612 0.000	0.091 0.557	0.311 0.040	0.598 0.000	-0.689 0.000	-0.003 0.984	
K_{sat} (in/hr)	0.122 0.470	-0.178 0.292	-0.167 0.324	-0.141 0.404	0.056 0.741	-0.469 0.003	0.250 0.136	0.031 0.854	0.225 0.180	-0.434 0.007	0.504 0.001	0.200 0.236

Embankment Slope

The results for the embankment slope will be evaluated first since this site characteristic is the measure of the effectiveness of an embankment to maintain sheet flow based on the presence or lack of erosion along the slope. As shown in Table 4.1 the embankment slope has a correlation coefficient of 0.207 (where an r = -1 or 1 is the most linear) indicating a weak positive relationship to erosion severity. As the embankment slope increases, there is a tendency for erosion severity to increase (see Figure 4.1). However, the embankment slope had the fifth largest correlation coefficient and a p-value of 0.172 indicates that the relationship between embankment slope and erosion severity is not statistically significant (p-value > 0.05) compared to other site characteristics. While sites with no erosion overall had lower embankment slopes, the range of data (noted in Table 4.2) at these sites with no erosion ranged from 20% to an outlier at 90%, which is similar to the 30%-80% range for sites with high erosion. This range of embankment slopes suggests slopes steeper than the current 15% design limit can support sheet flow and embankment slope alone is not an indicator of erosion severity. Considering reference lines drawn on Figure 4.1, at the desired slope limit range for VFS and dispersion of 25% (recoverable slopes) and 33% (traversable slopes), it is apparent the majority of sites without erosion were located at sites with slopes steeper than 25%. As shown in Table 4.2, on average the embankment slopes were nearly 40% at these sites, which is steeper than the preferred 33% limit. These observations are consistent with other studies, that concluded embankment slopes 30% and steeper could successfully meet runoff treatment and flow control requirements (Yonge, 2005; CALTrans, 2003; Barrett, 2005).

Table 4.2 Basic Statistics for Embankment Slopes

Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	0	39.8	18.2	20	90	20.0	25	35	45.0
Low	9	0	51.7	19.0	30	90	27.5	35	45	63.5
Moderate	9	0	45.0	18.0	25	75	32.5	30	40	63.5
High	7	0	50.7	19.9	30	80	35.0	30	50	65.0

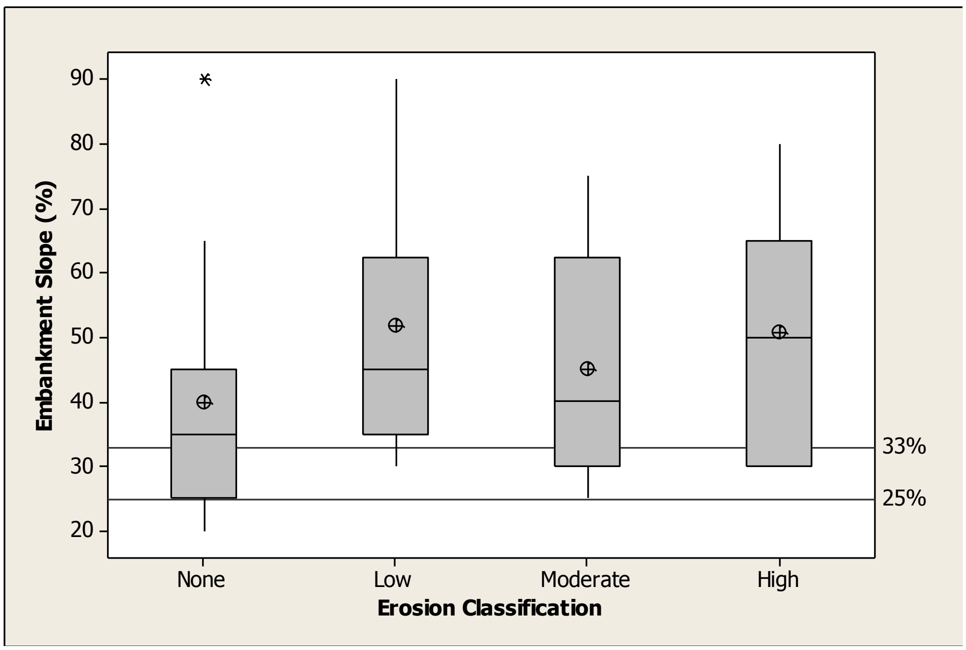

Figure 4.1 Embankment Slope sorted by Erosion Severity Classification

Vegetation coverage had the strongest correlation coefficient of r =-0.559 which indicates a moderately strong negative relationship to erosion severity meaning as vegetation coverage decreases erosion severity has a tendency to increase (see Figure 4.2). The p-value was 0 indicating the percentage of vegetation was highly significant (p-value < 0.01) compared to other site characteristics. Standard practices to stabilized soils and prevent erosion typically includes vegetation, which further supports to the statistical relationship noted between vegetation coverage and erosion severity (TXDOT, 2009; WSDOT, 2003). Table 4.3 shows that all the sites with no erosion had a minimum of 20% vegetative cover, and an average of 66.75%, which is consistent with the 65% minimum value recommended by the CALTrans study to prevent flows from channelizing (CALTrans, 2003).

Table 4.3 Basic Statistics for Percent Vegetation Coverage

Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	0	66.8	21.8	20	95	33.8	50.0	70	83.8
Low	9	0	55.6	39.4	0	90	80.0	10.0	70	90.0
Moderate	9	0	21.1	21.0	0	60	35.0	2.5	10	37.5
High	7	0	25.7	28.2	0	70	60.0	0.0	20	60.0

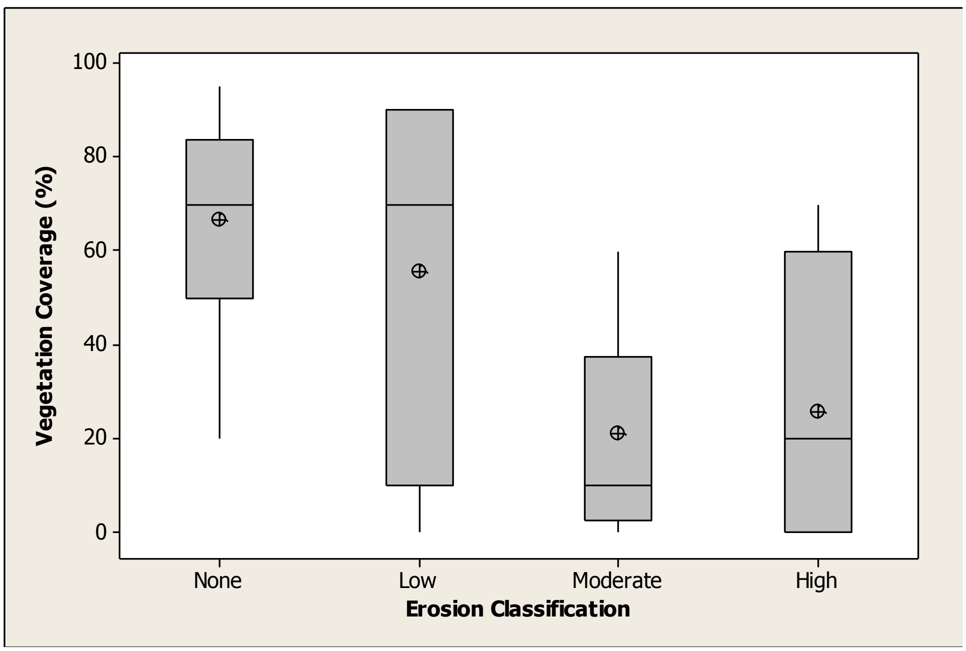

Figure 4.2 Percent Vegetation Coverage by Erosion Severity Classification

The percentage of sand composition in the embankment soils had the second strongest correlation coefficient at 0.363 indicating a moderately low positive relationship to erosion severity. In other word, as the percentage of sand increases, erosion severity also has a tendency to increase (see Figure 4.3). This relationship can also be observed in Table 4.3 where the mean percentage of sand is lower at the sites with no or low erosion compared to sites with moderate to high erosion. The p-value for percentage sand was 0.015 indicating there was a strong significance (p-value < 0.05) compared to other site factors.

Table 4.4 Basic Statistics for Percent Sand

Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	1	35.6	14.6	18.6	66.0	15.1	25.7	32.2	40.8
Low	9	0	37.9	18.7	17.9	67.4	31.9	22.5	25.5	54.4
Moderate	9	0	53.0	18.0	15.3	71.3	26.5	42.4	57.1	68.9
High	7	0	49.8	16.5	20.8	67.5	29.9	36.4	52.1	66.2

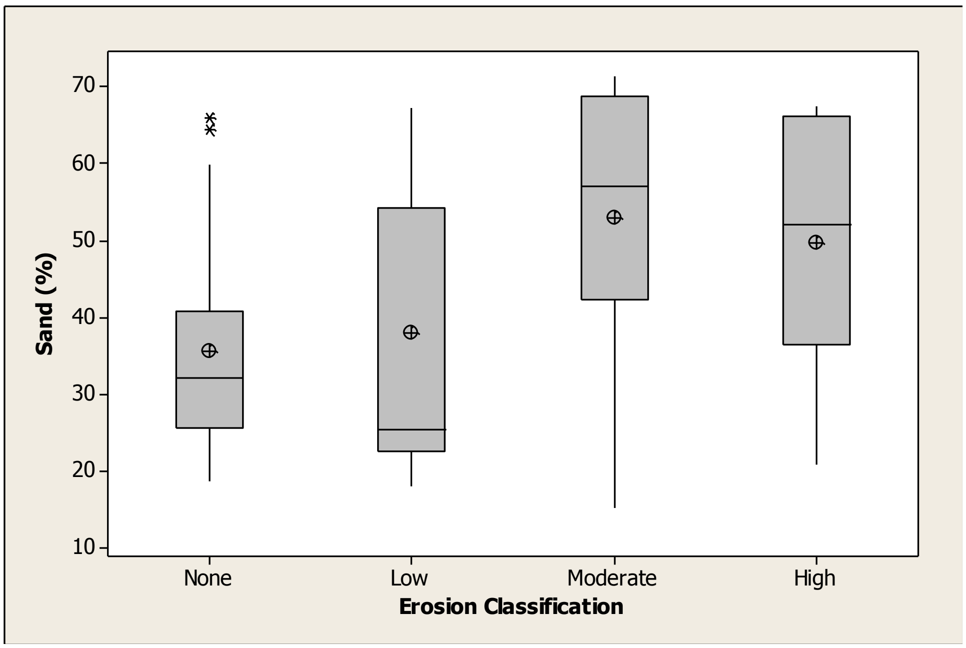

Figure 4.3 Percent Sand by Erosion Severity Classification

Considering erosion severity has a positive correlation to sand content compared to the negative correlation with vegetation coverage, suggests an obvious correlation between high sand content and low vegetation coverage which is shown in statistical analysis results in Table 4.1. This relationship is consistent with standard practices to establish and sustain vegetation which generally require top soils characteristics with a balance of organic matter, microorganisms, and water absorption capabilities (WSDOT, 2003). Since sand is a coarse grain soil material that is primarily composed of small rock fragments, alone sand generally does not have the characteristics necessary to support desirable vegetation growth. However these components can provide an ideal environment for some noxious weeds which can result in costly maintenance practices (WSDOT, 1997). Considering the benefit to the structural integrity of the road, many embankments are frequently constructed with coarse grain soils and, in response, practices have been developed to enhance vegetation growth and establishment for these soil conditions including integrating amendments into the soil composition along the top layers of the embankment. Soil amendments are accepted practices at WSDOT and used to meet stormwater requirements and support roadside maintenance practices (WSDOT, 2008b; WSDOT, 1997).

4.2 Empirical Observations

The most significant empirical observation noted was channelized flow in streamlets between the EOP and embankment interface which was documented at 10 of the 25 sites with erosion and only one site without erosion. This may indicate that the conditions at the interface location between the EOP and the embankment could be contributing to erosion by encouraging highway runoff to concentrate. Although observed less frequently, other site characteristics which may also encourage runoff to concentrate included guardrail and cracks or imperfections at the EOP. The worst case observed, site 155.70.8 RT, appeared to be caused by a combination of these site characteristics where the highest erosion severity was documented. As shown in Figure 4.16, at Site 155-70.8 RT, it appears flows concentrated along the guard rail curbing, travel in the channel along the EOP interface, to imperfection in the EOP where the embankment eroded.

Figure 4.4 Evidence of Concentrated Flows: along Guard Rail, in Streamlets at EOP Interface, and from Imperfections at EOP

While this research project did not exam how the streamlets were formed, the soil classification at sites where channels at the EOP interface were observed were mostly sandy soils (SW or SM) with a few gravelly soils (GW or GM) sites. This is also consistent with the correlation of erosion severity to a high percentage of sand. Beyond this observation, it is difficult to predict when channels at the EOP can form or an imperfections in the pavement may develop that could contribute to erosion. However, a level spreader installed at the EOP may have prevented flows from concentrating regardless of the EOP conditions. Research studies evaluated the long-term effectiveness of VFS and noted that a level spreader can enhance the performance by preventing concentrated flow (Dillaha, 1986; Winston, 2010). Level spreaders, generally constructed of 1-foot of gravel, can to be installed at the EOP to uniformly distribute the flow along the width of vegetation and prevent highway runoff from concentrating. New VFS and Engineered Dispersion BMPs at WSDOT and well as other agencies require a level spreader at the EOP (Ecology, 2004; Ecology, 2005; IDEQ, 2005; ODOT, 2008; WSDOT, 2008a; King County, 2009). As previously mentioned, the requirement for level spreaders is more recent than the age of most of the highway tested, and none of the sites tested had a gravel level spreader designed per the current HRM guidelines.

However, 2 of the 45 sites had features that appeared to act as level spreaders and distributed flows. One was located at a site 207-2.6 LT and had a roughed, tapered EOP from multiple pavement overlays and the other was located at site 2EB-304.7-RT and rumble strips at the edge of shoulder. The observation that these site feature may be acting as level spreaders was based on the site characteristics of each site. At site 207-2.6 LT, the embankment was sloped 90%, had a high percentage of sand, and no vegetation. As previously noted in the statistical analysis sites with no vegetation and a high percentage of sand most closely correlated with sites that had erosion. While the site was classified as low erosion, the flows appeared to be distributed and as evident by the sheet flow erosion observed. Site 207-2.6 LT had no evidence of erosion and had an embankment slope of 20%, 70% vegetation located just 2 feet from the EOP. The only site factor that correlated with erosion was the soils had a high percentage of sand (60%). 70% vegetation is the highest coverage noted for sites with greater than 41% sand and may indicate the rumble strip distributed the flow which contributed to establishing and maintaining vegetation coverage.

4.3 Shear Stress Analysis Results

As previously noted in section 3.2, the purpose of the shear stress analysis was to evaluate the importance of the statistical analysis results as well as any empirical observations, to support sheet flow along the embankment at slopes steeper than 15%. This was done by applying the concepts presented in Section 3.2 at each of the forty-five sites including a stability check to assess the conditions where erosion could be predicted.

Evaluate Statistical Analysis, Embankment Slope, and Empirical Observations

The critical shear stress of an embankment is a function of the soil properties, vegetation coverage, and slope. The two site characteristics that had the strongest correlation to erosion severity also play a significant role in this analysis. Sandy soils are the smallest non-cohesive soil and since the critical shear stress is based primarily on size for coarse grain soils, sands have lowest critical shear stress of all the soil properties present at the sites tested as shown in Table 3.5 (FHWA, 2005). Since the critical shear stress is lower, sites with sandy soils can fail at lower highway runoff flow rates compared to other soil types. The critical shear stress can be increased when vegetated is present along the embankment by dissipating the energy from highway runoff (FHWA, 2005). The use of vegetation to stabilize soils is common practice since the root system acts as soil stabilizer providing erosion control and slope stability. In addition root systems can increase infiltration by providing a channel for water to penetrate especially native grasses that have deeper root system allowing water penetration more efficiently and reduce highway runoff volumes (DNREC; Harper-Lore, Winter 1998; Lewisky, Spring 2002; Lucey, 2011).

Since embankment slope is proportional to the shear stress applied to the embankment, as the slope increases the critical shear stress will decrease under the same site conditions. The embankment slope only had a weak positive relationship to erosion severity; indicating slope alone is not the most significant site characteristic that contributes to erosion severity. Other site characteristics that may affect embankment stability were described in the empirical observations. Specifically, conditions at the EOP that cannot be measured or even predicted, can create longer contributing flow paths and/or encourage highway runoff to concentrate, which increases the applied shear stress along the embankment. These EOP conditions can cause an embankment to erode that might otherwise have been stable.

Stability Check

As previously mentioned, predicting embankment erosion is only as good as the analysis' assumptions and one cannot predict EOP conditions that could lead to channelized flow as shown in Section 4.2. However assuming the worst case highway geometry using the hypothetical contributing flow path, the sites tested were evaluated by comparing the critical flow rate the embankment could tolerate to the applied highway runoff flow rate. Considering slope is proportional to the shear stress, the slope of the embankments was represented in the analysis by deriving a relationship to flow rate using the critical shear stress. Sites were predicted to fail when the applied highway runoff flow rate was greater than the critical flow rate the embankment could tolerate.

Using the stability check described in Section 3.7, erosion was predicted on bared ground conditions at 52% of the sites that had erosion and 20% of the sites where erosion did not occur. The bare ground condition was considered first to represent distance from the EOP to vegetation coverage which on average is 3.2 feet for sites with no erosion compared to 7 feet for sites with erosion. This bare ground condition provides an area for possible erosion before the start of consistent vegetation coverage.

Next, the critical shear flow rate was recalculated with consideration of the percentage of vegetation along the embankment. The stability check was repeated and erosion was only predicted at 24% of the sites with erosion and none of the sites without erosion. The second stability check demonstrates how vegetation can stabilize the embankment, however with partial vegetation coverage flows can still channelize and travel around vegetation. The analysis was again repeated assuming each site was designed as a VFS following the HRM design criteria with an effective level spreader and dense vegetation coverage and a Manning's coefficient of 0.2. Using the stability check, none of the sites failed, indicating that if vegetation can be established and sheet flow can be maintained, the range of embankment slopes represented in this study may all have been stable. The results of the stability check are summarized in Table 4.14 and a complete list is located in Appendix H.

Table 4.5 Number of Sites Predicted Unstable

Erosion Classification	**Bare Ground**	**Vegetated Condition**	**VFS Design**
High	6/7	3/7	0/7
Moderate	5/9	1/9	0/9
Low	2/9	2/9	0/9
None	4/20	0/20	0/20

Some of the erosion sites that were predicted stable also had a condition at the EOP or guard rail present that may have caused flows to concentrate beyond what the model predicted. This occurred at 3 of the sites using bare ground conditions and 9 of the sites using vegetated conditions. This may indicate these types of EOP conditions are contributing to erosion on embankment slopes that would otherwise have been stable.

A comparison of the critical flow rate based on shear stresses is shown in Figure 4.17 at the high erosion sites. Since the range of critical flow rates was so large, the graph is shown at a reverse logarithmic scale so all values could be visible. The black bar represents the applied flow rate along the embankment and, with the exception of site 195-76.6 LT, all of the sites are predicted to fail since the critical flow rates are lower for both bare ground (gray bar) and existing vegetated embankment conditions (white bar). The one site that was not predicted to fail was at site 195-76.6 LT which has clayey soils and a higher critical flow rate based on the cohesive soil properties. At this site there was no obvious site factor affecting the stability of the embankment. Next, the VFS condition was assessed to determine if a densely vegetated embankment prevent erosion. As shown, the critical flow rate for VFS condition is higher than the applied flow rate for all sites indicating if these sites. This indicates that if these sites were constructed as VFS, all would have had a critical flow rate high enough to prevent erosion along the embankment.

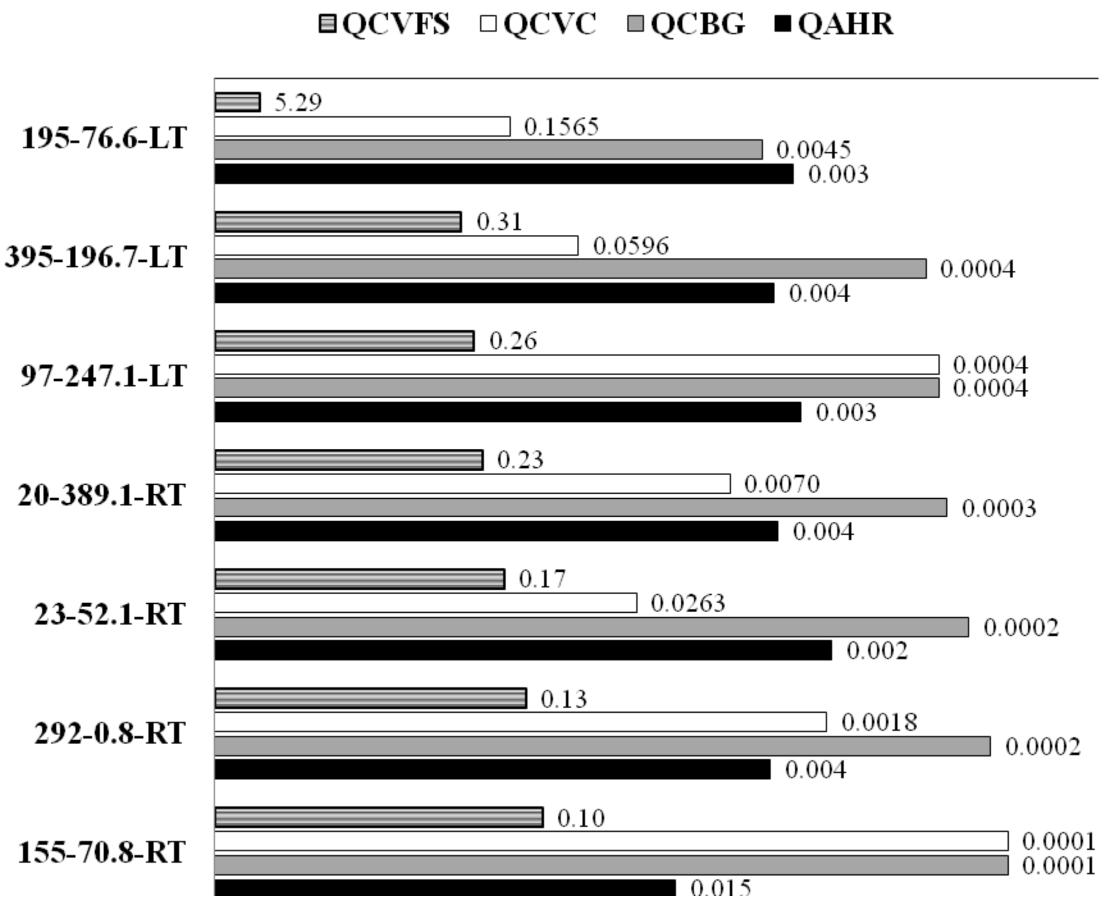

Figure 4.5 High Erosion Sites Comparison of Critical Flow Rates (cfs)
(Shown on a Reverse Logarithmic Scale)

4.5 Lower Slope (<40%) Stability

Based on the findings presented in this report, it appears highway runoff can concentrate and cause erosion given the following conditions: low vegetation coverage, high sand content, when certain EOP conditions exist or guard rail may be present, and in some cases without the presence of an effective level spreader. Using these factors, all embankment slopes less than 40% were evaluated and at sites where erosion was present, one of the following was noted:

- More than 50% sand in the embankment soils.
- Less than 65% vegetation coverage along the embankment.
- A distance of 8 or more feet from the EOP to vegetation.
- EOP conditions and/or guardrail that could contribute to concentrated runoff.

A 40% embankment slope was selected to provide a factor of safety above the preferred 33% slope limit for VFS and dispersion designs. The 65% vegetation limit was based recommendation from the CALTrans study that 65% vegetation coverage was necessary to prevent highway runoff flows from channelizing (CALTrans, 2003). The 8-foot limit for the distance from the EOP to vegetation was selected since this represents the longest observed distance at stable sites with slope <40% (see Appendix I). However, any distance from EOP to vegetation where bare ground is presents, represents an area where erosion could occur prior to the start of vegetation due to the lower critical shear stress. A complete list of all sites with embankment slopes <40% is located in Appendix I and a summary of the sites with erosion is located in Table 4.6.

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Table 4.6 Summary of Erosion Sites with Embankment Slopes < 40%

Site Identification	Guardrail/EOP Conditions	P_V (%)	D_{EOP-V} (ft)	Fines (%)	Gravel (%)	Sand (%)	Soil Classification
195-21.3-LT	Y	60	12	84.8	0.0	15.3	ML-CL
231-57.6-LT	Y	35	6	8.4	34.5	57.1	SW
20-356.7-RT	N	20	7	11.4	37	51.7	SM
395-196.7-LT	N	70	8	7.3	26.5	66.2	SW
195-76.6-LT	N	20	5	79.2	0.0	20.8	CL
97-247.1-LT	N	0	N/A	4.4	44.0	51.6	SW
155-14.4-RT	Y	0	N/A	4.6	52.0	43.4	GW
90WB-229.3-LT	Y	90	8	69.4	9.0	21.6	ML-CL
90WB-291.0-LT	N	70	15	17.4	57.5	25.2	GM
20-163-LT	Y	40	0	7.3	21.5	71.3	SW
2-82.8-LT	Y	30	2	18.2	21.0	60.9	SM
17-66.7-RT	N	0	N/A	7.6	42.5	50.0	SW

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Highway embankments provide an ideal location for integrating low impact development (LID) stormwater best management practices (BMPs) into a highway setting, specifically sheet flow BMPs such as vegetated filter strips (VFS) and dispersion. Locating VFS and dispersion along the embankment can also support supported practices along the roadside which, includes reducing the spread of noxious weeds and promoting indigenous grasses, (also considered an approved vegetation material for both VFS and dispersion) (WSDOT, 2008a; WSDOT, 2009b; Lucey, 2011).

Current HRM standards limit the sites where these BMPs can be located to 15%, which reduces the applicability use of these LID BMPs or may require the roadway footprint flattened to meet this limit. This in turn, may result in the need to purchase additional ROW. Based on a literature search, it appears the current design criteria for VFS was based on a biofiltration swales research and may be conservative when applied to VFS or dispersion. This is evident by research that demonstrates stormwater requirements for flow control and runoff treatment can be effectively achieved on slopes greater than 33%. Another justification for the slope limit may be safety of the traveling public which specifies a maximum allowable recoverable slope for an errant vehicle based on highway design standards (generally 33% before requiring traffic safety barrier).

The objective of this study was to evaluate whether embankment slopes steeper than 15% slopes can maintain sheet flow for VFS and dispersion BMPs designs. In pursuit of this objective, an inventory of existing vegetated embankment slopes and site characteristics from 45 sites in eastern Washington was evaluated to determine what site characteristics support sheet flow on steeper slopes. The effectiveness of an embankment to maintain sheet flow was characterized based on the presence or lack of erosion along the slope as well as any observations of runoff pooling or sediment buildup at the bottom or toe of the embankment. While no observations of runoff pooling or sediment build up the bottom of the embankment were noted, erosion was present at 20 of the 45 sites included in the inventory.

The sites inventoried included embankment slopes that ranged from 20-90% and slopes greater than 33% were observed without erosion, indicating slope alone was not the sole cause of erosion. This observation was supported by a statistical analysis that determined erosion severity and embankment slope were not statistically significant compared to other site characteristics. The most statistically significant site characteristics when erosion was present were low vegetation coverage and a high percentage of sand in the embankment soils. A shear stress analysis was used to validate these observations and indicated sand had the lowest critical shear stress, compared to other soils. This reduced the flow rates from highway runoff that could be applied to the embankment before erosion occurred. Vegetation was the most significant factor and is commonly used to stabilize the embankment and to allow for higher applied flow rates along the embankment before erosion occurs.

Further visual observations indicated that site characteristics (i.e., evidence of channelized flow at the EOP interface and imperfections at the EOP) may cause highway runoff to concentrate and erode the embankment. While problematic, EOP characteristics cannot be predicted or modeled, a level spreader at the EOP may mitigate EOP problems by distributing runoff and preventing erosion. None of the 45 sites had a level spreader designed per the WSDOT design requirements in the HRM. However two site features appeared to be providing the same function. These site features were a roughened EOP from multiple pavement overlays and a rumble strip at the EOP. The observations that these features were acting as a level spreader were based on site observations consistent with the findings in this study. Further research of these two site features may affirm them as additional option for level spreaders for stormwater sheet flow designs at the EOP.

