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I am submitting herewith a thesis written by Kelley H. Williams entitled "Linking Channel Stability and Bed Sediment Characteristics to Biological Integrity in Tennessee Ridge and Valley Streams." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

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***Linking Channel Stability and Bed
Sediment Characteristics to Biological
Integrity in Tennessee Ridge and Valley
Streams***

A Thesis Presented for the Master of Science Degree

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Abstract

Streambed sedimentation has plagued waterways since the beginning of civilization, whether as a natural flow process or human disturbances on the landscape in more recent times. Due to the continual degradation in the quantity and diversity of aquatic organisms within streams, the issue has finally surfaced as a significant concern. The need to develop better Total Maximum Daily Load (TMDL) assessment tools to link sediment impairment to biological integrity was the driving force behind this study.

Within the Ridge and Valley Ecoregion, 76 stream reaches were analyzed to investigate the impacts of stability issues and bed sediment characteristics on stream biological integrity. The field data were correlated and related to benthic macroinvertebrate indices of biological integrity through non-parametric statistical procedures. It was found that the presence of larger sediment size classes was more significant, in a positive relationship, than the negative association of the finer particles. Medium to fine silt, channel stability, channel slope, and the percent below 2-mm from a modified Wolman pebble count, were also found to be significant parameters in their relationship to biological integrity scores.

The analyses revealed the importance of the larger bed materials and heterogeneity of bed sediment along the riffles. The significance of these results indicates that habitat heterogeneity from larger bed substrate material may be more relevant to the biological integrity than the weaker effects of fine sediment. The negative impact from fine

sediments were observed and found to be mostly in the size range of medium to fine silt.

Overall, the processes from the Rapid Geomorphic Assessment, including channel stability, and slope, were found to have good correlations to biological integrity.

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1.0 Introduction

Streambed sedimentation has long since been degrading our nation's waterbodies.

Besides natural phenomena, sedimentation from land disturbances can be caused by human activities such as urbanization, mining, and agriculture practices. Impacts from sedimentation can be detrimental to rivers and streams down gradient, damaging the aquatic life they once supported (Freeman, 2004).

As mandated by the 1987 amendments to the