The relationship between erosion severity, vegetation coverage, the percentage of sand, and EOP conditions was validated by evaluating study sites with embankment slopes less than 40%. Using these factors, erosion was justified at all sites. Based on this study's findings, the following modification to the VFS and dispersion design criteria along with future research studies are recommended:

1. Increase the embankment slope limit for VFS and dispersion from 15% to 33% at sites where vegetation can be established.
2. Require additional methods to establish vegetation (i.e., such as soil amendments) at sites with a high percentage of sand along the embankment.
3. Conduct further research to evaluate the effectiveness of other site features that function as level spreaders (i.e., rumble strips or roughened EOP).

The proposed design modification would allow for increased use of these LID BMPs supporting emergent NPDES stormwater management goals and current roadside maintenance practices. They would also reduce the need for additional ROW acquisition and there associate costs and impacts to adjacent vegetation and environmentally sensitive areas.

6.0 NOMENCLATURE

α^* - soil texture - structure coefficient (coarse grain 0.36, fine grain 0.12)

A - Basin Area (ft^2)

A_{RC} – Area of reservoir (double head 35.22, single head 2.15n cm^2)

C - Dimensionless shape factor (0.7 coarse grain or 0.77 fine grain)

C_{FG} - Cover Factor for uniform grass.

CF - 2 year 2 hour Conversion factor

C_u - Hazen Uniformity Coefficient

d - Depth of runoff on the embankment (ft)

D_{10} - diameter at which 10% soil material by mass is finer

D_{60} - diameter at which 60% soil material by mass is finer

D_{EOP-V} Distance from edge of pavement to vegetation (ft)

e – Super elevation rate (%)

e_S – Shoulder super elevation rate (%)

e_{TL} – Travel lane super elevation rate (%)

G – The longitudinal incline of the pavement from the horizontal (%)

γ - Specific gravity of water (62.4 lb/ft^3)

K_{sat} - Saturated hydraulic conductivity (in/hr)

H - Height of water in reservoir (double head 10, single head 5 cm)

IQR - Inter-quartile range of data or the middle 50%

L_{CFP} – hypothetical length of contributing flow length (ft)

LW – Lower Whisker

MAP - Mean Annual Precipitation (in)

n_C - composite Mannings coefficient

n_V - vegetation Mannings coefficient

n_{BG} - bare ground Mannings coefficient

N – Number of sites analyzed

N* - Number of sites missing from analysis

P_{2yr2hr} - 2 year 2 hour precipitation depth (in)

P_{3hr} - 3 hour precipitate on depth (in)

P_V – Percentage of Vegetation Coverage (%)

p-value – statistical significance compared to other site characteristic

Q1 - Median value of the data below the median

Q3 - Median value of the data above the median

Q_{AHR} - Applied Highway Runoff Flow Rate (cfs)

Q_{CBG} - Critical Flow Rate for Bare Ground (cfs)

Q_{CEC} - Critical flow rate for existing embankment conditions (cfs)

Q_{CVFS} - Critical Flow Rate for VFS (cfs)

Q_{CEC} - Critical flow rate for existing embankment conditions (cfs)

r - Correlation coefficient

R - Radius of well hole (3 cm)

R1 - average steady state infiltration rate for single head (in/hr).

R2 – average steady state infiltration rate for double head (in/hr).

S_{CFP} - Slope of contributing flow path(%)

S_e - Slope of embankment in ft/ft

τ_{CBG} - Critical Shear Stress of Bare Soils (lb/in^2)

τ_{CEC} - Critical Shear Stress for Existing Embankment Conditions (lb/in^2)

τ_{VFS} - Critical Shear Stress for VFS (lb/in^2)

UW – Upper Whisker

W_S – Horizontal width of shoulder sloped toward the embankment (ft)

W_T – Total horizontal width of pavement sloped toward the embankment (ft)

W_{TL} – Horizontal width of the travel lane sloped toward the embankment (ft)

7.0 ACRONYMS

AASHTO - American Association of State Highway & Transportation Officials
BMP - Best Management Practices
CALTrans – California Department of Transportation
CL - Clays
Ecology – Washington State Department of Ecology
EOP - Edge of pavement
Eqn - Equation
FHWA – Federal Highway Administration
GM - Silty Sand
GW - Well Graded Gravel
HEC - Hydraulic Engineering Circular
HRM - Highway Runoff Manual
NPDES – National Pollutant Discharge Elimination System
LID - Low Impact Development
LT - Left side of highway
ML - Silts
ML-CL - Mixture of Silt and Clay
N/A – Not Applicable
NC – No Comment
ROW – Right of Way
RT - Right side of highway
SM - Silty Sands
SW - Well Graded Sands
TSS - Total Suspended Solids
VFS - Vegetated Filter Strip
WSDOT – Washington State Department of Transportation
WSU - Washington State University
USGS – United States Geological Survey

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APPENDICES

APPENDIX A. COMPLETE INVENTORY OF SITE CHARACTERISTICS

Site Identification	W_T (ft)	e (%)	G (%)	S_e (%)	P_V (%)	D_{EOP-V} (ft)	Erosion Severity	MAP (in)	$P_{100yr3hr}$ (in)	Fines (%)	Gravel (%)	Sand (%)	K_{sat} (in/hr)	Soil Classification
High Erosion Classification														
155-70.8-RT	16	0.5	6.3	80	0	8	7	14.4	1.297	6.5	26.0	67.5	9.49	SW
292-0.8-RT	20	2.4	5.5	65	10	1	7	20.6	1.368	3.9	44.0	52.1	40.43	SW
23-52.1-RT	24	5.2	1.4	65	60	1	6	15.0	1.156	27.7	36.0	36.4	0.58	SM
20-389.1-RT	15	1.6	4.9	50	20	1.5	6	26.9	1.274	18.5	27.5	54.1	0.02	SM
97-247.1-LT	32	9.0	0.5	35	0	8	6	11.2	1.364	4.4	44.0	51.6	0.70	SW
395-196.7-LT	36	4.4	4.2	30	70	8	6	24.2	1.323	7.3	26.5	66.2	7.61	SW
195-76.6-LT	40	3.4	0.3	30	20	5	6	19.5	1.262	79.2	0.0	20.8	2.50	CL
Moderate Erosion Classification														
410-70.8-RT	36	6.5	5.5	75	10	2	4	19.5	1.262	8.7	50.0	41.4	-	GW
231-44.5-LT	25	2.5	5.4	70	10	8	4	15.8	1.325	11.2	17.5	71.3	37.19	SM
25-49.0-RT	12	1.2	0.9	55	5	4.5	4	17.4	1.262	12.5	21.0	66.5	5.16	SM
20-163-LT	44	5.0	6.5	40	40	0	4	63.0	1.456	7.3	21.5	71.3	28.19	SW
2-82.8-LT	32	8.0	2	40	30	2	4	41.0	1.432	18.2	21.0	60.9	2.09	SM
17-66.7-RT	22	1.5	2.3	40	0	20	4	7.4	1.256	7.6	42.5	50.0		SW
155-14.4-RT	16	0.8	0.1	35	0	10	5	11.7	1.302	4.6	52.0	43.4	152.1	GW
195-21.3-LT	20	1.3	0.2	25	60	12	4	21.7	1.289	84.8	0.0	15.3	0.73	ML-CL
231-57.6-LT	25	7.3	4.5	25	35	6	4	20.0	1.315	8.4	34.5	57.1	12.32	SW

Site Identification	W_T (ft)	e (%)	G (%)	S_e (%)	P_V (%)	D_{EOP-V} (ft)	Erosion Severity	MAP (in)	$P_{100yr3hr}$ (in)	Fines (%)	Gravel (%)	Sand (%)	K_{sat} (in/hr)	Soil Classification
Low Erosion Classification														
211-0.25-RT	15	2.7	0.2	65	0	10	2	26.3	1.323	6.3	40.0	53.7	84.78	SW
261-19.4-LT	25	2.5	0.5	60	90	0	2	11.6	1.178	78.1	4.0	17.9	1.22	ML
231-11.2-LT	22.5	3.1	0.5	60	90	3	3	16.0	1.131	67.6	9.0	23.4	0.83	ML-CL
20-433.9-LT	15	1.0	1.6	45	50	3	1	28.8	1.276	17.0	28.0	55.0	8.83	SM
90WB-229.3-LT	21	2.8	2.5	35	90	8	2	12.4	1.1	69.4	9.0	21.6	1.75	ML-CL
90WB-291.0-LT	34	4.0	2	35	70	15	1	18.7	1.262	17.4	57.5	25.2	7.65	GM
207-2.6-LT	32	5.0	0.5	90	0	12	0	35.5	1.438	7.7	25.0	67.4		SW
27-65.4-RT	12	1.0	1.5	45	90	3	0	21.5	1.315	59.1	15.5	25.5	0.98	ML
20-356.7-RT	30	6.6	7	30	20	7	0	21.5	1.289	11.4	37.0	51.7	4.67	SM

Site Identification	W_T (ft)	e (%)	G (%)	S_e (%)	P_V (%)	D_{EOP-V} (ft)	Erosion Severity	MAP (in)	$P_{100yr3hr}$ (in)	Fines (%)	Gravel (%)	Sand (%)	K_{sat} (in/hr)	Soil Classification
None Erosion Classification														
261-61.0-LT	14	1.4	5.2	90	95	4	0	11.8	1.209					
410-77.8-LT	26	7.5	0.5	65	50	0	0	61.5	1.394	8.2	61.0	30.9		GW
24-33.5-LT	19	1.9	6	65	45	0	0	8.3	1.246	53.1	19.0	27.9	0.65	ML
125-19.1-LT	12	1.5	1	60	90	0.5	0	17.6	1.236	59.7	20.0	20.3	1.11	ML
195SB-84-LT	22	3.8	1.4	45	50	6	0	18.4	1.262	23.3	43.5	33.3	11.40	GM
124-12.6-LT	17	1.6	3	45	50	4	0	11.0	1.302	24.0	10.0	66.0	0.61	SM
206-2.26-LT	20	2.6	0.2	40	20	5	0	18.0	1.262	9.4	41.5	49.2	65.25	SW
206-2.27-LT	20	2.6	0.2	40	70	5	0	18.0	1.262	34.1	28.0	37.9	3.08	SM
25-14.7-RT	13	2.0	0.2	40	95	1.5	0	17.0	1.21	61.3	6.5	32.2	1.33	ML
20-412.8-RT	27	6.6	0.5	35	40	2.5	0	25.6	1.299	9.0	26.5	64.6	34.52	SW
12-409.6-RT	36	4.0	0.6	35	80	1	0	20.6	1.289	46.8	19.5	33.7	23.43	SM
274-0.71-LT	32	8.0	1.5	35	95	6	0	20.6	1.315	58.6	11.5	29.9	0.09	ML-CL
97-49.6-RT	18	2.0	1	35	65	0	0	9.5	1.312	7.9	66.5	25.7		GW
28-105.6-LT	31	3.0	1.3	30	80	8	0	12.2	1.128	74.0	7.5	18.6	0.62	ML
21-67.1-RT	14	1.9	6.1	25	80	6	0	10.7	1.209	49.2	15.5	35.4	2.90	SM
2EB-304.7-RT	38	2.2	2.8	20	70	2	0	20.0	1.315	18.6	21.5	60.0	1.94	SM
90EB-286.2-RT	56	4.4	0.2	25	85	0	0	17.9	1.236	27.8	31.5	40.8	1.68	SM
2-266.8-RT	40	3.2	0.3	25	40	8	0	17.3	1.236	25.5	46.0	28.5		GM
129-22.6-LT	34	2.2	3.6	20	55	2	0	17.2	1.262	5.1	75.0	19.9		GW
2-233.8-RT	16	3.0	2.1	20	80	3	0	13.9	1.213	19.1	59.0	21.9	39.49	GM

APPENDIX B. FIELD METHODS TO MEASURE SITE CHARACTERISTICS

Highway and Embankment Geometry

The highway and embankment geometry include site features that, unless otherwise indicated, were directly measured in the field with a standard measuring tape or level including:

- Width of pavement
- Roadway grade
- Super elevation
- Embankment slope.

Each of these geometry terms are defined in Table 3.1 and illustrated in Figure 3.2.

Since the embankment can have minor surface variations due to gravel or vegetation, the slope was measured at several locations and the slope that was most representative of the embankment was recorded to the nearest 5%.

The super elevation represents the weighted average for the width of pavement measured, which included the travel lanes and shoulder. The super elevation was measured directly for the travel lane and the shoulder, and then the weighted average was calculated using equation B1.

$$e=e_{TL}(W_{TL}/W_T)+e_S(W_S/W_T) \qquad \textit{Eqn B1}$$

Embankment Characteristics

The vegetation coverage and the severity of erosion were documented in the field. However, these characteristics were more subjective compared to the measured highway and embankment geometry. For consistency from site to site, a criterion was developed prior to the field investigation and is further described in the subsequent sections.

Estimating Vegetation Coverage

The vegetation along the embankments varied from 0-95% coverage and the majority of vegetation was native grasses or weeds. The density of coverage also varied from uniform to non-uniform, including bunch grasses. To estimate the percentage of area covered with vegetation, an approximate 10 ft by 10 ft area was located that appeared to represent the average amount of vegetation coverage and density along the embankment. Within this "square" the amount of area covered in vegetation was estimated and (usually) rounded to the nearest tenth percent. Figure B1 shows two sites where the vegetation was estimated at 0% on the left and 95% on the right.

Figure B1 Estimating the Vegetation Coverage

In addition to estimating the coverage of vegetation, the distance from the edge of pavement (EOP) to the start of consistent vegetation coverage was also documented. For sites with uniform density, it was fairly apparent (see left in Figure B2). However, for sites with non-uniform density, the distance represents an approximate average along the embankment (see right Figure B2).


Figure B2 Estimating the Distance From EOP to Vegetation

Classifying Erosion

Erosion is essentially the wearing a way of soil particles along the embankment. This study measured the effectiveness of an embankment to maintain sheet flow, which was assumed when no erosion was present. The inventory included 20 sites with erosion and 25 without. Each site was broken down into four groups of erosion classification based on the definitions of erosion from the National Soil Erosion Research Laboratory (NSERL). In addition, each site was given a numerical rating from 0-7 to represent the erosion severity in the statistical analysis, (0 representing no erosion and 7 for sites with the most extensive). Figure B3 illustrates each erosion classification, followed by the definitions for each erosion classification and the erosion severity rating. A summary of the number of sites that were grouped into each classification is also noted in the descriptions.

Figure B3 Erosion Classification –None, Low, Moderate, High (Left to Right)

None – Sites with no visual presence of erosion were observed at 20 sites. (Erosion severity rating - 0).

Low – Sites with sheet erosion or small rills. Small rill erosion is the removal of soil particles from runoff flows that form shallow channels measuring less than ½ inch deep. Small rills were observed at 5 sites. Sheet erosion is the uniform gradual removal of soil in thin layers and can be difficult to detect because it is a gradual process. Evidence of sheet erosion was determined by the presence of uniform soil deposits along the embankment or at the bottom (toe) of the embankment as shown in Figure B4. Sheet erosion along the embankment was noted at 4 sites and no sediment deposits were observed at the toe of the embankment. (Erosion severity – 1, 2, 3).

Moderate – Sites where small rill erosion had developed into deeper channels that measured between ½ - 4 inches deep which was observed at 9 sites. (Erosion severity – 4 and 5).

High – Sites where rills have advanced to deeper than 4 inches which was noted at 7 sites. (Erosion severity – 6 and 7).

Figure B4 Sheet Erosion, Low Classification

Precipitation

The precipitation was determined using the test site location and an Isopluvial map layer for Washington State in ArcGIS (WSDOT, 2008a). For each site, precipitation depths were recorded for the; Mean Annual Precipitation (MAP) and the short duration storm event. The short duration storm depth is the required design event for sizing VFS and dispersion. However, since it is specific to Eastern Washington applications, the MAP was included since it is more common. The MAP represents the historical average precipitation depth and varied from 7.4 to 63 inches at the test sites (WSDOT, 2008a).

The short duration storm represents a 3-hour duration, high intensity storm event that is typical of a summer thunderstorm in Eastern Washington (Schaefer, 2006). These storms generally produce peak flow rates and the 6-month 3-hour depth is used to design conveyance BMPs and hydraulic features in Eastern Washington (WSDOT, 2010b; Ecology, 2004; WSDOT, 2008a). For this research, the 100-year 3-hour precipitation depth was considered to determine how the higher intensity event would correlate with erosion. Unlike the MAP, Isopluvial maps do not exist for the 3-hour short duration storm, instead the 2-year 2-hour precipitation depths are found from Isopluvial Maps and multiplied by a conversion factor based on the MAP at the project site. Equation 3.5 was used along with the conversions in Table B1 to calculate the short duration storm depth (WSDOT, 2008a; Schaefer, 2006).

$$P_{3hr} = CF \times P_{2yr2hr} \quad \textit{Eqn B2}$$

Table B1 Conversion Factors (CF) for the 3 hour Event

MAP (in)	100-Year
6-8	3.49
8-10	3.28
10-12	3.10
12-16	2.82
16-22	2.63
22-28	2.45
28-40	2.32
40-60	2.17
60-120	2.05

Geological Properties

Since the geological properties on the 45 embankment were different are necessary to perform a shear stress analysis, the soil type was classified along with directly measuring the saturated hydraulic conductivity. The specific methods are further described in the following subsections.

Soil Classification

At each site the soils were classification following the process described in this section and summarized in Table B2 by erosion severity.

Table B2 Summary of Soil Classifications and Associated Erosion Severity

	High	**Moderate**	**Low**	**None**	**Total Number of Sites**
GM			1	2	3
GW	2	2		4	8
SM	1	3	2	7	13
SW	3	3	2	2	10
ML			2	3	5
ML-CL	1	1	2	1	5
CL	1				1
	7	9	9	19[1]	44

1. Soil samples were lost for one of the no erosion sites.

Soils samples were collected along the embankment near and at the location of saturated hydraulic conductivity testing. The distribution of soil size was determined by the WSDOT materials lab following AASHTO method T27 and T11 (WSDOT, 2011). Using the soil particle sizes, a particle size distribution curve was generated to evaluate the uniformity of the soils using the Hazen Coefficient (C_u) (see Equation B3) where coefficients greater than 10 are considered well graded and less than 4 or 5 are poorly graded (Lindeburg, 2006).

$$C_u = \frac{D_{60}}{D_{10}} \qquad \textit{Eqn B3}$$

All coarse grain soils were determined to be well graded based on a uniformity coefficient was greater than 10. For each site, the distribution of soil size and curves is located in Appendix C along with a complete list of uniformity coefficients in Appendix D.

The soil type was classified following the WSDOT Geotechnical Design Manual. However, since only the soil particle distribution was determined, some assumptions were necessary to classify fine grain properties based on field observations, highway design standards, and soils maps (WSDOT, 2005; Lindeburg, 2006). A more accurate classification to distinguish between clays and silts and low or high compressibility characteristics would have required knowledge of the plasticity characteristics to determine the plasticity and liquid index using the Atterburg limit test. Instead, clays were distinguished from silts following informal field identification which consisted of rubbing a small fragment between fingers and noting if the soil breaks easily (silt) or not (clay). Another test involved squeezing a soil sample and attempting to roll a thread, noting if the soils held shape (clay) or not (silt) (Lindeburg, 2006). Final distinction between silt and clays was based on Native Soil Classification using the Natural Resource Conservation Service (NRCS) soils maps since it is common practice to use native material or sources for embankment construction (NRCS, 2009; WSDOT, 2010c). A complete list of native soil classification for each site is located in Appendix D.

The section of low compressibility over high compressibility was based on the preference for non-plastic soils or soils with less than 15% fines (passing #200 sieve) as described in material specification for highway embankment construction. Soils with low compressibility are preferred since high compressibility soils can continue to settle after compaction (NCHRP, 2004; WSDOT, 2010c). The assumed low compressibility property is denoted by the letter of L after all fine grain soils. In addition, all soils were assumed to be inorganic based on the compressible nature of organic material and highway specification that limit some subgrade material mixes to 3% organic material by weight (Lindeburg, 2006; WSDOT, 2010c). A summary of the soil classification process is illustrated in Figure B5.

Since it is not possible to include the soil classification in the statistical analysis, the soils were further categorized into three groups by mass percentage of; gravel, sand, and fines. The soil constituent of these materials is based on the soil size distribution and WSDOT classification for these materials as summarized in Table B3.

Table B3 Estimating the Percent Gravel, Sand, and Fines

Soil Constituent	**Description**
% Gravel	The percentage of soil particles retained on the (4.75 mm) opening.
% Sand	The percentage of sand is difference between the amount of soil particles the pass through the 4.75mm sieve and are retained on the #200 sieve.
% Fines	The percentage of soils that will pass through a the #200 opening (0.075 mm).

Source: (WSDOT, 2005)

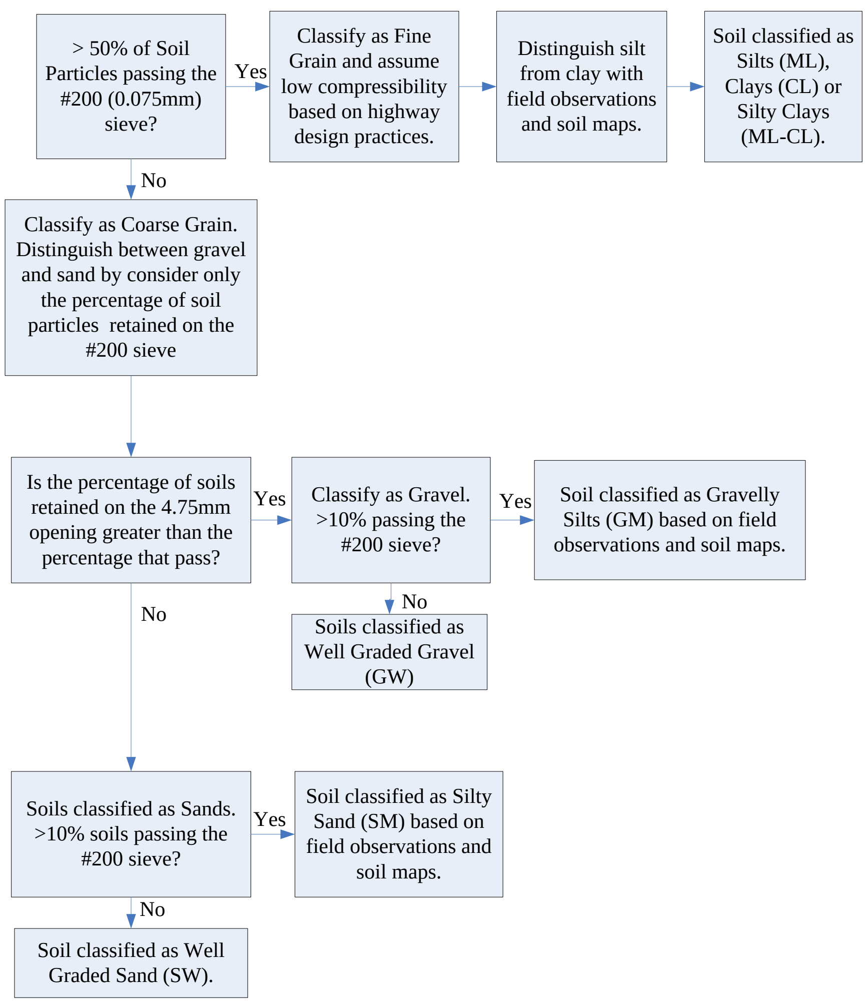


Figure B5 Soil Classification Process

Saturated Hydraulic Conductivity (K_{sat})

The saturated hydraulic conductivity is a steady state measure of the soils ability to transmit water through the soil and an indicator of how much highway runoff will infiltrate or runoff the embankment. Dispersion BMPs are designed so flow control (via infiltration and transpiration) of highway runoff will be provided in the roadside area and a key parameter to determine the area required for infiltration is K_{sat} (Yonge, 2005; WSDOT, 2008a). While numerical models have been developed to predict K_{sat}, studies have concluded it is difficult to predict surface infiltration rates along highway embankments as a result of the specification requirements to compact embankments to a maximum density of 90-95% (Yonge, 2005; Massman, 2008; WSDOT, 2010d). This is because the effect of compaction on K_{sat} are sensitive to a variety of site specific factors including; soil grain distribution, moisture content, and degree of saturation (Massman, J., 2008). Consequently, direct measurement in the field may provide a better estimate by minimizing disturbance and maintaining a functional connection to the surrounding soils (Bagarello, 2004; WSDOT, 2010a).

The K_{sat} was measured using the Guelph Permeameter which is a quasi steady state, constant head test used to measure the saturated hydraulic conductivity of unsaturated soil. This method was selected because it is the approved method to measure K_{sat} for sizing dispersion BMPs as part of the stormwater design guidance in the HRM (WSDOT, 2008a). For most sites, two tests were performed with the averaged reported in the inventory in Appendix A. Actual testing was performed within the vegetated area of the embankment and a minimum of 8 feet from the EOP. Test wells were prepared by auguring a hole approximately 8-12 inches deep and the soil removed was collected for sieve analysis. Figures 3.9 shows a typical Ksat test using the Guelph Permeameter along the highway embankment.

Figure B6 Typical Ksat Testing on a Highway Embankment Area

The K_{sat} was calculated based on Darcys Law and used the soil classification, the diameter of the well, the height of water (head) applied to the test well, and the rate of fall of the head (Soilmoisture, 2005). With the Guelph Permeameter, a single or double head test can be performed and the results of the double head can also be used to calculate Ksat for two single head test. The double head test is recommended for moderate to high permeability soils such as coarse grain and the single head test is recommended for low permeability soils such as fine grain. In most cases, the double head test was attempted first since it is assumed to be more accurate. The single head test was only used for sites where the soil visually appeared to be primarily fine grained. Since the test well diameter and head were the same depending on which test was performed, the actual equation used to calculate K_{sat} is based primarily on the rate of steady state fall as shown in Equation 3.8 and 3.9, representing the double head and single head analysis respectively.

$$K_{Sat}(in/hr) = (3.41106 \times R2) - (4.49266 \times R1) \qquad \textit{Eqn B4}$$

$$K_{Sat}(in/hr) = (0.208 \times R2) - (0.274 \times R1) \qquad \textit{Eqn B5}$$

R1 and R2 represent the average steady state infiltration rate of the soils along the embankment and were identified when the rate of fall of water in the reservoir remains consistent over three consecutive time intervals using the single and double head test respectively.

The analysis assumes homogeneous soils in the horizontal and vertical directions. However, if heterogeneous soils are present that have large pores and/or layered soils, this can lead to nonphysical results such as a negative hydraulic conductivity. For this case, a modified single head test was performed and is shown in Equation B6.

$$K_{Sat}(in/hr) = \frac{CA_{RC}R1}{2\pi H^2 + C\pi r^2 + \frac{2\pi H}{\alpha^*}} \times 23.62 \qquad \textit{Eqn B6}$$

Using the aforementioned processed, Ksat was calculated for most sites and is summarized by soil classification using the average values in Table B4. The K_{sat} for each site is listed in Appendix A.

Table B4 Summary of Average Ksat by Soil Classification

Soil Classification	**Ksat (in/hr)**
ML, ML-CL, CL	1.1
SM	7.1
GM	19.5
SW	31.48
GW	152.1

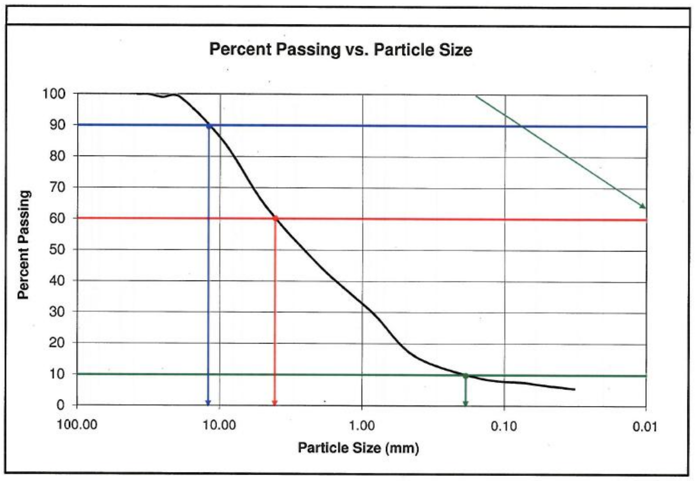
APPENDIX C. DISTRIBUTION OF SOIL SIZE TABLES AND CURVES

Sample ID: 231-57.6-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	99
3/4	19.08	99
3/8	9.54	85
4	4.75	64
10	2.0	45
20	0.85	30
40	0.425	16
100	0.15	9
200	0.075	7.6
270	0.053	6.7
450	0.032	5.6

From Gradation Curve:	
D10	0.19
D60	4.05
D90	12

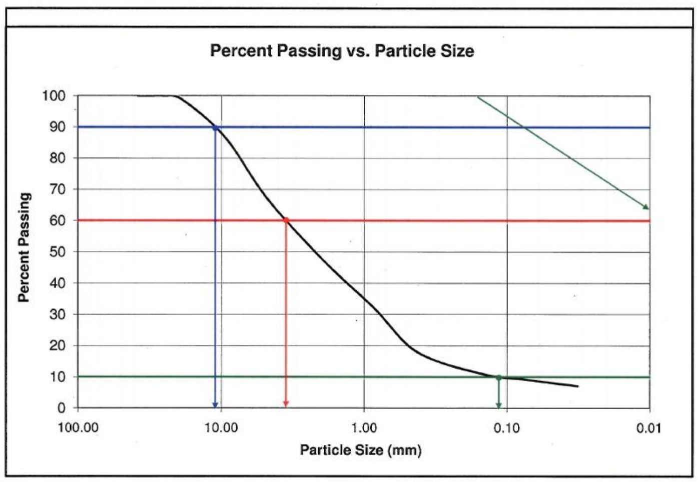


Sample ID: 231-57.6-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	99
3/8	9.54	87
4	4.75	67
10	2.0	48
20	0.85	32
40	0.425	18
100	0.15	11
200	0.075	9.2
270	0.053	8.3
450	0.032	7.1

From Gradation Curve:	
D10	0.12
D60	3.6
D90	11

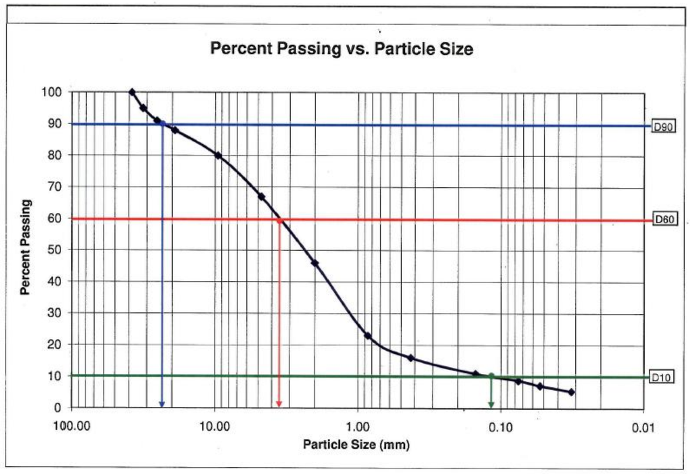


Sample ID: 231-44.5-GP1

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	95
1	25.44	91
3/4	19.08	88
3/8	9.54	80
4	4.75	67
10	2.0	46
20	0.85	23
40	0.425	16
100	0.15	11
200	0.075	8.8
270	0.053	7.2
450	0.032	5.4

From Gradation Curve:	
D10	0.12
D60	3.5
D90	22

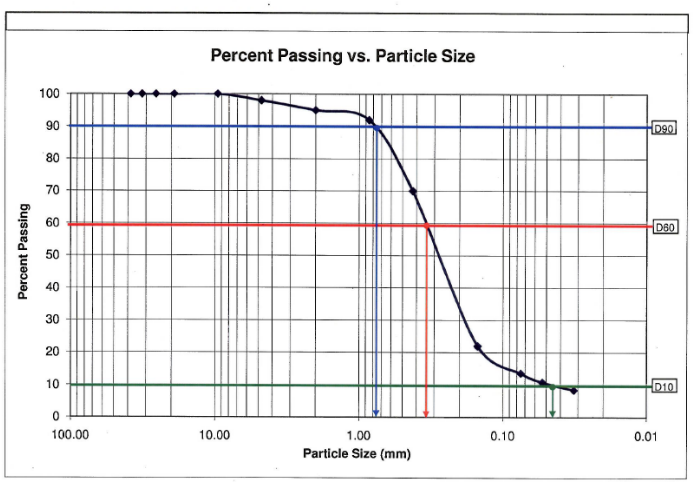


Sample ID: 231-44.5-GP2

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	100
4	4.75	98
10	2.0	95
20	0.85	92
40	0.425	70
100	0.15	22
200	0.075	13.6
270	0.053	10.8
450	0.032	8.4

From Gradation Curve:	
D10	0.048
D60	0.33
D90	0.75

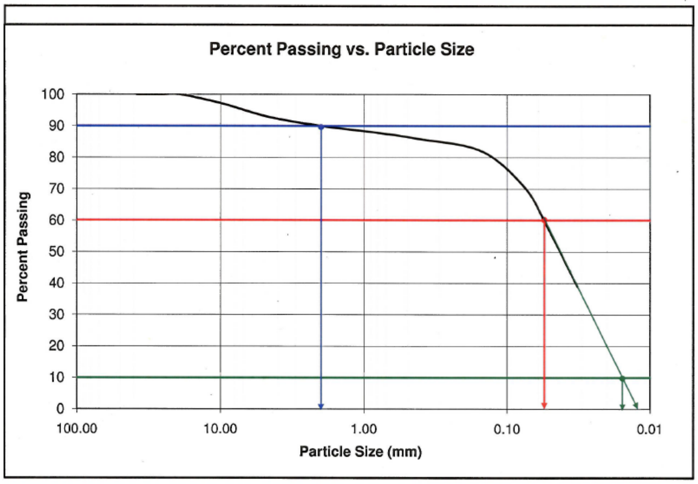


Sample ID: 231-11.2-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	97
4	4.75	93
10	2.0	90
20	0.85	88
40	0.425	86
100	0.15	82
200	0.075	70.4
270	0.053	58.5
450	0.032	38.9

From Gradation Curve:	
D10	0.017
D60	0.055
D90	2

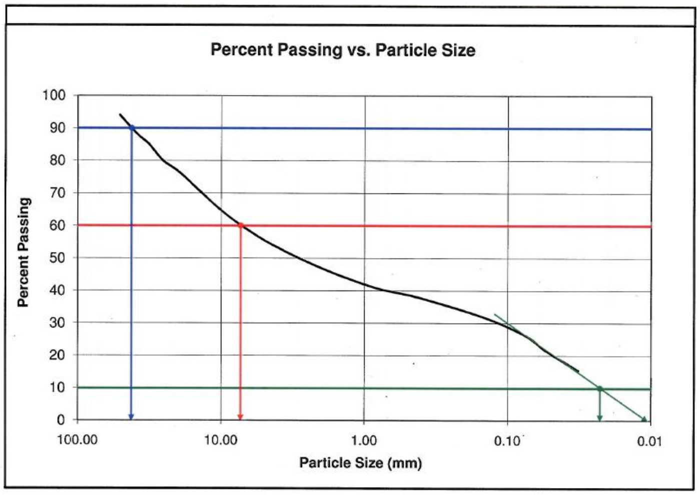


Sample ID: 2-266.8-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	94
1 1/2	38.16	88
1 1/4	31.80	85
1	25.44	80
3/4	19.08	76
3/8	9.54	64
4	4.75	55
10	2.0	47
20	0.85	41
40	0.425	38
100	0.15	32
200	0.075	26.2
270	0.053	21.3
450	0.032	15.4

From Gradation Curve:	
D10	0.022
D60	7.4
D90	42

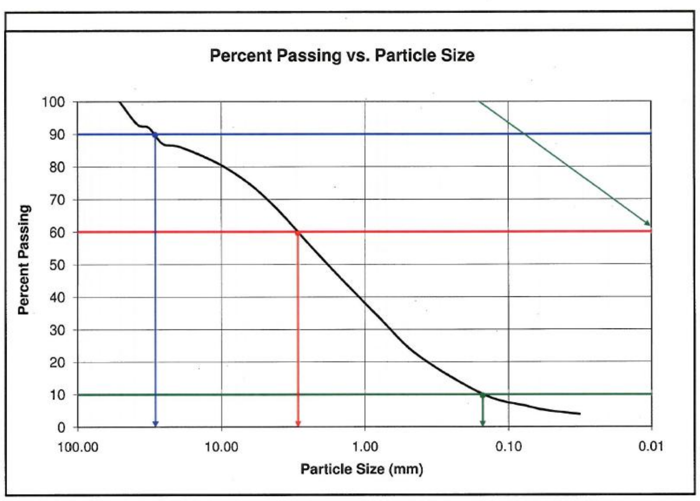


Sample ID: 395-196.7-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	93
1 1/4	31.80	92
1	25.44	87
3/4	19.08	86
3/8	9.54	80
4	4.75	70
10	2.0	52
20	0.85	35
40	0.425	22
100	0.15	10
200	0.075	6.4
270	0.053	5
450	0.032	3.9

From Gradation Curve:	
D10	0.16
D60	3
D90	29

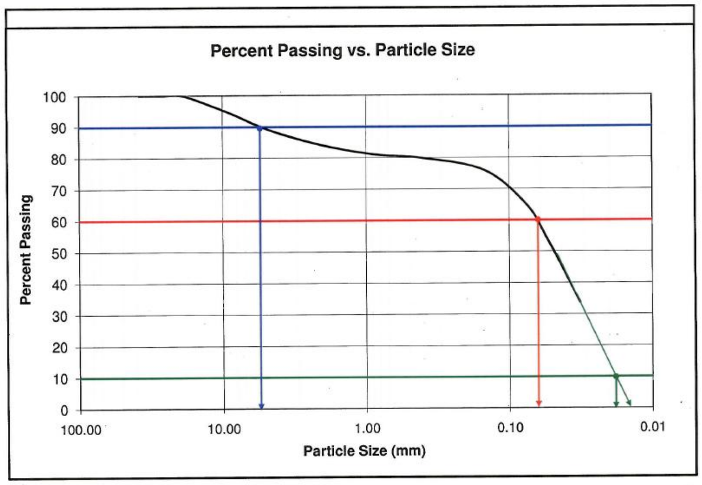


Sample ID: 231-11.2-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	95
4	4.75	89
10	2.0	84
20	0.85	81
40	0.425	80
100	0.15	76
200	0.075	64.8
270	0.053	53.2
450	0.032	33.8

From Gradation Curve:	
D10	0.018
D60	0.062
D90	5.5

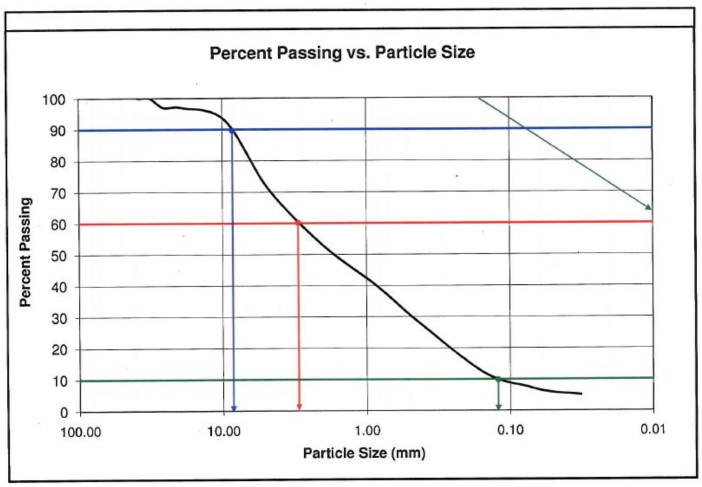


Sample ID: 207-2.6-S2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	97
3/4	19.08	97
3/8	9.54	93
4	4.75	71
10	2.0	53
20	0.85	40
40	0.425	28
100	0.15	12
200	0.075	7.6
270	0.053	6
450	0.032	5.1

From Gradation Curve:	
D10	0.12
D60	3
D90	8.5

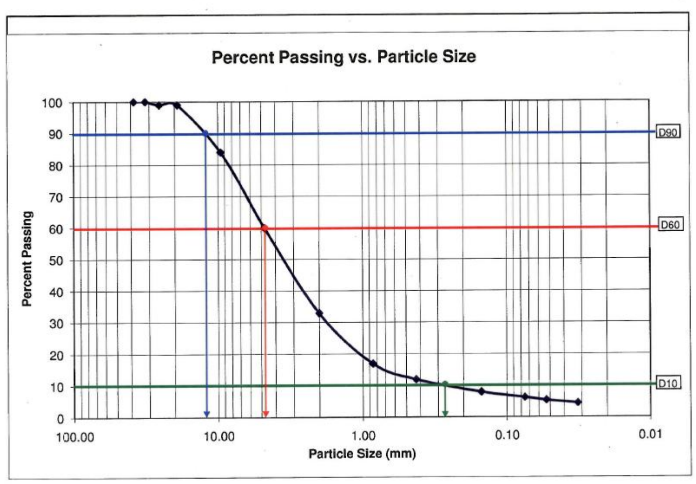


Sample ID: 211-0.25-GP2

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	99
3/4	19.08	99
3/8	9.54	84
4	4.75	60
10	2.0	33
20	0.85	17
40	0.425	12
100	0.15	8
200	0.075	6.3
270	0.053	5.4
450	0.032	4.5

From Gradation Curve:	
D10	0.28
D60	4.8
D90	13

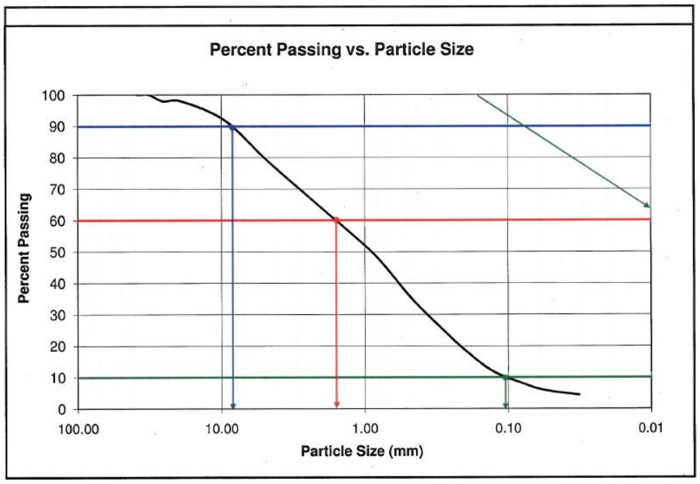


Sample ID: 207-2.6-S1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	98
3/4	19.08	98
3/8	9.54	92
4	4.75	79
10	2.0	64
20	0.85	49
40	0.425	33
100	0.15	14
200	0.075	7.7
270	0.053	5.7
450	0.032	4.4

From Gradation Curve:	
D10	0.11
D60	1.7
D90	8.5

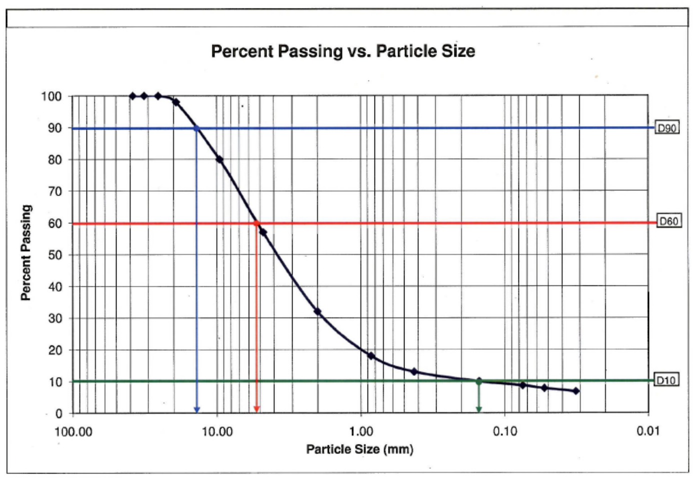


Sample ID: 206-2.26-GP2

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	98
3/8	9.54	80
4	4.75	57
10	2.0	32
20	0.85	18
40	0.425	13
100	0.15	10
200	0.075	8.7
270	0.053	7.8
450	0.032	6.8

From Gradation Curve:	
D10	0.17
D60	5.1
D90	15

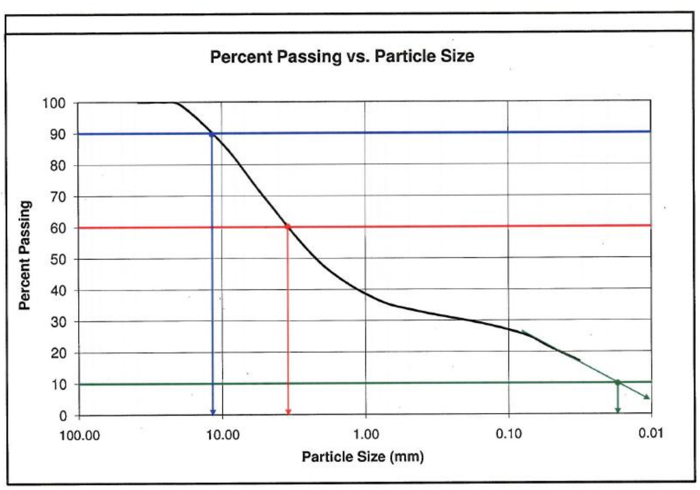


Sample ID:

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	99
3/8	9.54	86
4	4.75	68
10	2.0	48
20	0.85	37
40	0.425	33
100	0.15	29
200	0.075	25.3
270	0.053	21.8
450	0.032	17

From Gradation Curve:	
D10	0.018
D60	3.6
D90	12

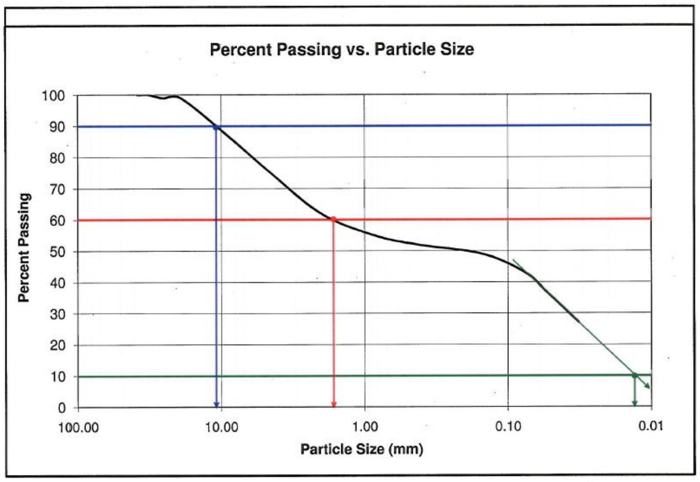


Sample ID: 206-2.27-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	99
3/4	19.08	99
3/8	9.54	88
4	4.75	76
10	2.0	62
20	0.85	55
40	0.425	52
100	0.15	49
200	0.075	42.9
270	0.053	36.6
450	0.032	27.1

From Gradation Curve:	
D10	0.014
D60	1.7
D90	11

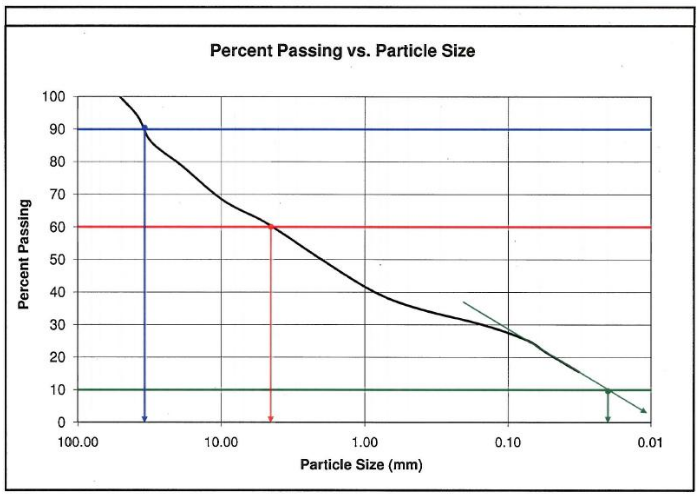


Sample ID: 195SB-84-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	94
1 1/4	31.80	87
1	25.44	83
3/4	19.08	79
3/8	9.54	68
4	4.75	61
10	2.0	50
20	0.85	40
40	0.425	35
100	0.15	30
200	0.075	25.4
270	0.053	21.3
450	0.032	15.6

From Gradation Curve:	
D10	0.02
D60	4.5
D90	35

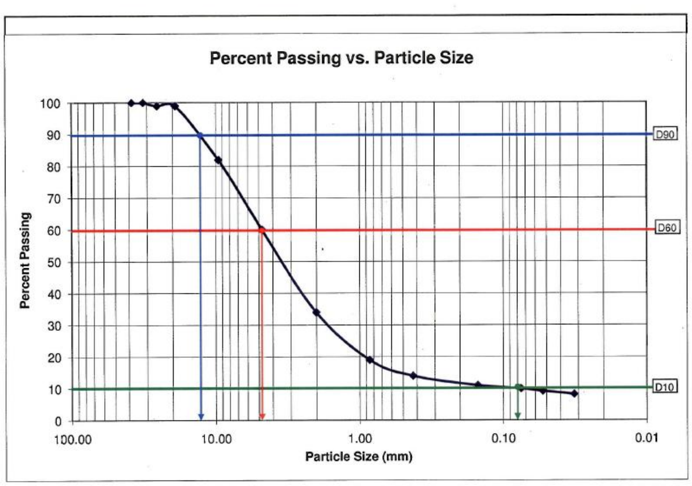


Sample ID: 206-2.26-GP1

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	99
3/4	19.08	99
3/8	9.54	82
4	4.75	60
10	2.0	34
20	0.85	19
40	0.425	14
100	0.15	11
200	0.075	10
270	0.053	9.2
450	0.032	8.2

From Gradation Curve:	
D10	0.08
D60	4.8
D90	14

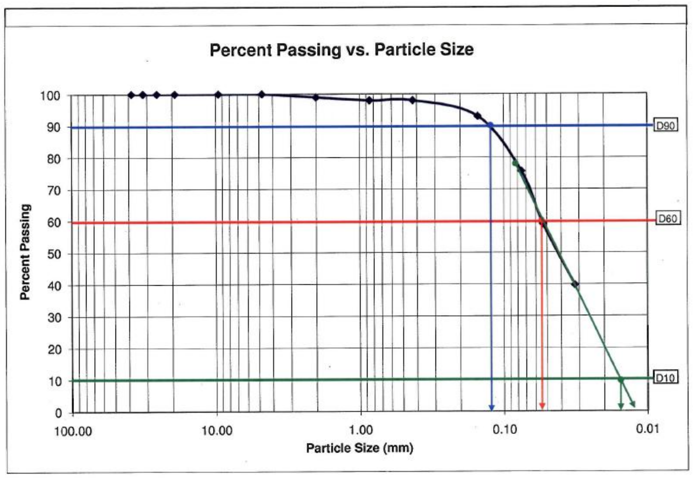


Sample ID: 195-76.6-GP2

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	100
4	4.75	100
10	2.0	99
20	0.85	98
40	0.425	98
100	0.15	93
200	0.075	75.7
270	0.053	59.1
450	0.032	39.8

From Gradation Curve:	
D10	0.017
D60	0.055
D90	0.12

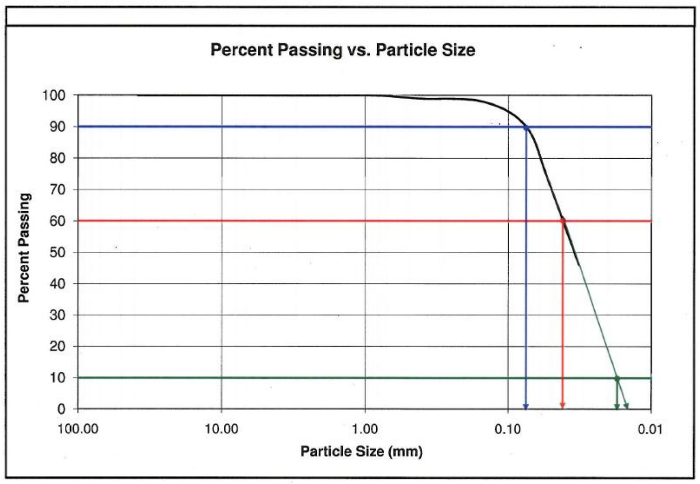


Sample ID: 195-21.3-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	100
4	4.75	100
10	2.0	100
20	0.85	100
40	0.425	99
100	0.15	98
200	0.075	90.1
270	0.053	73.6
450	0.032	46.1

From Gradation Curve:	
D10	0.017
D60	0.041
D90	0.075

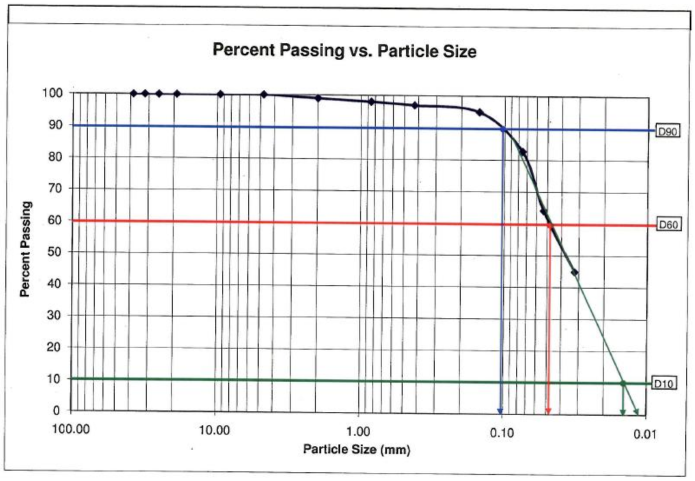


Sample ID: 195-76.6-GP1

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	100
4	4.75	100
10	2.0	99
20	0.85	98
40	0.425	97
100	0.15	95
200	0.075	82.7
270	0.053	64.1
450	0.032	44.9

From Gradation Curve:	
D10	0.015
D60	0.048
D90	0.106

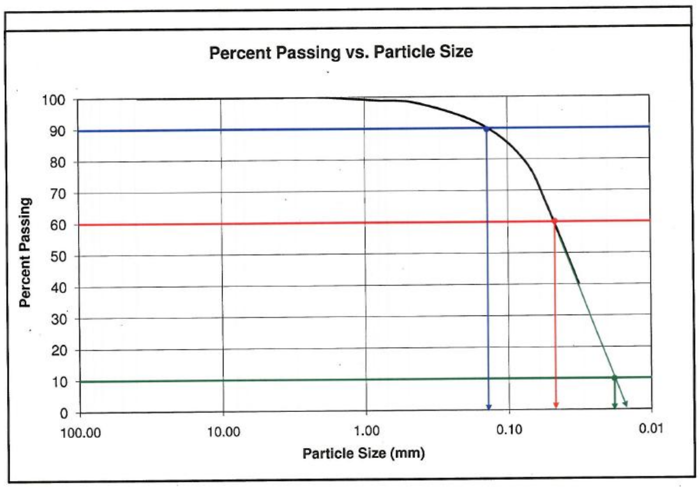


Sample ID: 195-21.3-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	100
4	4.75	100
10	2.0	100
20	0.85	99
40	0.425	98
100	0.15	91
200	0.075	79.4
270	0.053	65.4
450	0.032	40.2

From Gradation Curve:	
D10	0.018
D60	0.049
D90	0.15

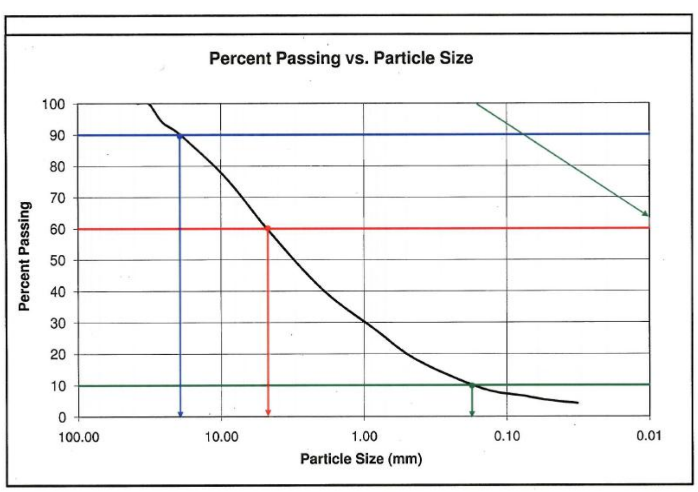


Sample ID: 155-70.8-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	94
3/4	19.08	90
3/8	9.54	77
4	4.75	60
10	2.0	41
20	0.85	28
40	0.425	18
100	0.15	9
200	0.075	6.5
270	0.053	5.3
450	0.032	4.2

From Gradation Curve:	
D10	0.18
D60	4.8
D90	19

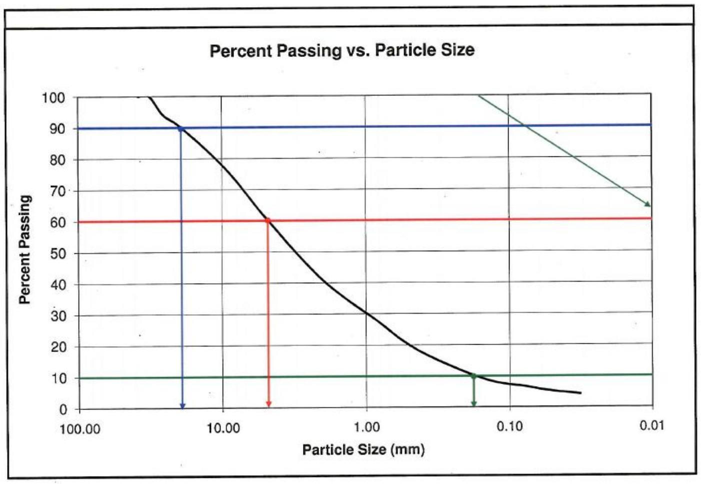


Sample ID: 155-70.8-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	94
3/4	19.08	90
3/8	9.54	77
4	4.75	60
10	2.0	41
20	0.85	28
40	0.425	18
100	0.15	9
200	0.075	6.5
270	0.053	5.3
450	0.032	4.2

From Gradation Curve:	
D10	0.18
D60	4.9
D90	19

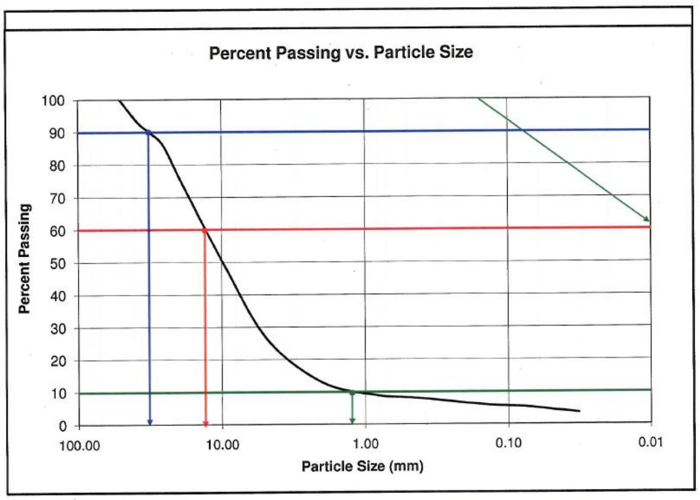


Sample ID: 129-22.6-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	93
1 1/4	31.80	90
1	25.44	86
3/4	19.08	75
3/8	9.54	49
4	4.75	26
10	2.0	13
20	0.85	9
40	0.425	8
100	0.15	6
200	0.075	5.3
270	0.053	4.6
450	0.032	3.6

From Gradation Curve:	
D10	1.2
D60	12
D90	31

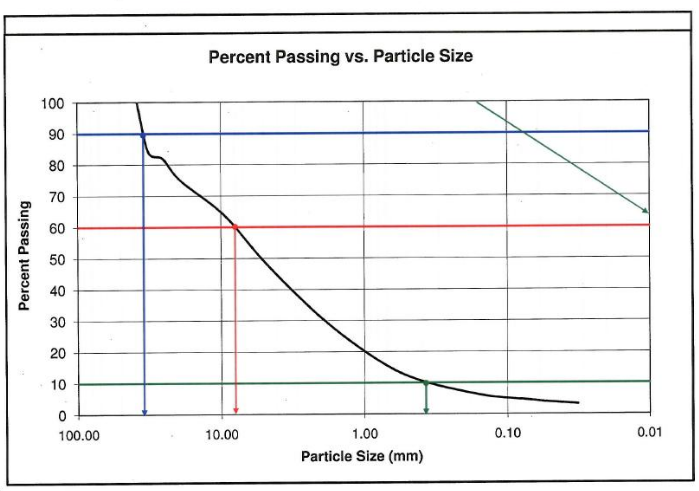


Sample ID: 155-14.4-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	84
1	25.44	82
3/4	19.08	75
3/8	9.54	64
4	4.75	48
10	2.0	31
20	0.85	18
40	0.425	11
100	0.15	6
200	0.075	4.6
270	0.053	3.9
450	0.032	3.2

From Gradation Curve:	
D10	0.38
D60	8
D90	35

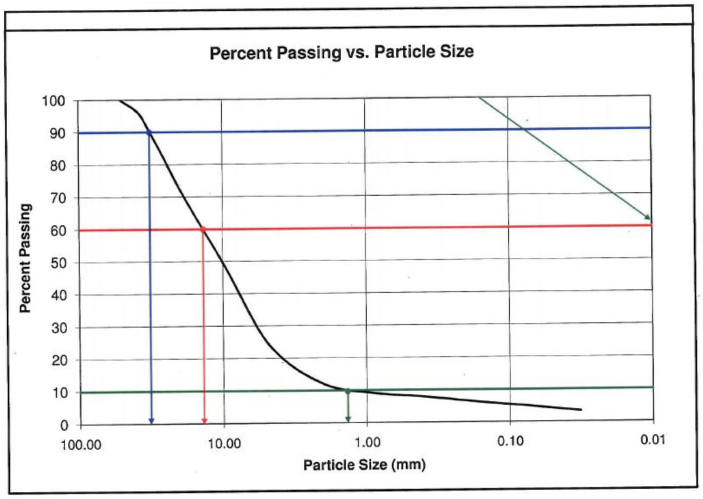


Sample ID: 129-22.6-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	96
1 1/4	31.80	90
1	25.44	82
3/4	19.08	71
3/8	9.54	48
4	4.75	24
10	2.0	12
20	0.85	9
40	0.425	8
100	0.15	6
200	0.075	4.9
270	0.053	4.2
450	0.032	3.3

From Gradation Curve:	
D10	1.2
D60	12
D90	31

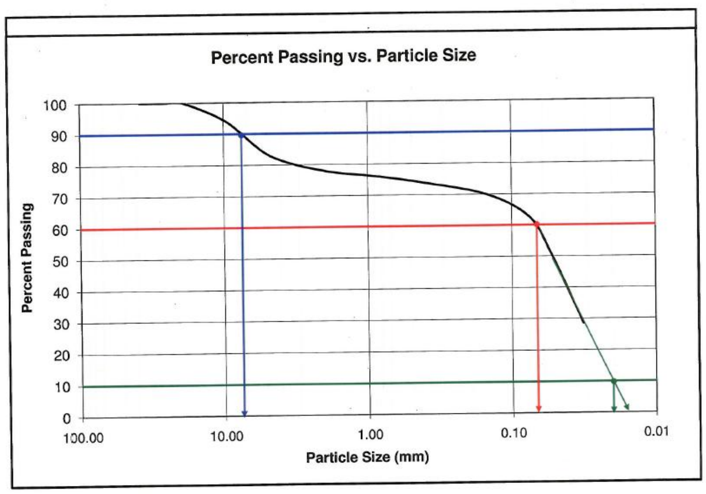


Sample ID: 125-19.1-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	94
4	4.75	83
10	2.0	78
20	0.85	76
40	0.425	74
100	0.15	70
200	0.075	62.6
270	0.053	50.6
450	0.032	28.5

From Gradation Curve:	
D10	0.02
D60	0.067
D90	7.5

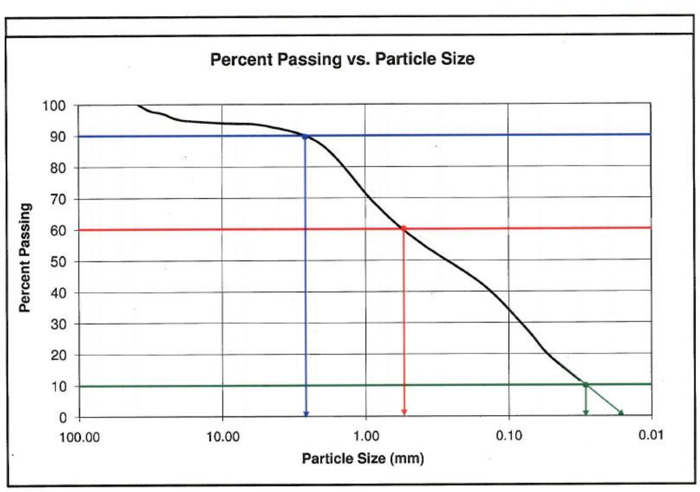


Sample ID: 124-12.6-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	98
1	25.44	97
3/4	19.08	95
3/8	9.54	94
4	4.75	93
10	2.0	87
20	0.85	68
40	0.425	56
100	0.15	42
200	0.075	27.9
270	0.053	19.7
450	0.032	11.4

From Gradation Curve:	
D10	0.029
D60	0.52
D90	2.7

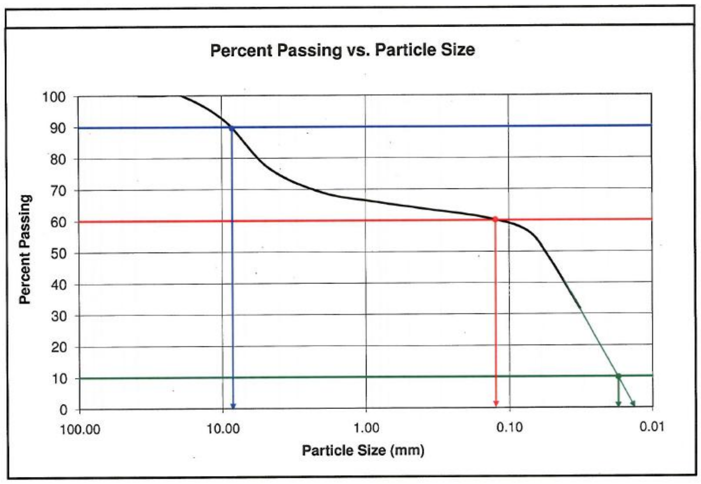


Sample ID: 125-19.1-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	92
4	4.75	77
10	2.0	69
20	0.85	66
40	0.425	64
100	0.15	61
200	0.075	56.8
270	0.053	48.3
450	0.032	31.8

From Gradation Curve:	
D10	0.017
D60	0.12
D90	8.5

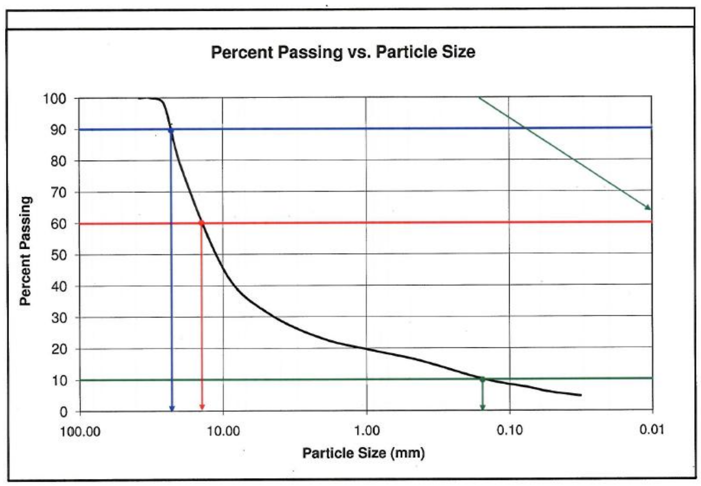


Sample ID: 97-49.6-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	98
3/4	19.08	77
3/8	9.54	44
4	4.75	31
10	2.0	23
20	0.85	19
40	0.425	16
100	0.15	10
200	0.075	7.5
270	0.053	6
450	0.032	4.7

From Gradation Curve:	
D10	0.16
D60	15
D90	22

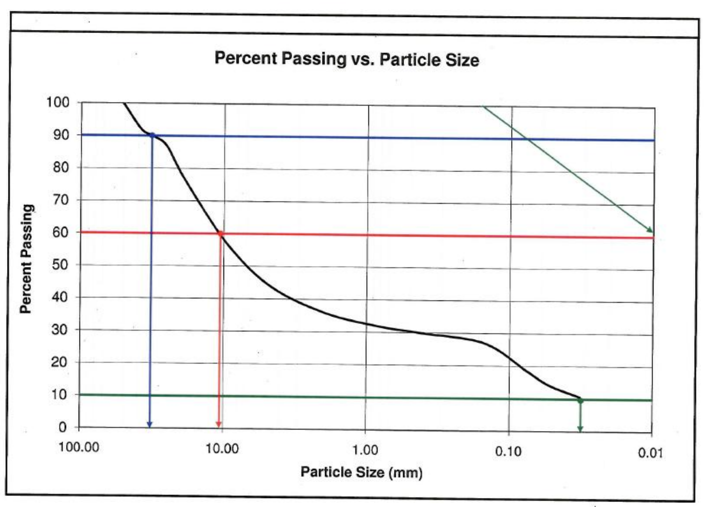


Sample ID: 90WB-291.0-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	92
1 1/4	31.80	90
1	25.44	87
3/4	19.08	77
3/8	9.54	57
4	4.75	44
10	2.0	36
20	0.85	32
40	0.425	30
100	0.15	27
200	0.075	18.4
270	0.053	14.2
450	0.032	10.6

From Gradation Curve:	
D10	0.031
D60	10.5
D90	32

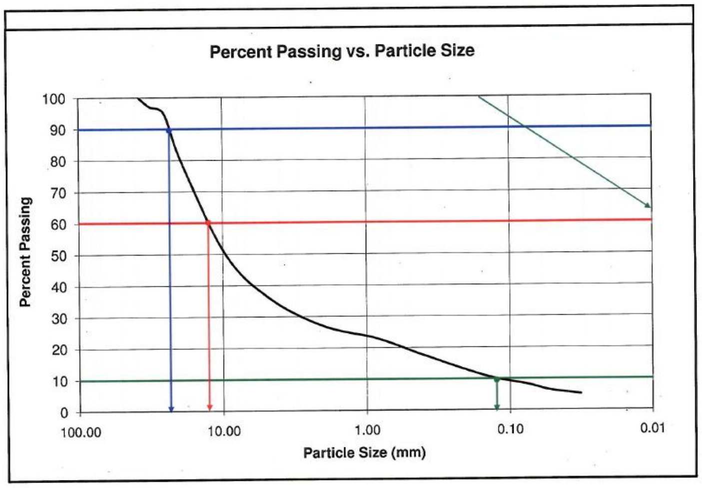


Sample ID: 97-49.6-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	97
1	25.44	95
3/4	19.08	79
3/8	9.54	50
4	4.75	36
10	2.0	27
20	0.85	23
40	0.425	18
100	0.15	11
200	0.075	8.2
270	0.053	6.4
450	0.032	5.1

From Gradation Curve:	
D10	0.13
D60	13
D90	23

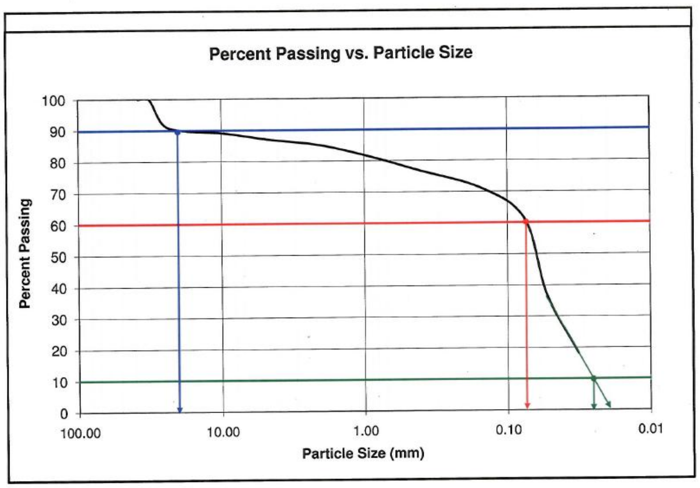


Sample ID: 90WB-229.3-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	92
3/4	19.08	90
3/8	9.54	89
4	4.75	87
10	2.0	85
20	0.85	81
40	0.425	77
100	0.15	71
200	0.075	61
270	0.053	37
450	0.032	18.2

From Gradation Curve:	
D10	0.026
D60	0.075
D90	20

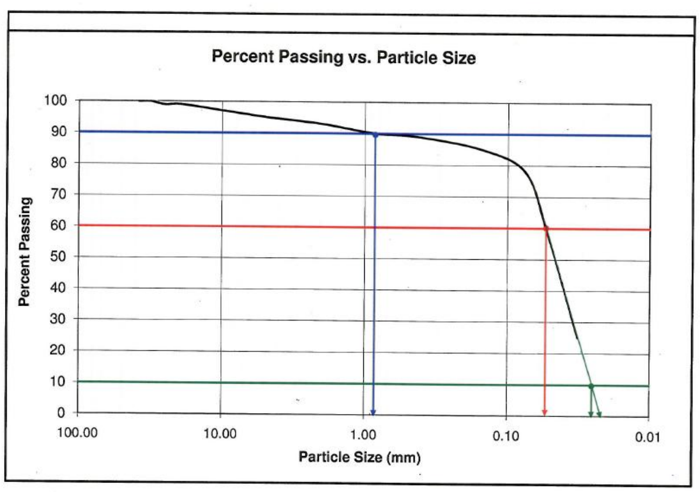


Sample ID: 90WB-229.3-LT

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	99
3/4	19.08	99
3/8	9.54	97
4	4.75	95
10	2.0	93
20	0.85	90
40	0.425	89
100	0.15	85
200	0.075	77.8
270	0.053	59.2
450	0.032	25.1

From Gradation Curve:	
D10	0.026
D60	0.055
D90	0.85

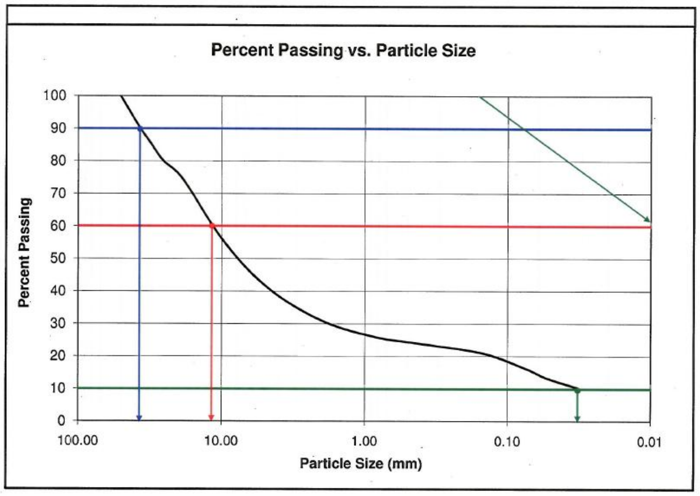


Sample ID: 90WB-291.0-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	91
1 1/4	31.80	86
1	25.44	80
3/4	19.08	75
3/8	9.54	55
4	4.75	41
10	2.0	31
20	0.85	26
40	0.425	24
100	0.15	21
200	0.075	16.3
270	0.053	13.3
450	0.032	10.3

From Gradation Curve:	
D10	0.031
D60	11
D90	38

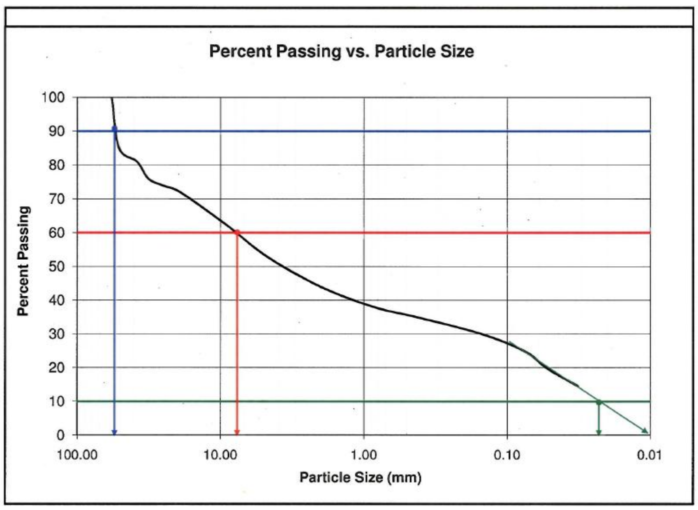


Sample ID: 2-266.8-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2 1/4	57.24	100
2	50.88	85
1 1/2	38.16	81
1 1/4	31.80	76
1	25.44	74
3/4	19.08	72
3/8	9.54	63
4	4.75	53
10	2.0	44
20	0.85	38
40	0.425	35
100	0.15	30
200	0.075	24.8
270	0.053	19.9
450	0.032	14.5

From Gradation Curve:	
D10	0.022
D60	7.8
D90	55

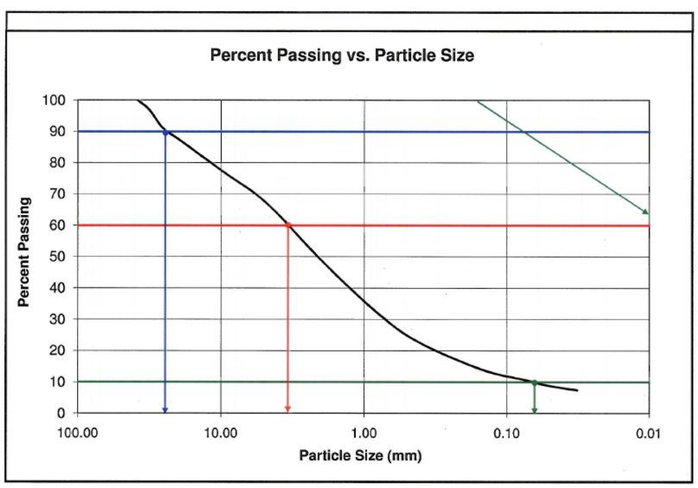


Sample ID: 410-70.8-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	97
1	25.44	91
3/4	19.08	87
3/8	9.54	77
4	4.75	67
10	2.0	49
20	0.85	33
40	0.425	23
100	0.15	14
200	0.075	10.7
270	0.053	9
450	0.032	7.4

From Gradation Curve:	
D10	0.064
D60	3.3
D90	24

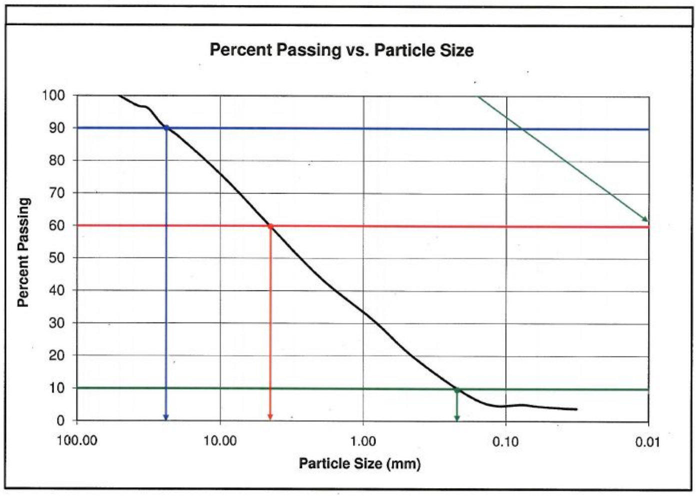


Sample ID: 292-0.8-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	97
1 1/4	31.80	96
1	25.44	91
3/4	19.08	87
3/8	9.54	75
4	4.75	61
10	2.0	44
20	0.85	31
40	0.425	19
100	0.15	6
200	0.075	5.1
270	0.053	4.4
450	0.032	3.9

From Gradation Curve:	
D10	0.21
D60	4.5
D90	24

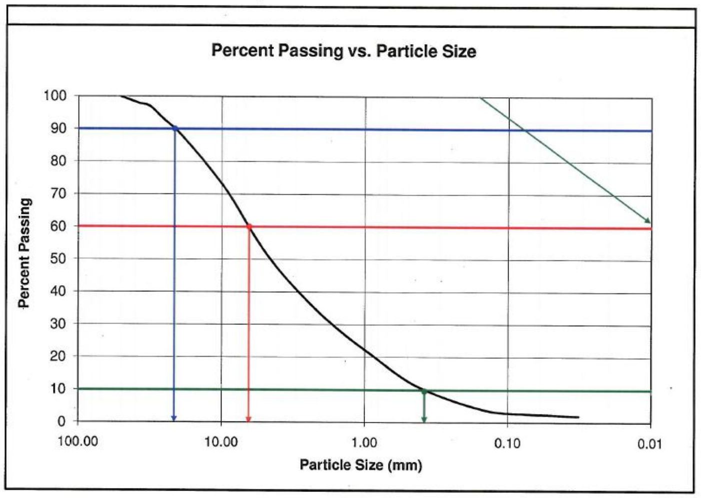


Sample ID: 292-0.8-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	98
1 1/4	31.80	97
1	25.44	93
3/4	19.08	88
3/8	9.54	72
4	4.75	51
10	2.0	33
20	0.85	20
40	0.425	11
100	0.15	4
200	0.075	2.7
270	0.053	2.4
450	0.032	2

From Gradation Curve:	
D10	0.39
D60	6.5
D90	21

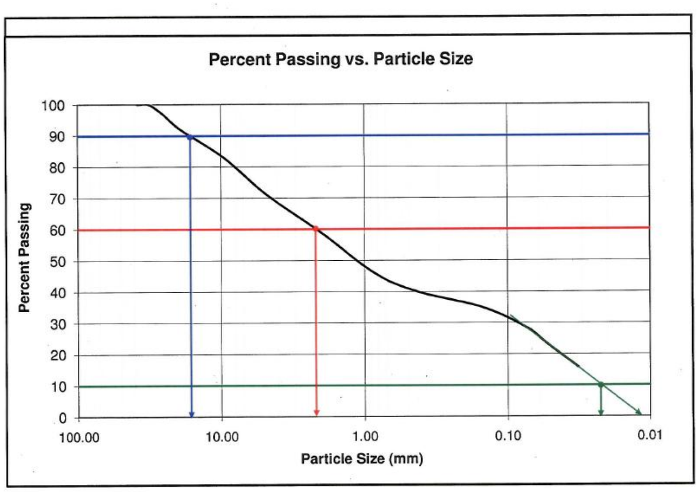


Sample ID: 90EB-286.2-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	97
3/4	19.08	92
3/8	9.54	83
4	4.75	71
10	2.0	59
20	0.85	46
40	0.425	40
100	0.15	35
200	0.075	28.7
270	0.053	23.4
450	0.032	15.8

From Gradation Curve:	
D10	0.021
D60	2.1
D90	17



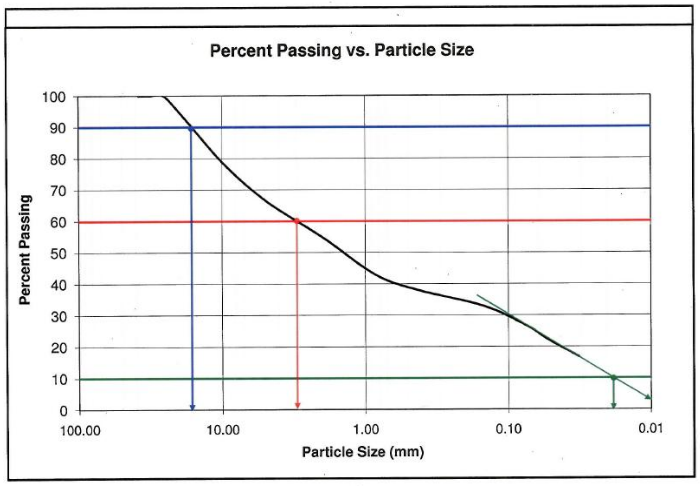
Sample ID: 90EB-286.2-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results

US Sieve (In / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	94
3/8	9.54	78
4	4.75	66
10	2.0	55
20	0.85	43
40	0.425	38
100	0.15	33
200	0.075	26.8
270	0.053	22.4
450	0.032	16.8

From Gradation Curve:	
D10	0.019
D60	3
D90	17



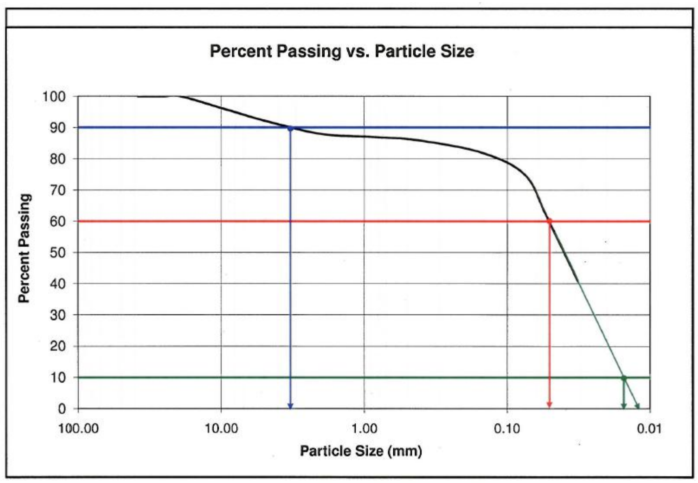
Sample ID: 28-105.6-LT

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results

US Sieve (In / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	96
4	4.75	92
10	2.0	88
20	0.85	87
40	0.425	86
100	0.15	82
200	0.075	74.9
270	0.053	61.8
450	0.032	40.9

From Gradation Curve:	
D10	0.016
D60	0.05
D90	3.1



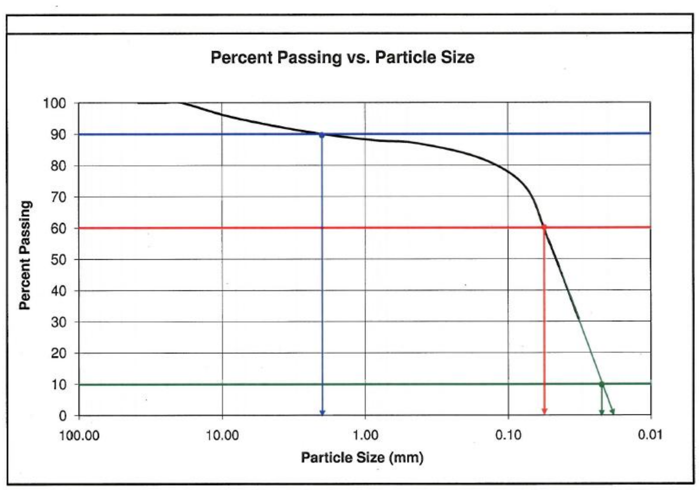
Sample ID: 28-105.6-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results

US Sieve (In / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	96
4	4.75	93
10	2.0	90
20	0.85	88
40	0.425	87
100	0.15	82
200	0.075	73
270	0.053	57.1
450	0.032	30.9

From Gradation Curve:	
D10	0.022
D60	0.055
D90	2

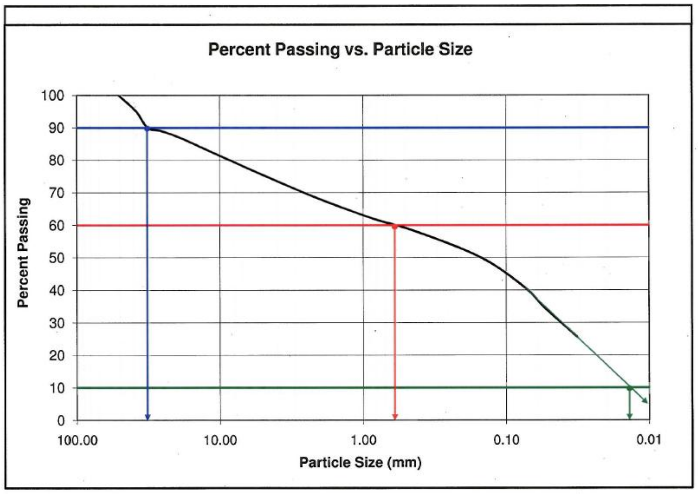


Sample ID: 27-65.4-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	95
1 1/4	31.80	90
1	25.44	89
3/4	19.08	87
3/8	9.54	81
4	4.75	75
10	2.0	68
20	0.85	62
40	0.425	58
100	0.15	50
200	0.075	41
270	0.053	34.3
450	0.032	25.7

From Gradation Curve:	
D10	0.015
D60	6
D90	32

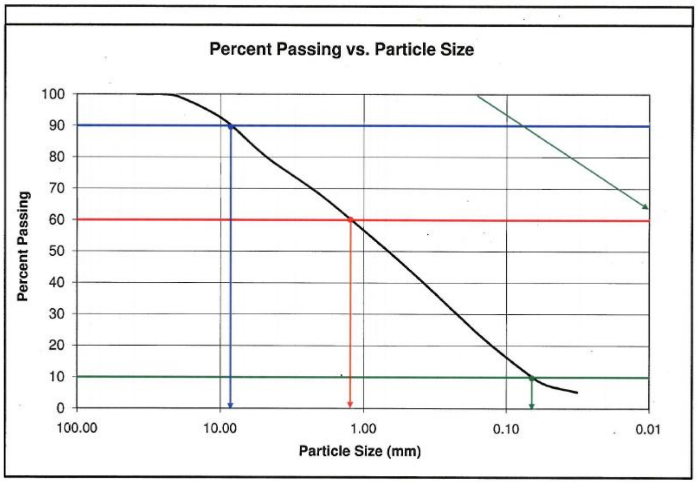


Sample ID: 25-49.0-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	99
3/8	9.54	92
4	4.75	80
10	2.0	68
20	0.85	54
40	0.425	42
100	0.15	23
200	0.075	12
270	0.053	7.7
450	0.032	5.3

From Gradation Curve:	
D10	0.067
D60	1.2
D90	8.5

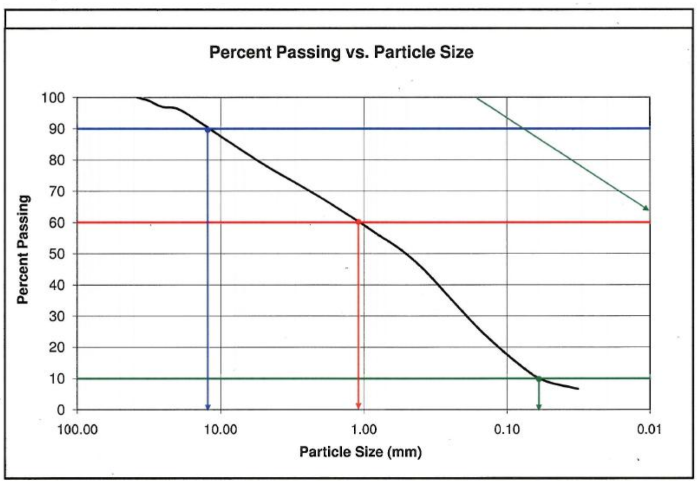


Sample ID: 25-49.0-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	99
1	25.44	97
3/4	19.08	96
3/8	9.54	87
4	4.75	78
10	2.0	68
20	0.85	57
40	0.425	47
100	0.15	25
200	0.075	13
270	0.053	9
450	0.032	6.6

From Gradation Curve:	
D10	0.06
D60	1.1
D90	12

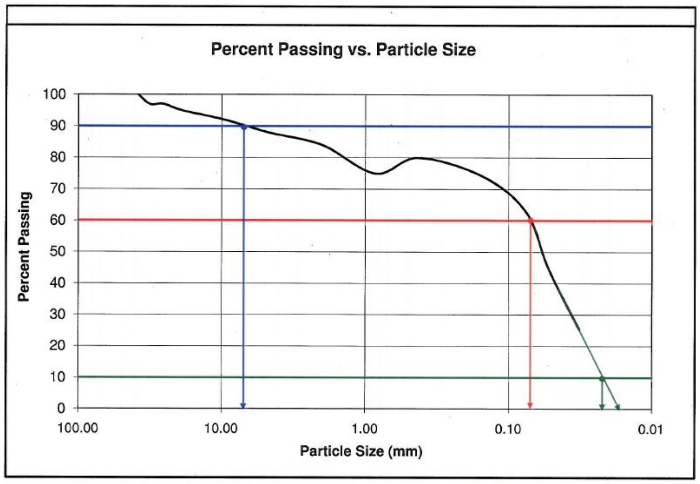


Sample ID: 24-33.5-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	97
1	25.44	97
3/4	19.08	95
3/8	9.54	92
4	4.75	88
10	2.0	84
20	0.85	75
40	0.425	80
100	0.15	74
200	0.075	62.6
270	0.053	45
450	0.032	25.3

From Gradation Curve:	
D10	0.022
D60	0.07
D90	7

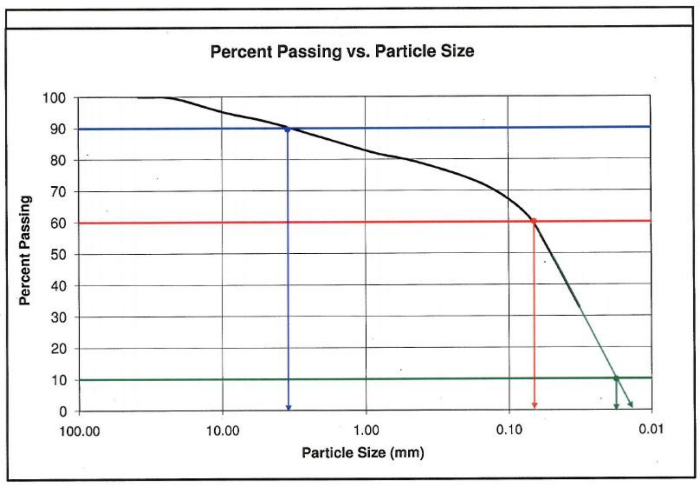


Sample ID: 25-14.7-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	99
3/8	9.54	95
4	4.75	92
10	2.0	87
20	0.85	82
40	0.425	79
100	0.15	72
200	0.075	62.5
270	0.053	51.6
450	0.032	32.9

From Gradation Curve:	
D10	0.018
D60	0.066
D90	3.5

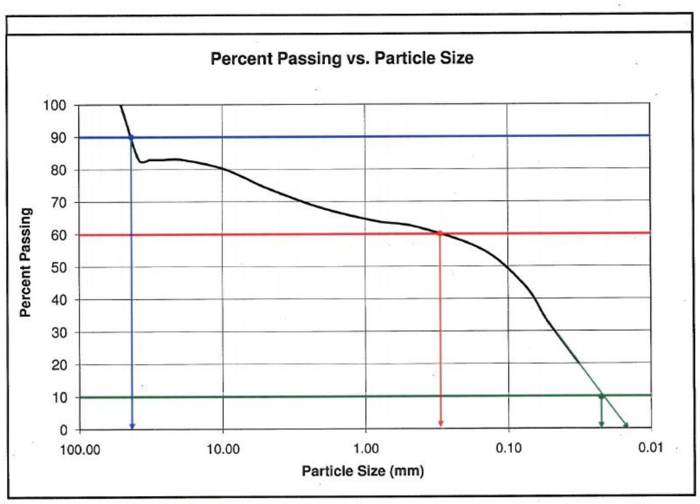


Sample ID: 24-33.5-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	83
1 1/4	31.80	83
1	25.44	83
3/4	19.08	83
3/8	9.54	80
4	4.75	74
10	2.0	68
20	0.85	64
40	0.425	62
100	0.15	55
200	0.075	43.6
270	0.053	33
450	0.032	20

From Gradation Curve:	
D10	0.022
D60	0.3
D90	42

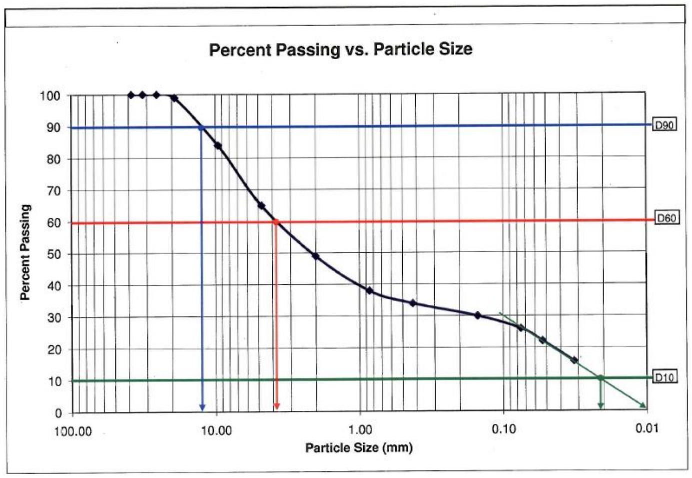


Sample ID: 23-52.1-GP2

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	99
3/8	9.54	84
4	4.75	65
10	2.0	49
20	0.85	38
40	0.425	34
100	0.15	30
200	0.075	26
270	0.053	22.1
450	0.032	15.7

From Gradation Curve:	
D10	0.021
D60	3.8
D90	13

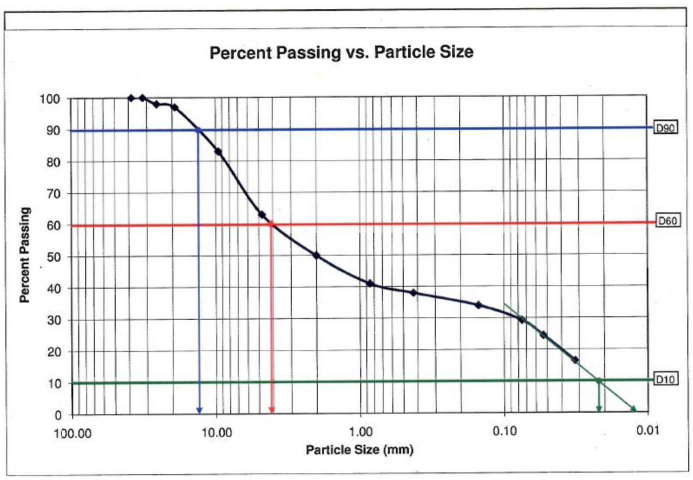


Sample ID: 23-52.1-GP1

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	98
3/4	19.08	97
3/8	9.54	83
4	4.75	63
10	2.0	50
20	0.85	41
40	0.425	38
100	0.15	34
200	0.075	29.3
270	0.053	24.5
450	0.032	16.5

From Gradation Curve:	
D10	0.021
D60	4.1
D90	14

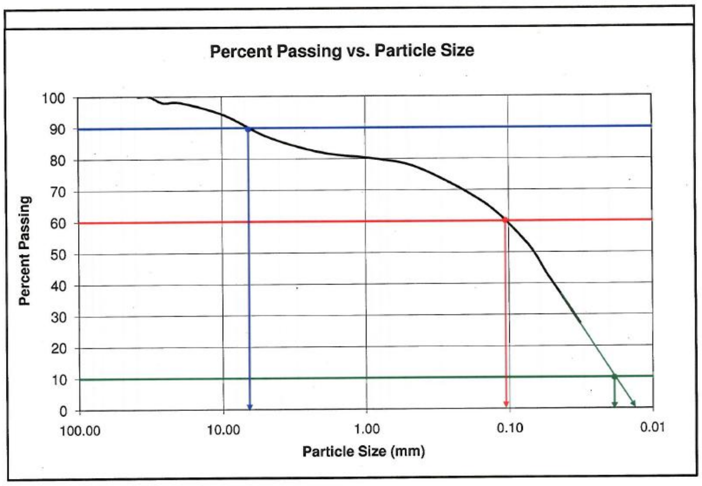


Sample ID: 21-67.1-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	98
3/4	19.08	98
3/8	9.54	94
4	4.75	87
10	2.0	82
20	0.85	80
40	0.425	77
100	0.15	66
200	0.075	53
270	0.053	42.3
450	0.032	27.3

From Gradation Curve:	
D10	0.018
D60	0.11
D90	6.5

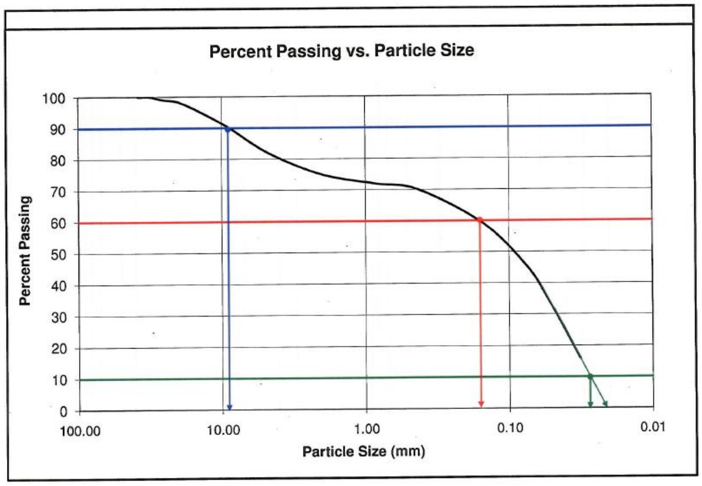


Sample ID: 21-67.1-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	99
3/4	19.08	98
3/8	9.54	91
4	4.75	82
10	2.0	75
20	0.85	72
40	0.425	70
100	0.15	59
200	0.075	45.3
270	0.053	34.5
450	0.032	15.9

From Gradation Curve:	
D10	0.028
D60	0.17
D90	9

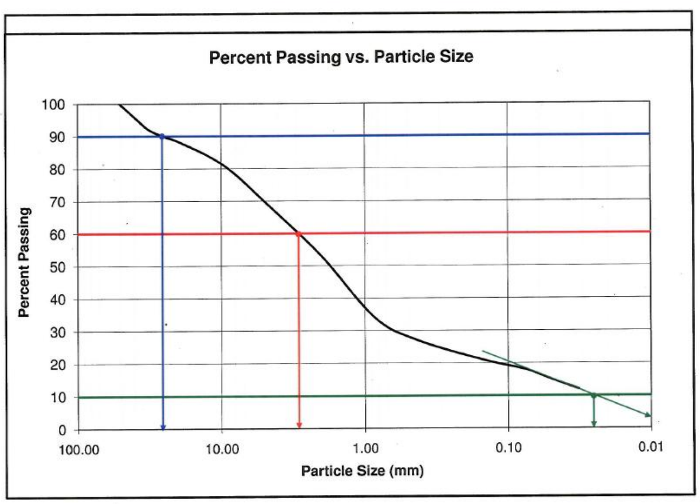


Sample ID: 20-433.9-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	95
1 1/4	31.80	92
1	25.44	90
3/4	19.08	88
3/8	9.54	81
4	4.75	69
10	2.0	53
20	0.85	34
40	0.425	27
100	0.15	21
200	0.075	18
270	0.053	15.5
450	0.032	12

From Gradation Curve:	
D10	0.026
D60	2.9
D90	27

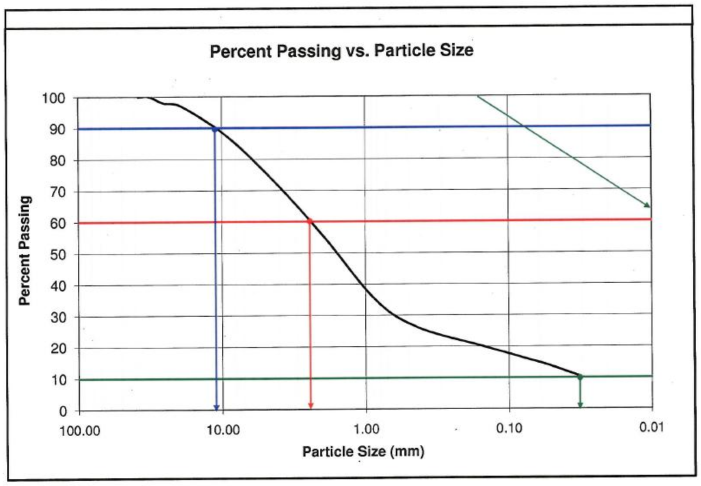


Sample ID: 20-433.9-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	98
3/4	19.08	97
3/8	9.54	88
4	4.75	75
10	2.0	56
20	0.85	35
40	0.425	26
100	0.15	20
200	0.075	16
270	0.053	14
450	0.032	10.4

From Gradation Curve:	
D10	0.031
D60	2.5
D90	11

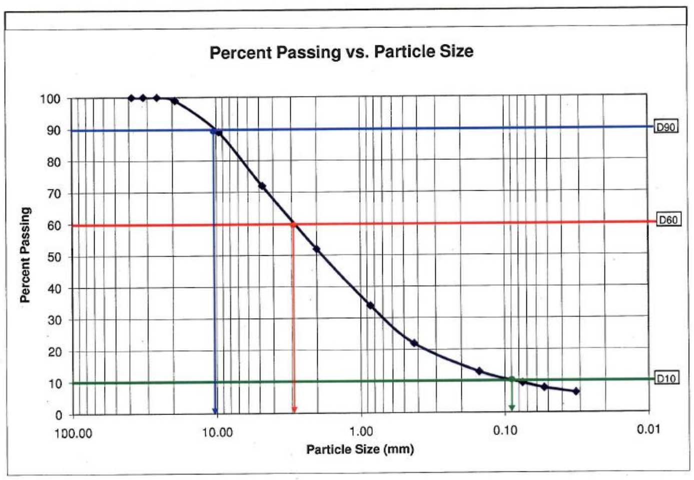


Sample ID: 20-412.8-GP2

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	99
3/8	9.54	89
4	4.75	72
10	2.0	52
20	0.85	34
40	0.425	22
100	0.15	13
200	0.075	9.5
270	0.053	7.9
450	0.032	6.4

From Gradation Curve:	
D10	0.095
D60	2.9
D90	10.5

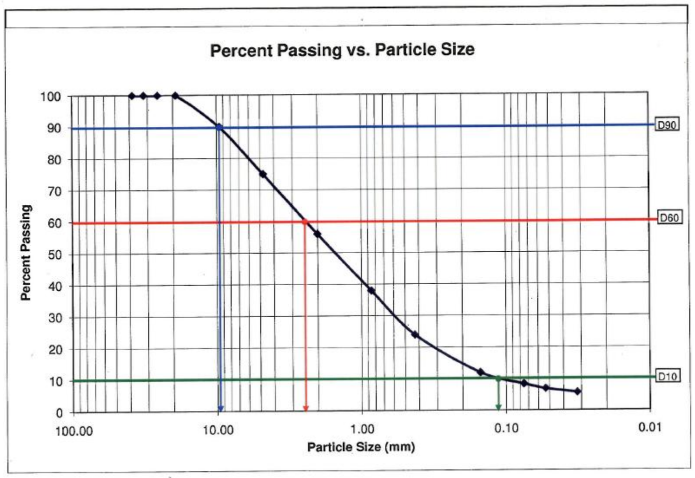


Sample ID: 20-412.8-GP1

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	90
4	4.75	75
10	2.0	56
20	0.85	38
40	0.425	24
100	0.15	12
200	0.075	8.4
270	0.053	6.9
450	0.032	5.7

From Gradation Curve:	
D10	0.13
D60	2.5
D90	9.8

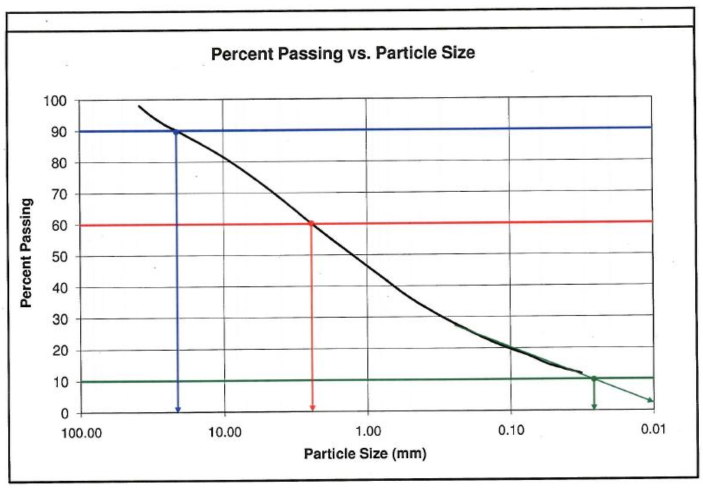


Sample ID: 20-389.1-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	98
1 1/4	31.80	95
1	25.44	92
3/4	19.08	89
3/8	9.54	81
4	4.75	71
10	2.0	57
20	0.85	44
40	0.425	34
100	0.15	23
200	0.075	17.6
270	0.053	14.6
450	0.032	11.8

From Gradation Curve:	
D10	0.027
D60	2.5
D90	21

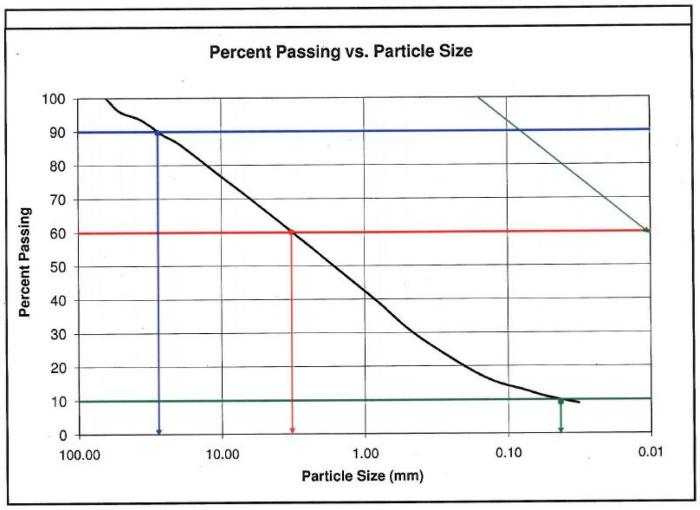


Sample ID: 20-356.7-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2 1/2	63.60	100
2	50.88	96
1 1/2	38.16	94
1 1/4	31.80	92
1	25.44	89
3/4	19.08	86
3/8	9.54	76
4	4.75	66
10	2.0	53
20	0.85	40
40	0.425	29
100	0.15	17
200	0.075	12.8
270	0.053	10.9
450	0.032	9

From Gradation Curve:	
D10	0.042
D60	3.1
D90	28

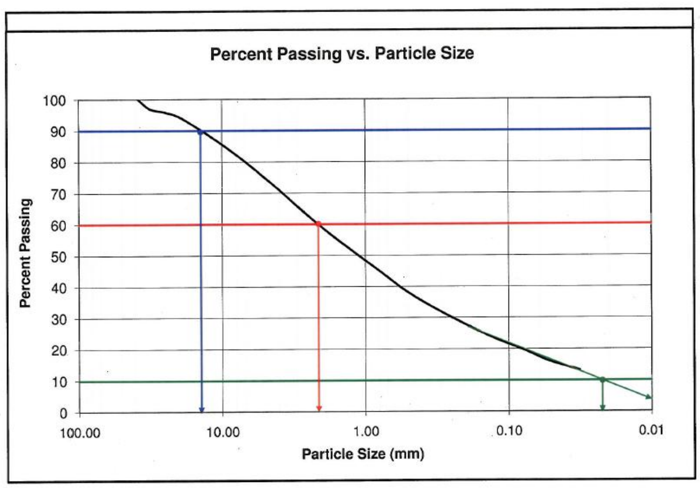


Sample ID: 20-389.1-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	97
1	25.44	96
3/4	19.08	94
3/8	9.54	85
4	4.75	74
10	2.0	59
20	0.85	46
40	0.425	36
100	0.15	25
200	0.075	19.3
270	0.053	16.2
450	0.032	13.2

From Gradation Curve:	
D10	0.021
D60	2.1
D90	15

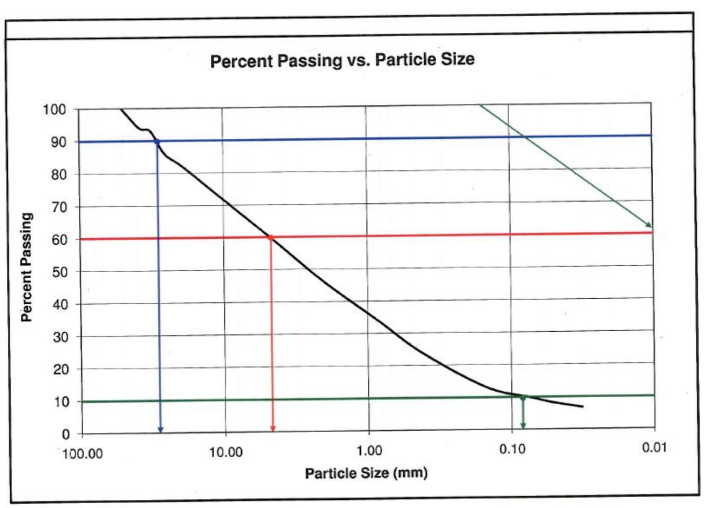


Sample ID: 20-356.7-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	94
1 1/4	31.80	93
1	25.44	86
3/4	19.08	82
3/8	9.54	71
4	4.75	60
10	2.0	46
20	0.85	34
40	0.425	24
100	0.15	13
200	0.075	9.9
270	0.053	8.3
450	0.032	6.7

From Gradation Curve:	
D10	0.085
D60	4.7
D90	29

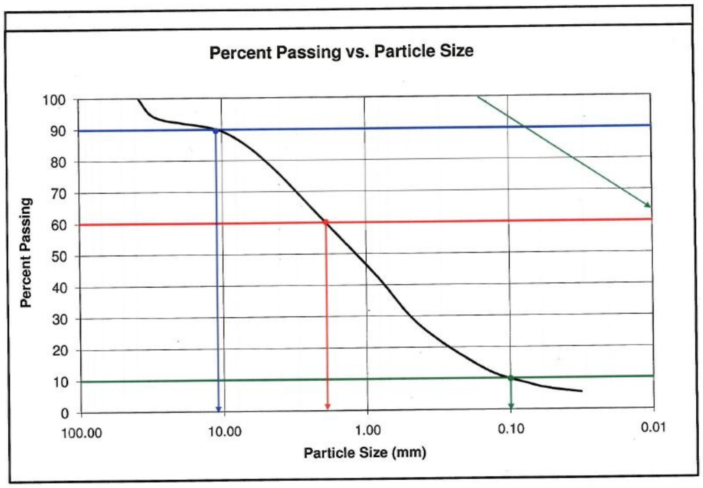


Sample ID: 20-163-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	95
1	25.44	93
3/4	19.08	92
3/8	9.54	89
4	4.75	79
10	2.0	61
20	0.85	43
40	0.425	27
100	0.15	13
200	0.075	8.3
270	0.053	6.7
450	0.032	5.4

From Gradation Curve:	
D10	0.1
D60	1.9
D90	11

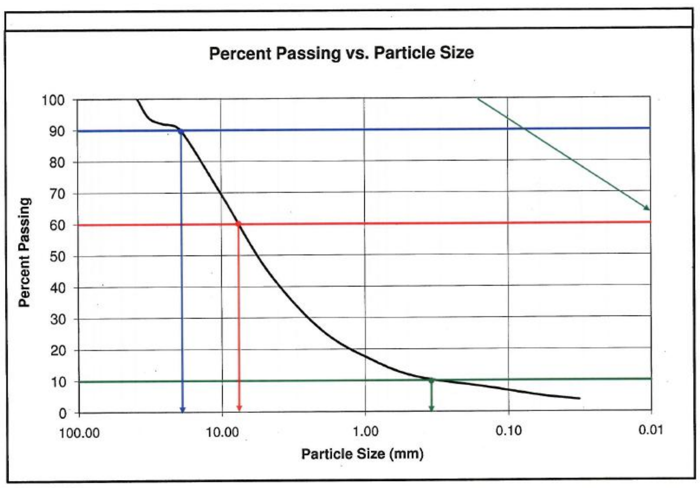


Sample ID: 17-66.7-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	94
1	25.44	92
3/4	19.08	90
3/8	9.54	68
4	4.75	45
10	2.0	26
20	0.85	16
40	0.425	11
100	0.15	8
200	0.075	5.8
270	0.053	4.8
450	0.032	3.8

From Gradation Curve:	
D10	0.35
D60	7.6
D90	19

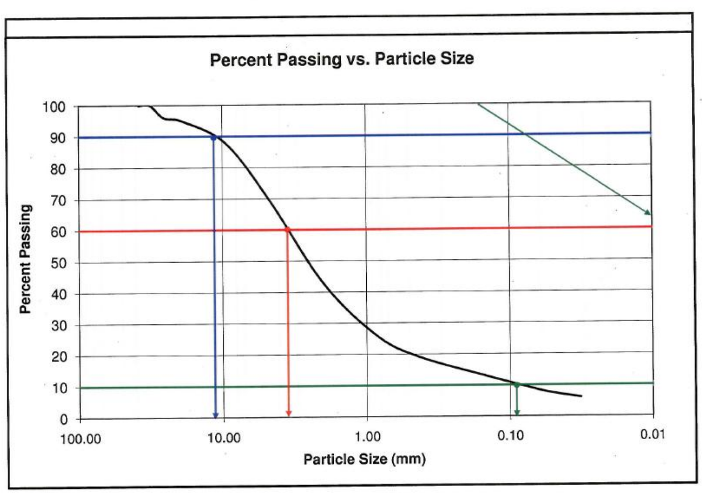


Sample ID: 17-66.7-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	96
3/4	19.08	95
3/8	9.54	88
4	4.75	70
10	2.0	43
20	0.85	26
40	0.425	19
100	0.15	13
200	0.075	9.3
270	0.053	7.6
450	0.032	6

From Gradation Curve:	
D10	0.09
D60	3.5
D90	11

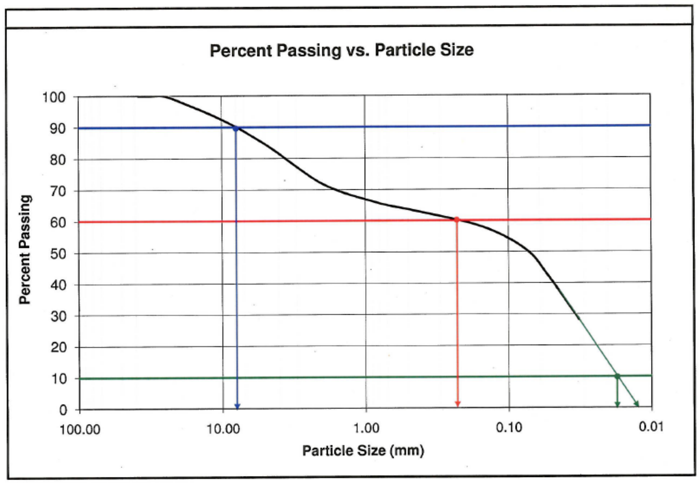


Sample ID: 12-409.6-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	98
3/8	9.54	92
4	4.75	84
10	2.0	72
20	0.85	66
40	0.425	63
100	0.15	58
200	0.075	50.7
270	0.053	42.6
450	0.032	28.2

From Gradation Curve:	
D10	0.017
D60	0.22
D90	8

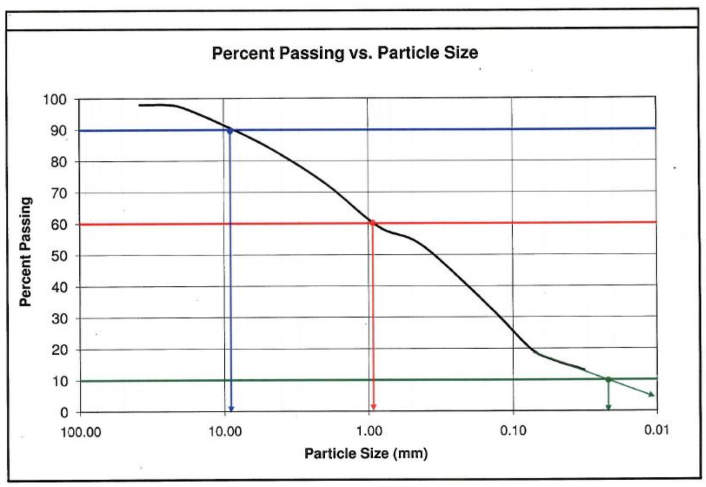


Sample ID: 2-304.7-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	98
1 1/4	·31.80	98
1	25.44	98
3/4	19.08	97
3/8	9.54	91
4	4.75	84
10	2.0	73
20	0.85	59
40	0.425	53
100	0.15	34
200	0.075	19.8
270	0.053	16.3
450	0.032	13

From Gradation Curve:	
D10	0.022
D60	0.93
D90	9

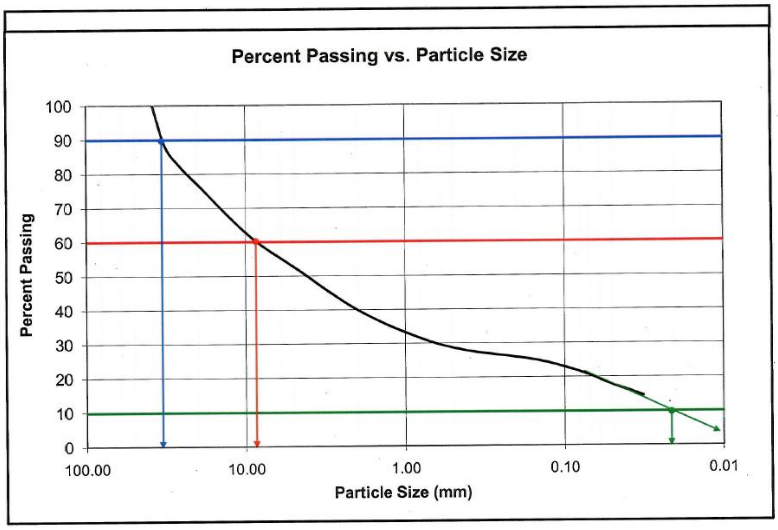


Sample ID: 195-84-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	88
1	25.44	82
3/4	19.08	76
3/8	9.54	62
4	4.75	52
10	2.0	40
20	0.85	32
40	0.425	28
100	0.15	25
200	0.075	21.1
270	0.053	18.2
450	0.032	14.5

From Gradation Curve:	
D10	0.021
D60	8.6
D90	34

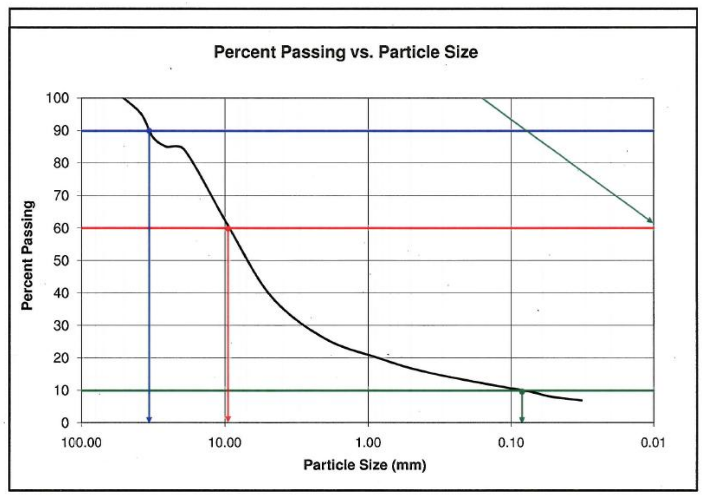


Sample ID: 410-77.8-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	95
1 1/4	31.80	88
1	25.44	85
3/4	19.08	84
3/8	9.54	61
4	4.75	39
10	2.0	26
20	0.85	20
40	0.425	16
100	0.15	12
200	0.075	9.7
270	0.053	8.1
450	0.032	6.9

From Gradation Curve:	
D10	0.085
D60	9.5
D90	34

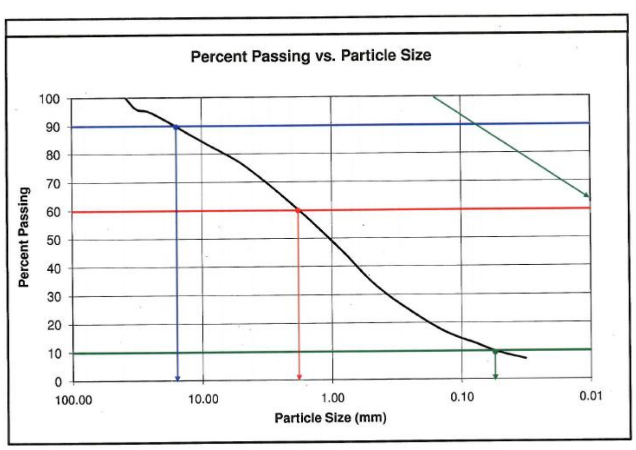


Sample ID: 2-82.8-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	96
1	25.44	95
3/4	19.08	92
3/8	9.54	84
4	4.75	76
10	2.0	62
20	0.85	46
40	0.425	32
100	0.15	18
200	0.075	12.4
270	0.053	9.7
450	0.032	7.2

From Gradation Curve:	
D10	0.055
D60	1.9
D90	17

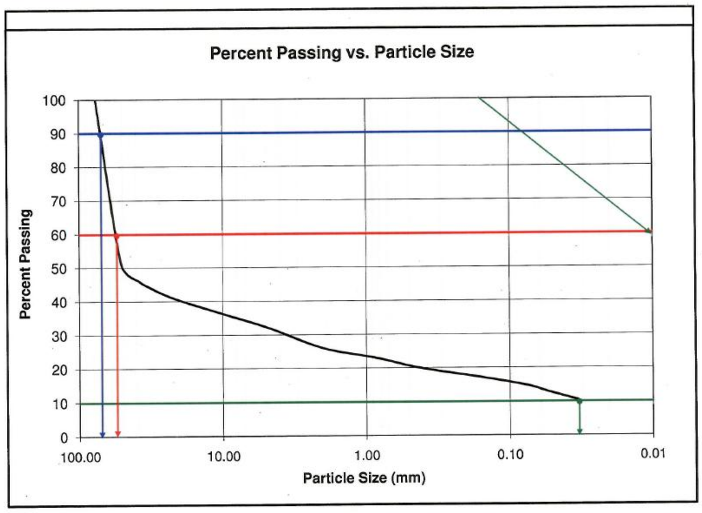


Sample ID: 2-233.8-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
3	76.32	100
2	50.88	51
1 1/2	38.16	46
1 1/4	31.80	44
1	25.44	42
3/4	19.08	40
3/8	9.54	36
4	4.75	32
10	2.0	26
20	0.85	23
40	0.425	20
100	0.15	17
200	0.075	14.7
270	0.053	12.8
450	0.032	10.2

From Gradation Curve:	
D10	0.032
D60	55
D90	70

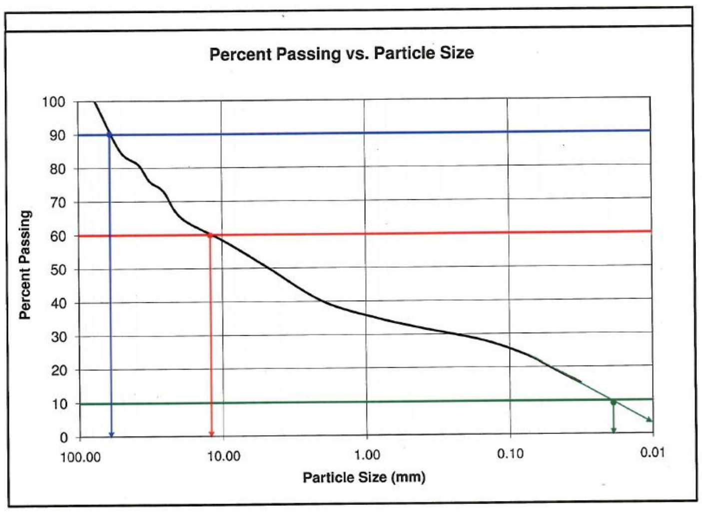


Sample ID: 2-233.8-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
3	76.32	100
2	50.88	85
1 1/2	38.16	81
1 1/4	31.80	76
1	25.44	73
3/4	19.08	65
3/8	9.54	58
4	4.75	50
10	2.0	40
20	0.85	35
40	0.425	32
100	0.15	28
200	0.075	23.5
270	0.053	20.1
450	0.032	15.2

From Gradation Curve:	
D10	0.019
D60	11
D90	60

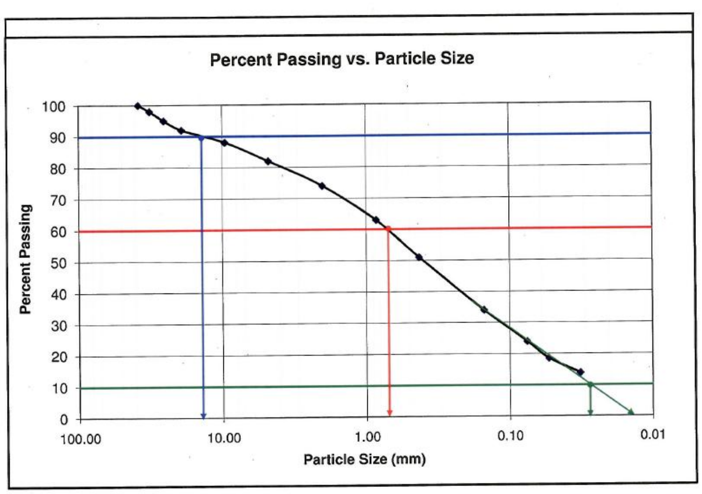


Sample ID: 2-82.8-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	98
1	25.44	95
3/4	19.08	92
3/8	9.54	88
4	4.75	82
10	2.0	74
20	0.85	63
40	0.425	51
100	0.15	34
200	0.075	23.9
270	0.053	18.5
450	0.032	13.8

From Gradation Curve:	
D10	0.028
D60	0.7
D90	13

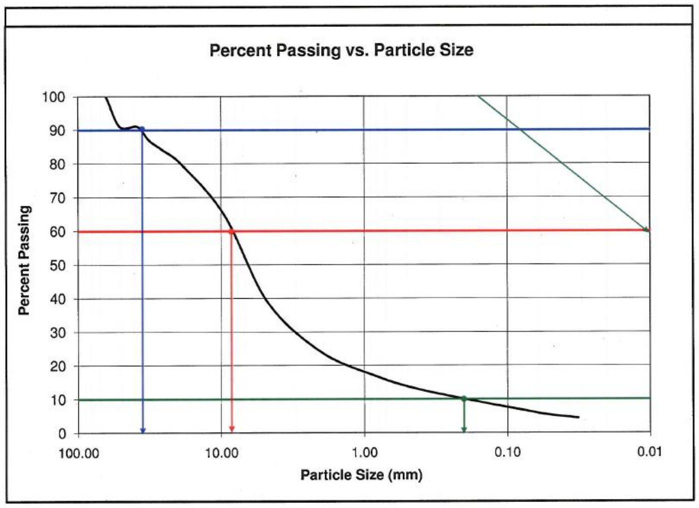


Sample ID: 410-77.8-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2 1/2	63.60	100
2	50.88	91
1 1/2	38.16	91
1 1/4	31.80	87
1	25.44	84
3/4	19.08	80
3/8	9.54	65
4	4.75	39
10	2.0	24
20	0.85	17
40	0.425	13
100	0.15	9
200	0.075	6.6
270	0.053	5.4
450	0.032	4.4

From Gradation Curve:	
D10	0.2
D60	8.5
D90	37

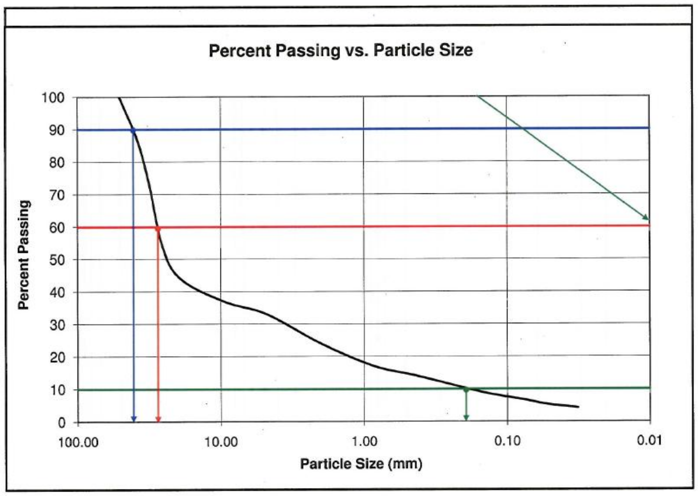


Sample ID: 410-70.8-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	87
1 1/4	31.80	74
1	25.44	54
3/4	19.08	44
3/8	9.54	37
4	4.75	33
10	2.0	24
20	0.85	17
40	0.425	14
100	0.15	9
200	0.075	6.6
270	0.053	5.3
450	0.032	4.2

From Gradation Curve:	
D10	0.19
D60	28
D90	40

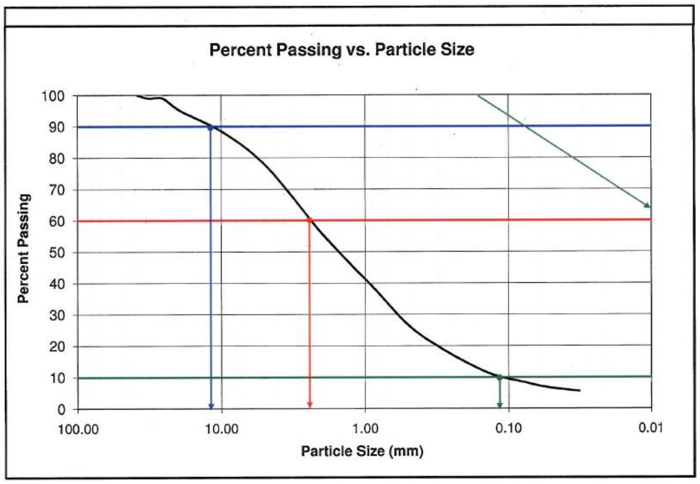


Sample ID: 395-196.7-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	99
1	25.44	99
3/4	19.08	95
3/8	9.54	88
4	4.75	77
10	2.0	56
20	0.85	38
40	0.425	24
100	0.15	12
200	0.075	8.2
270	0.053	6.7
450	0.032	5.5

From Gradation Curve:	
D10	0.12
D60	2.5
D90	12

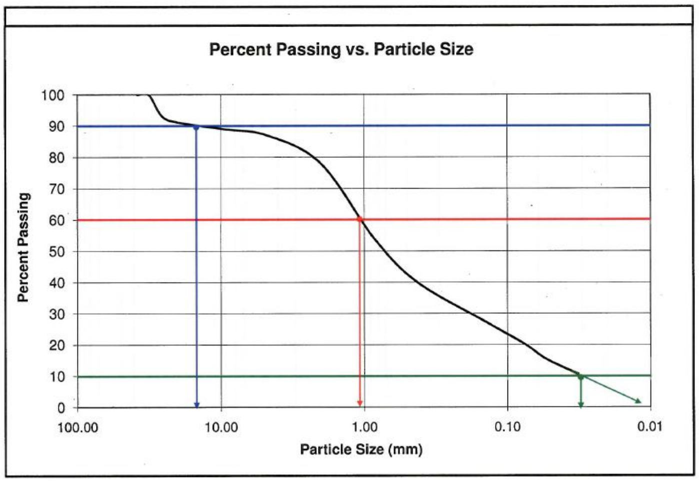


Sample ID: 124-12.6-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	93
3/4	19.08	91
3/8	9.54	89
4	4.75	87
10	2.0	78
20	0.85	54
40	0.425	40
100	0.15	28
200	0.075	20.1
270	0.053	15.3
450	0.032	10.6

From Gradation Curve:	
D10	0.03
D60	1.1
D90	15

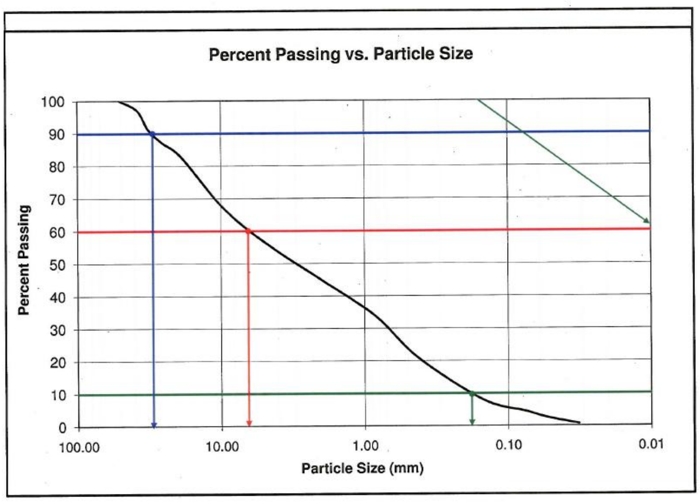


Sample ID: 97-247.1-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	97
1 1/4	31.80	91
1	25.44	87
3/4	19.08	83
3/8	9.54	67
4	4.75	56
10	2.0	45
20	0.85	34
40	0.425	21
100	0.15	8
200	0.075	4.4
270	0.053	2.5
450	0.032	0.6

From Gradation Curve:	
D10	0.18
D60	6.5
D90	30

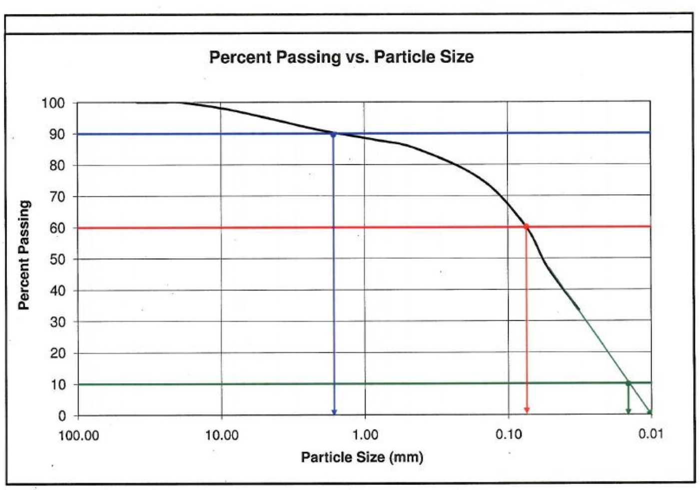


Sample ID: 25-14.7-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	98
4	4.75	95
10	2.0	91
20	0.85	88
40	0.425	85
100	0.15	75
200	0.075	60.1
270	0.053	47.2
450	0.032	33.5

From Gradation Curve:	
D10	0.015
D60	0.075
D90	1.7

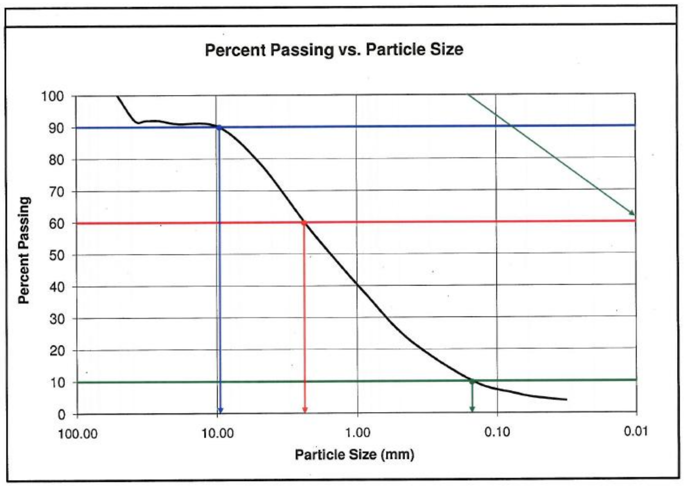


Sample ID: 20-163-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
2	50.88	100
1 1/2	38.16	92
1 1/4	31.80	92
1	25.44	92
3/4	19.08	91
3/8	9.54	90
4	4.75	78
10	2.0	56
20	0.85	37
40	0.425	23
100	0.15	10
200	0.075	6.2
270	0.053	4.9
450	0.032	3.9

From Gradation Curve:	
D10	0.16
D60	2.4
D90	9.5

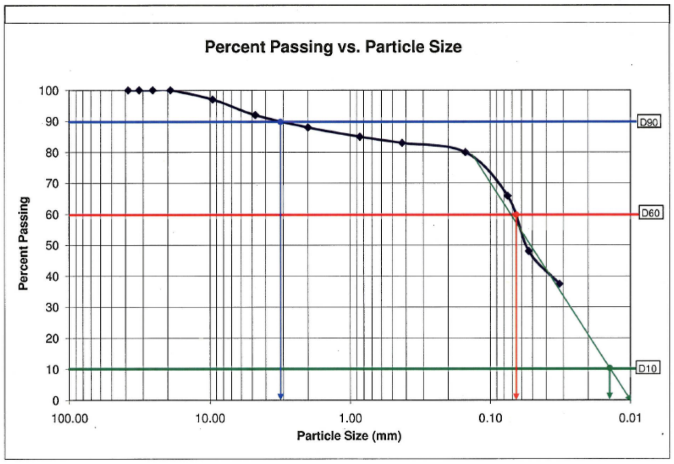


Sample ID: 274-0.71-GP2

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	97
4	4.75	92
10	2.0	88
20	0.85	85
40	0.425	83
100	0.15	80
200	0.075	65.9
270	0.053	48.1
450	0.032	37.5

From Gradation Curve:	
D10	0.015
D60	0.067
D90	3.05

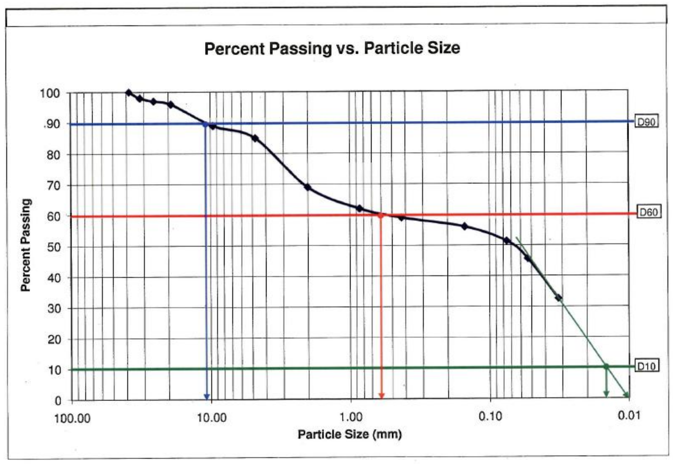


Sample ID: 274-0.71-GP1

Enter information in yellow boxes, gray boxes are calculated results.

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	98
1	25.44	97
3/4	19.08	96
3/8	9.54	89
4	4.75	85
10	2.0	69
20	0.85	62
40	0.425	59
100	0.15	56
200	0.075	51.3
270	0.053	45.6
450	0.032	32.6

From Gradation Curve:	
D10	0.016
D60	0.6
D90	11

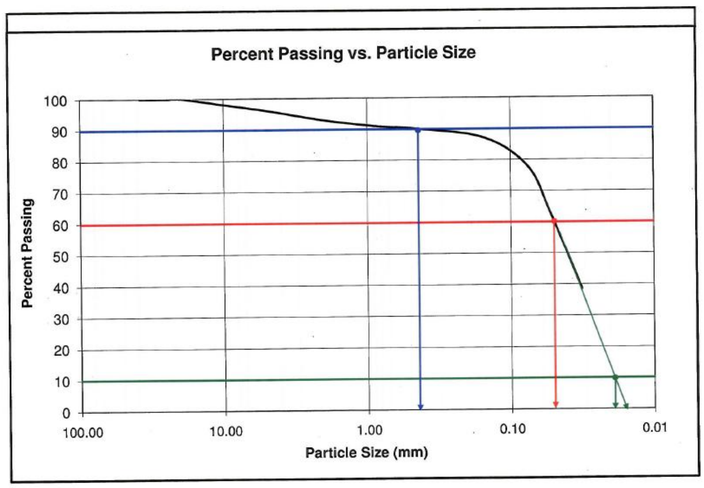


Sample ID: 261-19.4-GP2

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	98
4	4.75	96
10	2.0	93
20	0.85	91
40	0.425	90
100	0.15	87
200	0.075	77.7
270	0.053	63.2
450	0.032	38.6

From Gradation Curve:	
D10	0.019
D60	0.05
D90	0.44

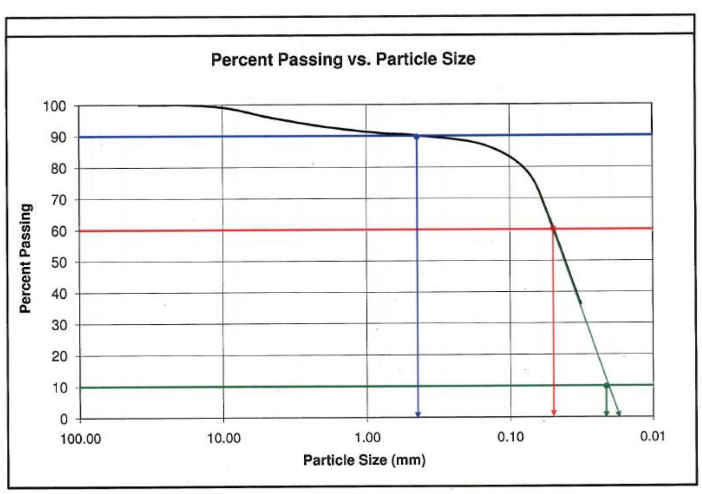


Sample ID: 261-19.4-GP1

Fill Color Key
Input gradation data in turquoise cells
Calculated results appear in gray cells

Gradation Results		
US Sieve (in / #)	Metric Sieve (mm)	Percent Passing
1 1/2	38.16	100
1 1/4	31.80	100
1	25.44	100
3/4	19.08	100
3/8	9.54	99
4	4.75	96
10	2.0	93
20	0.85	91
40	0.425	90
100	0.15	87
200	0.075	78.5
270	0.053	63.8
450	0.032	36.1

From Gradation Curve:	
D10	0.021
D60	0.05
D90	0.45



APPENDIX D. NATIVE SOIL CLASSIFICATION & UNIFORMITY COEFFICIENTS

Site Identification	Slope Soil Field Classification	Hydrologic Soil Group	Native Soil Classification	Cu
High Erosion Classification				
155-70.8-RT	Sandy Silt w/ Gravel	-	-	27
292-0.8-RT	Loose Gravelly Sand	B	Bonner Silt Loam	19
23-52.1-RT	Silt w/ Sand and Some Gravel	-	-	188
20-389.1-RT	Silty Loam	B	Orwig Sand Loam	96
97-247.1-LT	Sandy silt w/ gravel	D	Rock Outcrop	36
395-196.7-LT	Gravelly Sand w/ Some Silt	B	Bonner Silt Loam	20
195-76.6-LT	Clay Loam	B	Naff Silt Loam	3
Moderate Erosion Classification				
410-70.8-RT	Sandy Gravel	B	Naff Silt Loam	99
231-44.5-LT	Sandy Gravel w/ Some Silt	-	-	18
25-49.0-RT	Loose Gravelly Sand w/ Silt	B	Cedonia Silt Loam	18
20-163-LT	Sandy Silt w/ Gravel and Cobbles	-	-	17
2-82.8-LT	Silt w/ Some clay	B	Beverly gravelly fine sandy loam	30
17-66.7-RT	Sandy Gravel w/ Cobbles	D/C	Umapine silt loam	30
155-14.4-RT	Gravelly Sand w/ Some Silt	A	Rubble land-Rock outcrop complex	21
195-21.3-LT	Silty Clay Loam	C/B	Palouse Silt Loam	3
231-57.6-LT	Silty Sand w/ Gravel	B/C	Spokane Stony Loam	26

Site Identification	Slope Soil Field Classification	Hydrologic Soil Group	Native Soil Classification	Cu
Low Erosion Classification				
211-0.25-RT	Gravelly Sand	B	Kaniksu Sandy Loam	17
261-19.4-LT	Soft Silt w/ some fine sand	C/D	Rolof-Rock Outcrop Complex	3
231-11.2-LT	Loose Silt w/ Some Clay	-	-	3
20-433.9-LT	Sandy Silt w/ Gravel	B/C	Bonner Gravelly Silt Loam	96
90WB-229.3-LT	Clayey Silt	B/C	Benge Gravelly Silt Loam	3
90WB-291.0-LT	Silty Gravel w/ Sand	B	Garrison Gravelly Loam	347
207-2.6-LT	Sandy Silt w/ Gravel	B/C	Nevine stony sandy loam	20
27-65.4-RT	Sandy Loam	B	Naff Silt Loam	22
20-356.7-RT	Sandy Silt w/ Gravel	B/A	Spens very gravelly loamy sand	65

Site Identification	Slope Soil Field Classification	Hydrologic Soil Group	Native Soil Classification	Cu
None Erosion Classification				
261-61.0-LT	Silt Loam	B	Ritzville Silt Loam	
410-77.8-LT	Sandy Gravel	-	-	77
24-33.5-LT	Sandy silt	B/C	Burke Silt Loam	8
125-19.1-LT	Silt w/ some gravel	B	Walla Walla Silt Loam	5
195SB-84-LT	Silty Gravel w/ Sand	B/C	Hesseltine Stony Silt Loam	317
124-12.6-LT	Silty Sand	A/B	Quincy loamy fine sand	27
206-2.26-LT	Gravelly Silt w/ Sand	B/D	Snow Silt Loam	45
206-2.27-LT	Gravelly Silt w/ Some Sand	B/D	Snow Silt Loam	161
25-14.7-RT	Sandy Silt w/ Some Gravel	-	-	4
20-412.8-RT	Silty Sand w/ Some Gravel	B	Cusik Silty Clay Loam	25
12-409.6-RT	Gravelly Silt	B	Athena Silt Loam	30
274-0.71-LT	Silty Clay	B	Palouse Silt Loam	21
97-49.6-RT	Sandy Gravel	-	-	97
28-105.6-LT	Loose Silt w/ Some Sand	-	-	3
21-67.1-RT	Silt Loam w/ Ash	-	-	6
2EB-304.7-RT	Sandy Loam w/ Gravel	B/D	Peone silt loam	89
90EB-286.2-RT	Gravelly Silt	B	Garrison Gravelly Loam	129
2-266.8-RT	Gravelly Clay Loam w/ Cobbles	-	-	345
129-22.6-LT	Gravel w/ cobbles	C/D	Limekiln Stembler Complex	10
2-233.8-RT	Silty Gravel w/ Cobbles	D	Anders-Bakeoven-Rock Outcrop	1149

APPENDIX E. EMPIRICAL OBSERVATIONS INVENTORY BY SITE

Site Identification	Imperfections at EOP	Channeling at EOP Interface	Flow Spreader Feature	Guard Rail Present
High Erosion Classification				
155-70.8-RT	Yes	Yes	No	Yes
292-0.8-RT	No	Yes	No	No
23-52.1-RT	No	Yes	No	No
20-389.1-RT	No	Yes	No	Yes
97-247.1-LT	No	No	No	No
395-196.7-LT	No	No	No	No
195-76.6-LT	No	No	No	No
Moderate Erosion Classification				
410-70.8-RT	Yes	Yes	No	Yes
231-44.5-LT	No	Yes	No	No
25-49.0-RT	No	No	No	No
20-163-LT	No	Yes	No	No
2-82.8-LT	No	Yes	No	No
17-66.7-RT	No	No	No	No
155-14.4-RT	No	Yes	No	No
195-21.3-LT	Yes	No	No	Yes
231-57.6-LT	No	Yes	No	No
Low Erosion Classification				
211-0.25-RT	No	No	No	No
261-19.4-LT	No	No	No	No
231-11.2-LT	No	No	No	No
20-433.9-LT	No	No	No	No
90WB-229.3-LT			No	Yes
90WB-291.0-LT	No	No	No	No
207-2.6-LT	Yes	No	Yes	No
27-65.4-RT	Yes	No	No	No
20-356.7-RT	No	No	No	No

Site Identification	Imperfections at EOP	Channeling at EOP Interface	Flow Spreader Feature	Guard Rail Present
None Erosion Classification				
261-61.0-LT	Yes	No	No	No
410-77.8-LT	No	No	No	No
24-33.5-LT	No	No	No	Yes
125-19.1-LT	No	No	No	No
195SB-84-LT	No	No	No	No
124-12.6-LT	No	No	No	Yes
206-2.26-LT	No	No	No	Yes
206-2.27-LT	No	No	No	Yes
25-14.7-RT	No	No	No	No
20-412.8-RT	No	No	No	No
12-409.6-RT	No	No	No	No
274-0.71-LT	No	No	No	No
97-49.6-RT	No	No	No	Yes
28-105.6-LT	No	No	No	No
21-67.1-RT	No	No	No	No
2EB-304.7-RT	No	No	Y-	No
90EB-286.2-RT	No	No	No	No
2-266.8-RT	Yes	Yo	No	No
129-22.6-LT	No	No	No	No
2-233.8-RT	No	No	No	No

APPENDIX F. STATISTICAL ANALYSIS BACK UP DATA

Box Plots

The box plots generated provide a visual representation of the spread of data by erosion classification where a longer box indicates a larger spread of data and a smaller box indicates a more dense spread. Figure F1 illustrates the data provided from the box plots. Each box represents the inter-quartile (IQR) range of data or the middle 50% of data and is calculated using Equation F1 and Q1is the median value of the data below the median and Q3 is the median value of the data above the median.

$$IQR=Q_3-Q_1 \qquad \text{Eqn F1}$$

The whiskers that extend above and below the box represent 1.5 times the upper and lower quartile and are calculated using Equation F2 and F3. If the maximum or minimum value is less than 1.5 times the upper and low quartile, then the whiskers only extend to those values. If no whiskers are present, then the maximum or minimum value is the same as Q1 or Q3. Any value that does not fall in within 1.5 times Q1 or Q3 is considered an outlier.

$$LW=1.5Q_1 \qquad \text{Eqn F2}$$

$$UW=1.5Q_3 \qquad \text{Eqn F3}$$

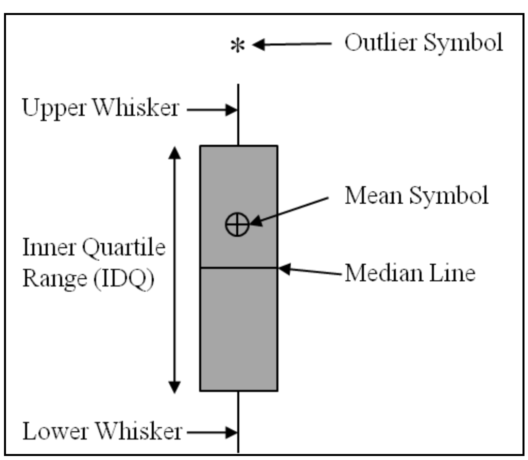


Figure F1 Illustration of Box Plot

Discussion for Site Characteristics that did not Correlate With Erosion Severity

The roadway profile had the third closest correlation coefficient of 0.258 indicating a low positive relationship. As the roadway profile increases, there was also a tendency for erosion severity to increase (see Figure F1). The p-value was 0.088 indicating that the relationship between roadway profile and erosion severity is not as statistically significant (p-value > 0.05) compared to other site factors.

The 100-year 3-hour precipitation depth had the fourth highest correlation coefficient of 0.213 indicating a weak positive relationship. As the 100-year 3-hour precipitation depth increased, there was a tendency for erosion severity to increase (see Figure F2). The p-value was 0.16, indicating that the relationship between 100-year 3-hour precipitation and erosion severity is not statistically significant (p-value > 0.05) compared to other site characteristics.

The percentage of fines present along the embankment had the sixth highest correlation coefficient of -0.205, indicating a weak negative relationship. As the percentage of fines decreased, there was an increased trend in erosion severity (see Figure F3). The mean values shown in Figure F3 also show a decrease in fines at sites with high erosion severity. This is consistent with the correlation to sand they since are inversely related. However, the p-value was 0.181, indicates the relationship between the percentage of fines and erosion severity is not statistically significant (p-value > 0.05) compared to other site characteristics.

The distance from the EOP to vegetation had the seventh largest correlation coefficient of 0.189, indicating a weak positive relationship. As the distance from EOP increased, there was a slight increased trend with erosion severity (see Figure F4). The p-value was 0.215 indicating that the relationship between distance from EOP to vegetation and erosion severity is not statistically significant (p-value > 0.05) compared to other site characteristics.

The Ksat had the eighth highest correlation coefficient of 0.122, indicating a positive weak relationship to erosion severity. As Ksat increased there, was a slight increased trend in erosion severity. The p-value was 0.47, indicating that the relationship between Ksat and erosion severity is not statistically significant (p-value > 0.05) compared to other site characteristics. This is also shown in Figure F5, which shows that while the average Ksat values for sites with no erosion were lower than sites with low and moderate erosion classifications. The lowest mean Ksat was noted at sites with high erosion.

The percentage of gravel along the embankment had the ninth highest correlation coefficient of 0.063, indicating a minor positive relationship. As the percentage of gravel increased, there was a slight increased trend in erosion severity. The p-value was 0.682, indicating the relationship between the percentage of gravel and erosion severity is not statistically significant (p-value > 0.05) compared to other site characteristics. This is also shown in Figure F6 which shows the spread of data at each site is similar with the highest mean percentage of gravel at sites with no erosion and then steadily increased from the low to high erosion sites.

The super elevation had the tenth highest correlation coefficient of 0.012, indicating a weak positive relationship. As the super elevation increased, there was a slight increased trend with erosion severity. The p-value was 0.92, indicating the relationship between super elevation and erosion severity was not statistically significant (p-value > 0.05) compared to other site characteristics. This is also shown in Figure F7 which shows a large spread of data at all sites with the mean lowest at sites with low erosion then sites with no erosion site followed by a slight increase from moderate to high erosion sites.

The MAP had the twelfth highest correlation coefficient of 0.053, indicating a weak positive relationship. As MAP increased, there was a slight increased trend with erosion severity. The p-value was 0.728, indicating the relationship between MAP and erosion severity was not statistically significant (p-value > 0.05) compared to other site. This is also shown in Figure F8, which shows the mean is nearly the same at sites with no erosion and high erosion.

The width of pavement had the thirteenth and least strong correlation coefficient of 0.012, indicating a weak positive relationship. As the width of pavement increased, there was a slight increased trend to erosion severity. The p-value was 0.92, indicating the relationship between the width of pavement and erosion severity is not statistically significant (p-value > 0.05) compared to other site characteristics. This is can be observed in Figure F9, which shows the mean is nearly consistent at both the no erosion and high erosion sites.

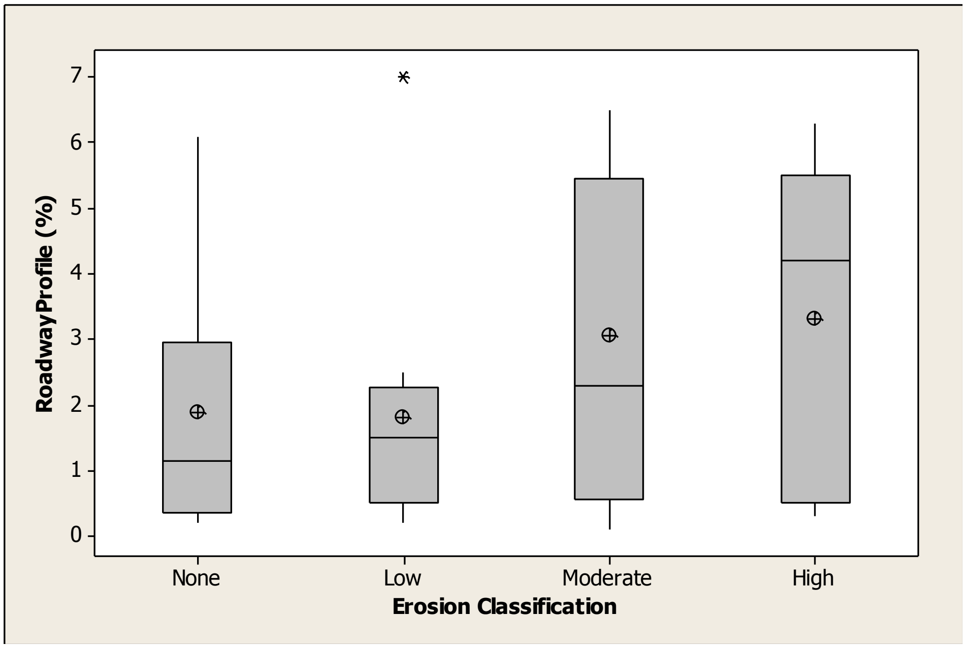


Figure F1 Roadway Profile vs Erosion Severity Classification

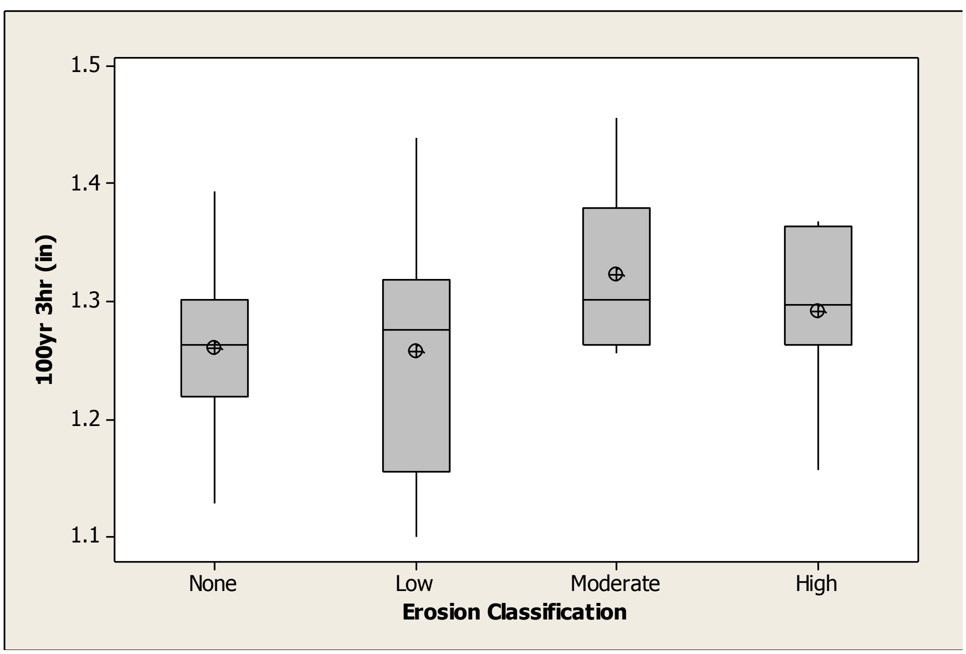


Figure F2 100 year 3 hour Precipitation by Erosion Severity Classification

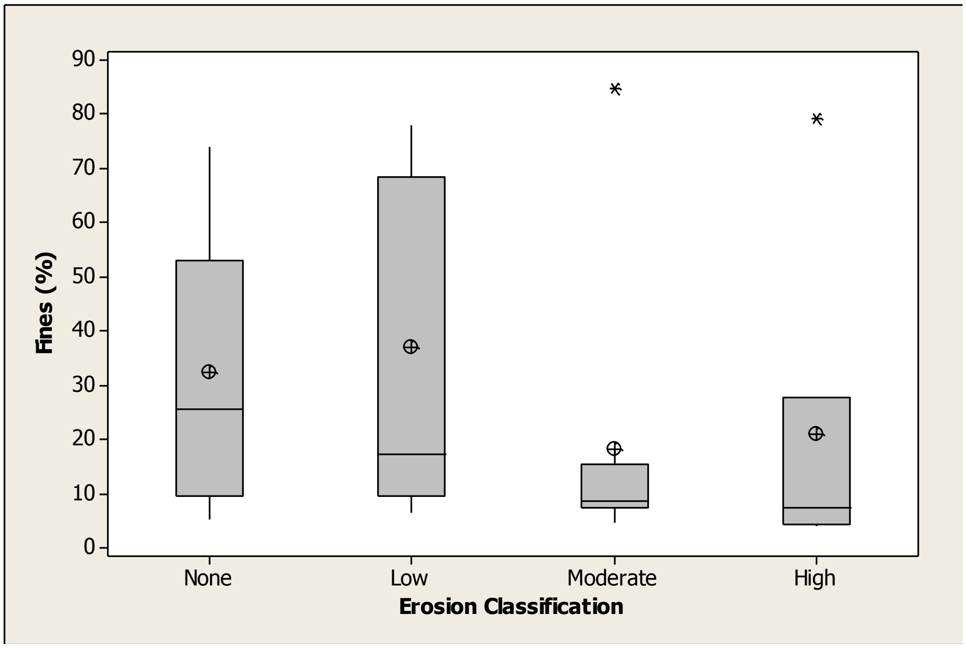


Figure F3 Percentage Fines by Erosion Severity Classification

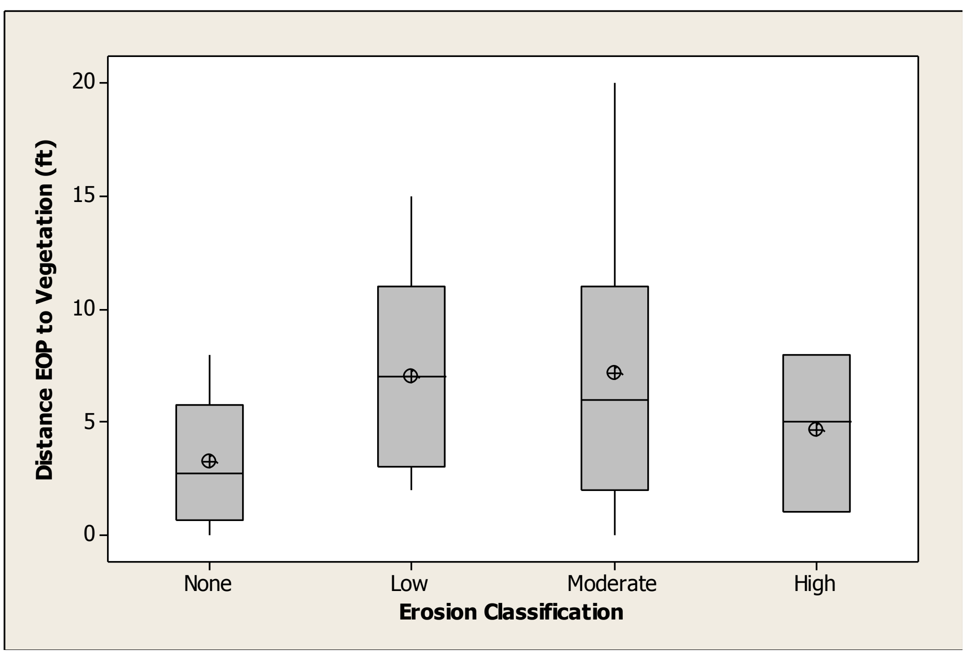


Figure F4 Distance EOP to Vegetation by Erosion Severity Classification

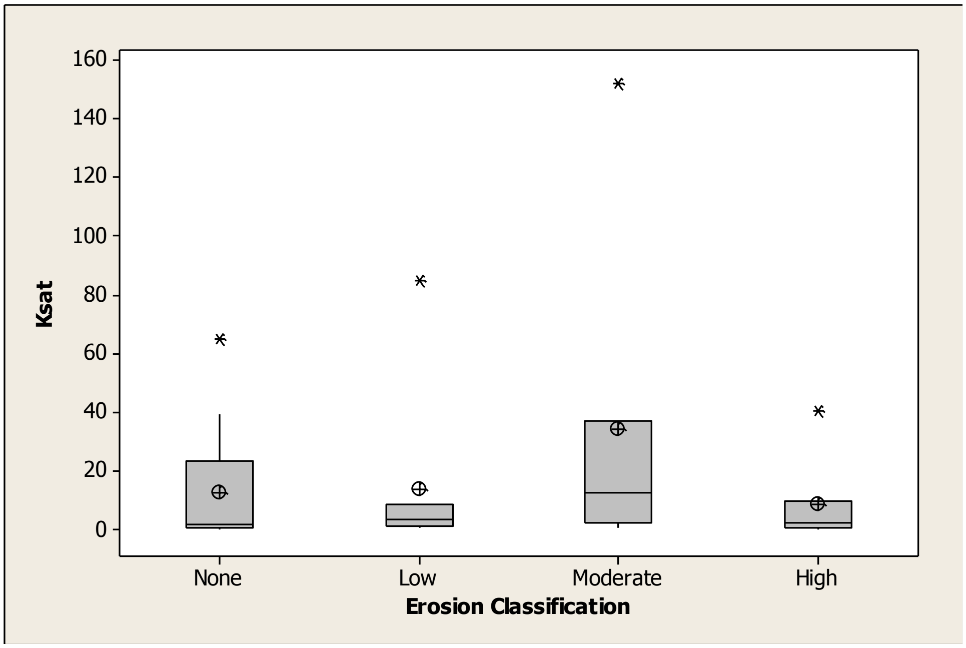


Figure F5 Saturated Hydraulic Conductivity by Erosion Severity Classification

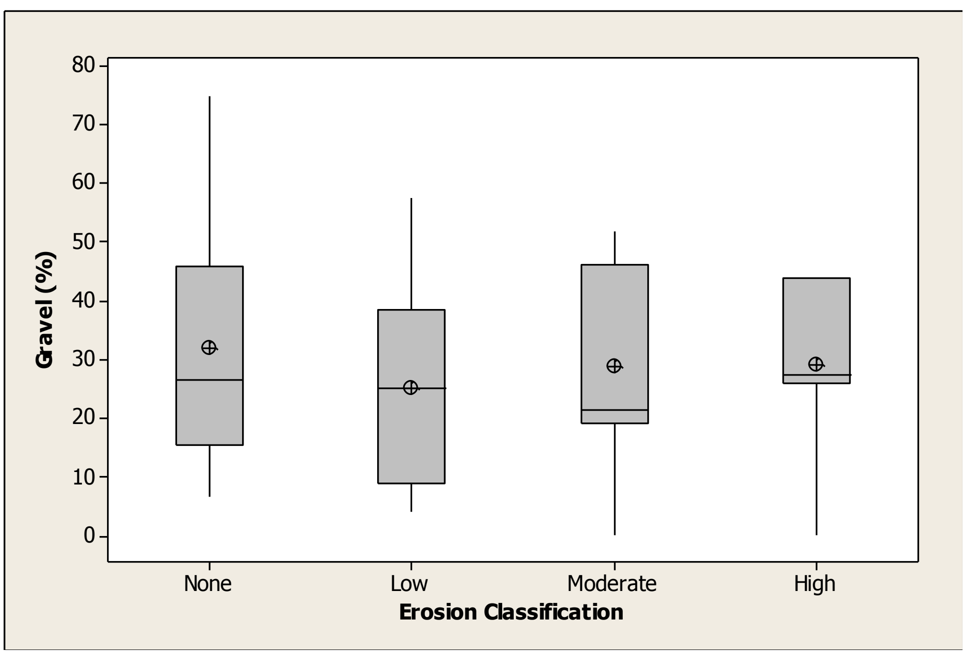


Figure F6 Percentage Gravel by Erosion Severity Classification

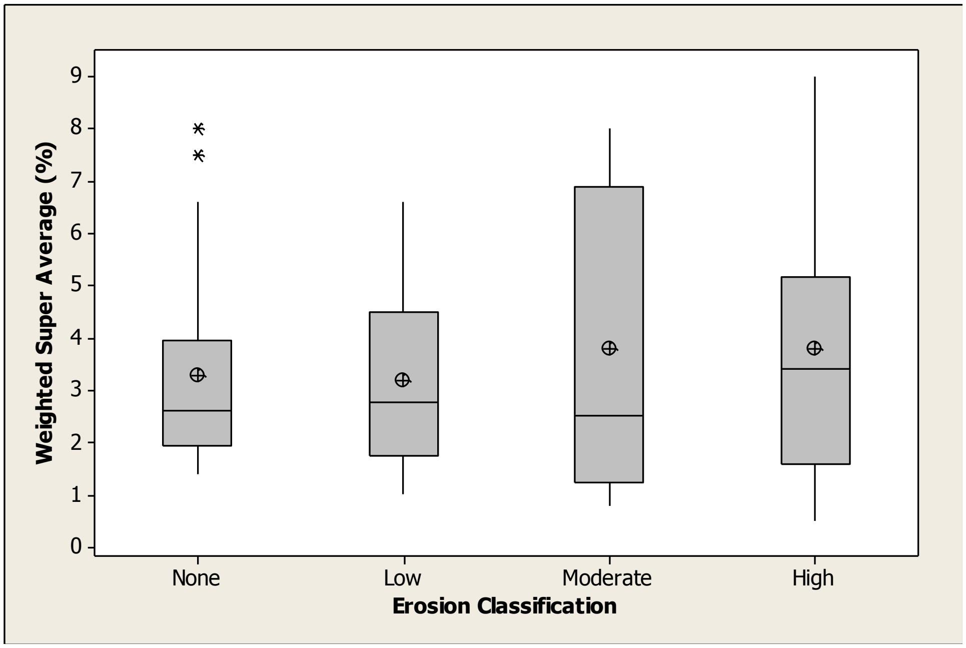


Figure F7 Super Elevation vs Erosion Severity Classification

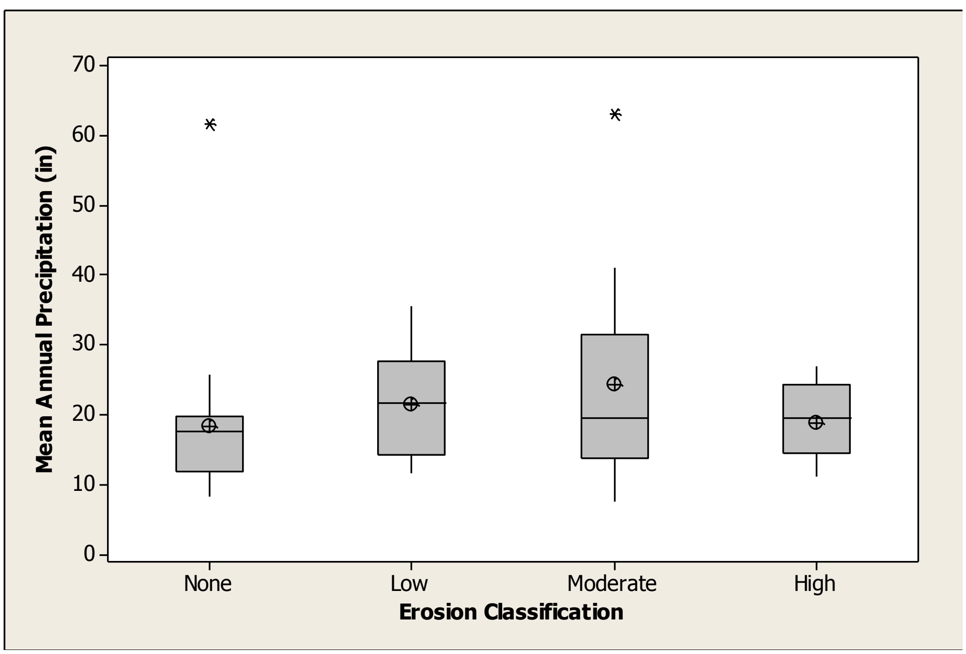


Figure F8 Mean Annual Precipitation vs Erosion Severity Classification

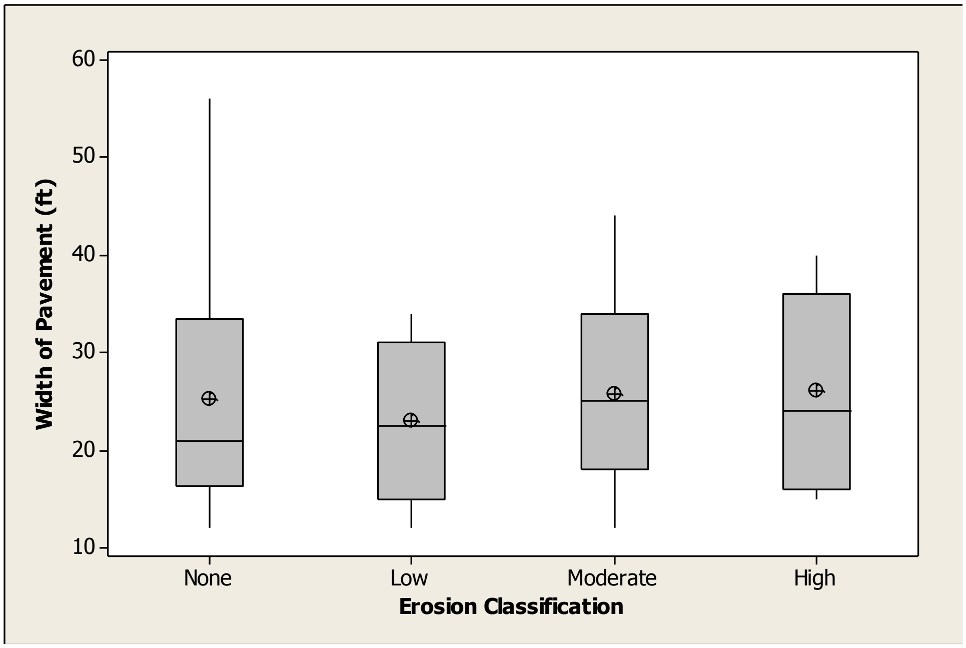


Figure F9 Width of Pavement by Erosion Severity Classification

Basic Statistics for Independent Site Characteristics that did not correlate with Erosion Severity

Roadway Profile										
Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	0	1.885	1.952	0.200	6.100	2.600	0.350	1.150	2.950
Low	9	0	1.811	2.101	0.200	7.000	1.750	0.500	1.500	2.250
Moderate	9	0	3.044	2.466	0.100	6.500	4.900	0.550	2.300	5.450
High	7	0	3.300	2.505	0.300	6.300	5.000	0.500	4.200	5.500
100 year 3 hour Precipitation										
Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	0	1.259	0.056	1.128	1.394	0.082	1.218	1.2624	1.301
Low	9	0	1.256	0.105	1.099	1.438	0.164	1.154	1.2760	1.319
Moderate	9	0	1.322	0.073	1.256	1.455	0.116	1.262	1.3020	1.378
High	7	0	1.292	0.072	1.156	1.367	0.101	1.262	1.2972	1.364
Percentage Fines										
Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	1	32.33	21.76	5.10	73.95	43.75	9.35	25.50	53.10
Low	9	0	37.1	30.4	6.3	78.1	59.0	9.5	17.4	68.5
Moderate	9	0	18.12	25.29	4.60	84.75	7.92	7.40	8.65	15.32
High	7	0	21.1	27.1	3.9	79.2	23.3	4.4	7.3	27.6
Distance EOP to Vegetation										
Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	0	3.225	2.683	0.000	8.000	5.125	0.625	2.750	5.750
Low	9	0	7.00	4.64	2.00	15.00	8.00	3.00	7.00	11.00
Moderate	9	0	7.17	6.22	0.00	20.00	9.00	2.00	6.00	11.00
High	7	0	4.64	3.42	1.00	8.00	7.00	1.00	5.00	8.00
Saturated Hydraulic Conductivity										
Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	5	12.54	19.56	0.09	65.25	22.78	0.65	1.94	23.43
Low	9	1	13.8	28.8	0.8	84.8	7.5	1.0	3.2	8.5
Moderate	9	2	34.0	53.8	0.7	152.0	35.1	2.1	12.3	37.2
High	7	0	8.76	14.45	0.02	40.43	8.91	0.58	2.50	9.49
Percent Gravel										
Erosion Class	N	N*	Mean	StDev	Min.	Max.	IQR	Q1	Median	Q3
None	20	1	32.08	21.19	6.50	75.00	30.50	15.50	26.50	46.00
Low	9	0	25.00	17.60	4.00	57.50	29.50	9.00	25.00	38.50
Moderate	9	0	28.89	17.10	0.00	52.00	27.00	19.25	21.50	46.25
High	7	0	29.14	15.04	0.00	44.00	18.00	26.00	27.50	44.00

Super Elevation										
Erosion Class	**N**	**N***	**Mean**	**StDev**	**Min.**	**Max.**	**IQR**	**Q1**	**Median**	**Q3**
None	20	0	3.271	1.959	1.400	8.000	2.008	1.946	2.600	3.955
Low	9	0	3.185	1.804	1.000	6.600	2.750	1.750	2.771	4.500
Moderate	9	0	3.780	2.915	0.800	8.000	5.667	1.233	2.500	6.900
High	7	0	3.78	2.80	0.50	9.00	3.59	1.58	3.40	5.17
Mean Annual Precipitation										
Erosion Class	**N**	**N***	**Mean**	**StDev**	**Min.**	**Max.**	**IQR**	**Q1**	**Median**	**Q3**
None	20	0	18.34	11.07	8.27	61.54	7.70	11.90	17.44	19.60
Low	9	0	21.35	7.83	11.57	35.47	13.34	14.19	21.50	27.53
Moderate	9	0	24.17	17.28	7.40	62.99	17.62	13.74	19.55	31.36
High	7	0	18.82	5.63	11.18	26.85	9.80	14.40	19.55	24.20
Width of Pavement										
Erosion Class	**N**	**N***	**Mean**	**StDev**	**Min.**	**Max.**	**IQR**	**Q1**	**Median**	**Q3**
None	20	0	25.25	11.45	12.00	56.00	17.25	16.25	21.00	33.50
Low	9	0	22.94	7.97	12.00	34.00	16.00	15.00	22.50	31.00
Moderate	9	0	25.78	10.06	12.00	44.00	16.00	18.00	25.00	34.00
High	7	0	26.14	9.94	15.00	40.00	20.00	16.00	24.00	36.00

APPENDIX G. HIGHWAY RUNOFF DESIGN FLOW RATES

Design Event	Precipitation Depth (inch)
1	1.1
2	1.13
3	1.16
4	1.18
5	1.21
6	1.24
7	1.25
8	1.26
9	1.27
10	1.28
11	1.29
12	1.30
13	1.31
14	1.32
15	1.33
16	1.36
17	1.37
18	1.39
19	1.43
20	1.44
21	1.46

Site Identification	Precip. Event	Q_{AHR} (cfs)	Peak T (hrs)	Peak Vol (ac-cf)	A (ac)	Method/Loss	Storm Event
12-409.6-RT	11	0.0027	0.94	0.0001	0.0008	SBUH	Short.rac
124-12.6-LT	12	0.0027	0.94	0.0001	0.0008	SBUH	Short.rac
125-19.1-LT	6	0.001	0.94	0.00	0.0003	SBUH	Short.rac
129-22.6-LT	8	0.0048	0.94	0.0001	0.0015	SBUH	Short.rac
155-14.4-RT	12	0.0012	0.94	0.00	0.0004	SBUH	Short.rac
155-70.8-RT	12	0.0153	0.94	0.0004	0.0046	SBUH	Short.rac
17-66.7-RT	8	0.003	0.94	0.0001	0.0009	SBUH	Short.rac
195-21.3-LT	8	0.0015	0.94	0.00	0.0005	SBUH	Short.rac
195-76.6-LT	8	0.0029	0.94	0.0001	0.0009	SBUH	Short.rac
195SB-84-LT	8	0.0017	0.94	0.00	0.0005	SBUH	Short.rac
2-233.8-RT	5	0.0014	0.94	0.00	0.0004	SBUH	Short.rac
2-266.8-RT	6	0.0029	0.94	0.0001	0.0009	SBUH	Short.rac
2-82.8-LT	19	0.0028	0.94	0.0001	0.0008	SBUH	Short.rac
20-163-LT	21	0.0062	0.94	0.0002	0.0017	SBUH	Short.rac
20-356.7-RT	11	0.0033	0.94	0.0001	0.001	SBUH	Short.rac
20-389.1-RT	9	0.0036	0.94	0.0001	0.0011	SBUH	Short.rac
20-412.8-RT	12	0.002	0.94	0.0001	0.0006	SBUH	Short.rac
20-433.9-LT	10	0.0021	0.94	0.0001	0.0006	SBUH	Short.rac
206-2.26-LT	8	0.0015	0.94	0.00	0.0005	SBUH	Short.rac
206-2.27-LT	8	0.0015	0.94	0.00	0.0005	SBUH	Short.rac

Site Identification	Precip. Event	Q_{AHR} (cfs)	Peak T (hrs)	Peak Vol (ac-cf)	A (ac)	Method/Loss	Storm Event
207-2.6-LT	20	0.0027	0.94	0.0001	0.0007	SBUH	Short.rac
21-67.1-RT	5	0.0032	0.94	0.0001	0.0011	SBUH	Short.rac
211-0.25-RT	14	0.0012	0.94	0.00	0.0003	SBUH	Short.rac
23-52.1-RT	3	0.0017	0.94	0.00	0.0006	SBUH	Short.rac
231-11.2-LT	2	0.0015	0.94	0.00	0.0005	SBUH	Short.rac
231-44.5-LT	15	0.0046	0.94	0.0001	0.0014	SBUH	Short.rac
231-57.6-LT	14	0.0023	0.94	0.0001	0.0007	SBUH	Short.rac
24-33.5-LT	7	0.0046	0.94	0.0001	0.0015	SBUH	Short.rac
25-14.7-RT	5	0.0009	0.94	0.00	0.0003	SBUH	Short.rac
25-49.0-RT	8	0.0011	0.94	0.00	0.0003	SBUH	Short.rac
261-19.4-LT	4	0.0017	0.94	0.00	0.0006	SBUH	Short.rac
261-61.0-LT	5	0.0038	0.94	0.0001	0.0012	SBUH	Short.rac
27-65.4-RT	14	0.0017	0.94	0.00	0.0005	SBUH	Short.rac
274-0.71-LT	14	0.0025	0.94	0.0001	0.0007	SBUH	Short.rac
28-105.6-LT	2	0.0022	0.94	0.0001	0.0008	SBUH	Short.rac
292-0.8-RT	17	0.004	0.94	0.0001	0.0011	SBUH	Short.rac
2EB-304.7-RT	14	0.0047	0.94	0.0001	0.0014	SBUH	Short.rac
395-196.7-LT	14	0.0038	0.94	0.0001	0.0011	SBUH	Short.rac
410-70.8-RT	8	0.0034	0.94	0.0001	0.0011	SBUH	Short.rac
410-70.8-RT	9	0.0035	0.94	0.0001	0.0011	SBUH	Short.rac

Site Identification	Precip. Event	Q_{AHR} (cfs)	Peak T (hrs)	Peak Vol (ac-cf)	A (ac)	Method/Loss	Storm Event
410-70.8-RT	10	0.0035	0.94	0.0001	0.0011	SBUH	Short.rac
410-70.8-RT	11	0.0035	0.94	0.0001	0.0011	SBUH	Short.rac
410-70.8-RT	12	0.0036	0.94	0.0001	0.0011	SBUH	Short.rac
410-70.8-RT	13	0.0036	0.94	0.0001	0.0011	SBUH	Short.rac
410-70.8-RT	14	0.0036	0.94	0.0001	0.0011	SBUH	Short.rac
410-70.8-RT	15	0.0037	0.94	0.0001	0.0011	SBUH	Short.rac
410-70.8-RT	16	0.0038	0.94	0.0001	0.0011	SBUH	Short.rac
410-77.8-LT	18	0.0021	0.94	0.0001	0.0006	SBUH	Short.rac
90EB-286.2-RT	6	0.004	0.94	0.0001	0.0013	SBUH	Short.rac
90WB-229.3-LT	1	0.0018	0.94	0.00	0.0006	SBUH	Short.rac
90WB-291.0-LT	8	0.0028	0.94	0.0001	0.0009	SBUH	Short.rac
97-247.1-LT	16	0.0026	0.94	0.0001	0.0007	SBUH	Short.rac
97-49.6-RT	13	0.0015	0.94	0.00	0.0005	SBUH	Short.rac

APPEDIX H. SHEAR STRESS ANALYSIS INVENTORY

Site Identification	P_V (%)	D_{EOP-V} (ft)	$P_{100yr3hr}$ (in)	Q_{AHR} (cfs)	n_C	τ_{CBG} (lb/sqft)	Q_{CBG} (cfs)	Stability Check Bare Ground	τ_{CEC} (lb/sqft)	Q_{CEC} (cfs)	Stability Check Embankment Vegetation	τ_{VFS} (lb/sqft))	Q_{CVFS} (cfs)	Stability Check VFS
High Erosion														
155-70.8-RT	0	8	1.3	0.015	0.02	0.020	0.0001	Fail	0.02	0.0001	Fail	4	0.098	Stable
292-0.8-RT	10	1	1.37	0.004	0.037	0.020	0.0002	Fail	0.12	0.0018	Fail	4	0.125	Stable
23-52.1-RT	60	1	1.16	0.002	0.094	0.072	0.0015	Fail	2.99	0.1645	Stable	14.4	1.065	Stable
20-389.1-RT	20	1.5	1.27	0.004	0.051	0.072	0.0021	Fail	0.78	0.0441	Stable	14.4	1.448	Stable
97-247.1-LT	0	8	1.36	0.003	0.02	0.020	0.0004	Fail	0.02	0.0004	Fail	4	0.258	Stable
395-196.7-LT	70	8	1.32	0.004	0.103	0.020	0.0004	Fail	1.00	0.0596	Stable	4	0.310	Stable
195-76.6-LT	20	5	1.26	0.003	0.05	0.095	0.0075	Stable	1.57	0.2607	Stable	29.7	8.813	Stable
Moderate Erosion														
410-70.8-RT	10	2	1.26	0.004	0.039	0.240	0.0024	Stable	1.00	0.0540	Stable	30.7	3.194	Stable
231-44.5-LT	10	8	1.33	0.005	0.037	0.072	0.0014	Fail	0.41	0.0140	Stable	14.4	0.977	Stable
25-49.0-RT	5	4.5	1.26	0.001	0.029	0.072	0.0019	Stable	0.25	0.0110	Stable	14.4	1.296	Stable
20-163-LT	40	20	1.46	0.006	0.074	0.020	0.0003	Fail	0.51	0.0190	Stable	4	0.221	Stable
2-82.8-LT	30	2	1.43	0.003	0.063	0.072	0.0027	Fail	1.34	0.1130	Stable	14.4	1.880	Stable
17-66.7-RT	0	20	1.26	0.003	0.02	0.020	0.0003	Fail	0.02	0.0003	Fail	4	0.221	Stable
155-14.4-RT	0	10	1.3	0.001	0.025	0.240	0.0059	Stable	0.24	0.0190	Stable	30.7	7.792	Stable
195-21.3-LT	60	12	1.29	0.002	0.096	0.089	0.0083	Stable	6.04	1.5910	Stable	27.8	9.783	Stable
231-57.6-LT	35	6	1.32	0.005	0.068	0.020	0.0006	Fail	0.44	0.0280	Stable	4	0.384	Stable

Site Identification	P_V (%)	D_{EOP-V} (ft)	$P_{100yr3hr}$ (in)	Q_{AHR} (cfs)	n_C	τ_{CBG} (lb/sqft)	Q_{CBG} (cfs)	Stability Check Bare Ground	τ_{CEC} (lb/sqft)	Q_{CEC} (cfs)	Stability Check Embankment Vegetation	τ_{VFS} (lb/sqft))	Q_{CVFS} (cfs)	Stability Check VFS
Low Erosion														
211-0.25-RT	0	10	1.32	0.001	0.02	0.020	0.0002	Fail	0.02	0.0002	Fail	4	0.125	Stable
261-19.4-LT	90	0	1.18	0.002	0.17	0.083	0.0027	Stable	18.8	2.1470	Stable	25.9	3.126	Stable
231-11.2-LT	90	3	1.13	0.002	0.17	0.089	0.0030	Stable	20.18	2.4130	Stable	27.8	3.513	Stable
20-433.9-LT	50	3	1.28	0.002	0.115	0.072	0.0024	Stable	4.49	0.4070	Stable	14.4	1.638	Stable
90WB-229.3-LT	90	8	1.1	0.002	0.17	0.089	0.0056	Stable	20.2	4.5330	Stable	27.8	6.600	Stable
90WB-291.0-LT	70	15	1.26	0.003	0.139	0.120	0.0059	Stable	6.97	0.9440	Stable	15.3	2.449	Stable
207-2.6-LT	0	12	1.44	0.003	0.02	0.020	0.0001	Fail	0.02	0.0001	Fail	4	0.086	Stable
27-65.4-RT	90	3	1.32	0.002	0.17	0.083	0.0037	Stable	18.8	3.0060	Stable	25.9	4.377	Stable
20-356.7-RT	20	7	1.29	0.003	0.067	0.072	0.0038	Stable	1.35	0.1520	Stable	14.4	2.633	Stable
None Erosion														
261-61.0-LT	95	4	1.21	0.004										
410-77.8-LT	50	0	1.39	0.004	0.113	0.240	0.0029	Stable	9.24	0.9000	Stable	30.7	3.776	Stable
24-33.5-LT	45	0	1.25	0.005	0.109	0.083	0.0024	Fail	7.28	0.6250	Stable	25.9	2.847	Stable
125-19.1-LT	90	0.5	1.24	0.001	0.17	0.083	0.0027	Stable	18.8	2.1470	Stable	25.9	3.126	Stable
195SB-84-LT	50	6	1.26	0.002	0.113	0.120	0.0044	Stable	4.62	0.4350	Stable	15.3	1.825	Stable
124-12.6-LT	50	4	1.3	0.003	0.115	0.072	0.0024	Fail	4.49	0.4070	Stable	14.4	1.638	Stable
206-2.26-LT	20	5	1.26	0.002	0.067	0.020	0.0003	Fail	0.38	0.0130	Stable	4	0.221	Stable
206-2.27-LT	70	5	1.26	0.002	0.142	0.072	0.0027	Stable	6.85	0.7660	Stable	14.4	1.880	Stable
25-14.7-RT	95	1.5	1.21	0.001	0.176	0.083	0.0043	Stable	20.2	3.7470	Stable	25.9	5.024	Stable
20-412.8-RT	40	2.5	1.3	0.002	0.1	0.020	0.0004	Fail	0.95	0.0470	Stable	4	0.259	Stable

Site Identification	P_V (%)	D_{EOP-V} (ft)	$P_{100yr3hr}$ (in)	Q_{AHR} (cfs)	n_C	τ_{CBG} (lb/sqft)	Q_{CBG} (cfs)	Stability Check Bare Ground	τ_{CEC} (lb/sqft)	Q_{CEC} (cfs)	Stability Check Embankment Vegetation	τ_{VFS} (lb/sqft))	Q_{CVFS} (cfs)	Stability Check VFS
None Erosion Cont.														
12-409.6-RT	80	1	1.29	0.003	0.155	0.072	0.0032	Stable	8.61	1.2040	Stable	14.4	2.198	Stable
274-0.71-LT	95	6	1.32	0.003	0.176	0.089	0.0056	Stable	21.6	4.9220	Stable	27.8	6.600	Stable
97-49.6-RT	65	0	1.31	0.002	0.133	0.240	0.0059	Stable	12.7	2.6980	Stable	30.7	7.792	Stable
28-105.6-LT	80	8	1.13	0.002	0.158	0.083	0.0060	Stable	16.1	4.0390	Stable	25.9	7.034	Stable
21-67.1-RT	80	6	1.21	0.003	0.155	0.072	0.0047	Stable	8.61	1.7850	Stable	14.4	3.259	Stable
2EB-304.7-RT	70	2	1.32	0.005	0.142	0.072	0.0061	Stable	6.85	1.7230	Stable	14.4	4.231	Stable
90EB-286.2-RT	85	0	1.24	0.004	0.161	0.072	0.0047	Stable	9.30	1.9550	Stable	14.4	3.259	Stable
2-266.8-RT	40	8	1.24	0.003	0.099	0.120	0.0088	Stable	3.55	0.6340	Stable	15.3	3.630	Stable
129-22.6-LT	55	2	1.26	0.005	0.12	0.240	0.0114	Stable	10.3	4.0880	Stable	30.7	14.99	Stable
2-233.8-RT	80	3	1.21	0.001	0.151	0.120	0.0114	Stable	21.8	11.232	Stable	15.3	4.713	Stable

APPENDIX I. APPLIED FINDINGS TO LOWER (40%) EMBANKMENT SLOPES

Site Identification	Erosion Classification	W_T (ft)	e (%)	G (%)	S_e (%)	P_V (%)	D_{EOP-V} (ft)	MAP (in)	$P_{100yr3hr}$ (in)	Fines (%)	Gravel (%)	Sand (%)	K_{sat} (in/hr)	Soil Classification
2EB-304.7-RT	N	38	2.2	2.8	20	70	2	20.0	1.32	18.6	21.5	60.0	1.94	SM
129-22.6-LT	N	34	2.2	3.6	20	55	2	17.2	1.26	5.1	75.0	19.9		GW
2-233.8-RT	N	16	3.0	2.1	20	80	3	13.9	1.21	19.1	59.0	21.9	39.5	GM
195-21.3-LT	M	20	1.3	0.2	25	60	**12**	21.7	1.29	**84.8**	**0.0**	15.3	0.73	ML-CL
231-57.6-LT	M	25	7.3	4.5	25	**35**	**6**	20.0	1.32	8.4	34.5	57.1	12.3	SW
21-67.1-RT	N	14	1.9	6.1	25	80	6	10.7	1.21	49.2	15.5	35.4	2.90	SM
90EB-286.2-RT	N	56	4.4	0.2	25	85	0	17.9	1.24	27.8	31.5	40.8	1.68	SM
2-266.8-RT	N	40	3.2	0.3	25	40	8	17.3	1.24	25.5	46.0	28.5		GM
395-196.7-LT	H	36	4.4	4.2	30	70	**8**	24.2	1.32	7.3	26.5	**66.2**	7.61	SW
195-76.6-LT	H	40	3.4	0.3	30	**20**	**5**	19.5	1.26	**79.2**	**0.0**	20.8	2.50	CL
20-356.7-RT	L	30	6.6	7	30	**20**	**7**	21.5	1.29	11.4	37.0	**51.7**	4.67	SM
28-105.6-LT	N	31	3.0	1.3	30	80	8	12.2	1.13	74.0	7.5	18.6	0.62	ML
97-247.1-LT	H	32	9.0	0.5	35	**0**	8	11.2	1.36	4.4	44.0	**51.6**	0.70	SW
155-14.4-RT	M	16	0.8	0.1	35	**0**	10	11.7	1.30	4.6	52.0	43.4	152	GW
90WB-229.3-LT	L	21	2.8	2.5	35	90	**8**	12.4	1.10	69.4	9.0	21.6	1.75	ML-CL
90WB-291.0-LT	L	34	4.0	2	35	70	**15**	18.7	1.26	17.4	57.5	25.2	7.65	GM
20-412.8-RT	N	27	6.6	0.5	35	40	2.5	25.6	1.30	9.0	26.5	64.6	34.5	SW
12-409.6-RT	N	36	4.0	0.6	35	80	1	20.6	1.29	46.8	19.5	33.7	23.4	SM
274-0.71-LT	N	32	8.0	1.5	35	95	6	20.6	1.32	58.6	11.5	29.9	0.09	ML-CL
97-49.6-RT	N	18	2.0	1	35	65	0	9.5	1.31	7.9	66.5	25.7		GW
20-163-LT	M	44	5.0	6.5	40	**40**	**0**	63.0	1.46	7.3	21.5	**71.3**	28.2	SW
2-82.8-LT	M	32	8.0	2	40	**30**	**2**	41.0	1.43	18.2	21.0	**60.9**	2.09	SM
17-66.7-RT	M	22	1.5	2.3	40	**0**	20	7.4	1.26	**7.6**	42.5	**50.0**		SW
206-2.26-LT	N	20	2.6	0.2	40	20	5	18.0	1.26	9.4	41.5	49.2	65.3	SW
206-2.27-LT	N	20	2.6	0.2	40	70	5	18.0	1.26	34.1	28.0	37.9	3.08	SM
25-14.7-RT	N	13	2.0	0.2	40	95	1.5	17.0	1.21	61.3	6.5	32.2	1.33	ML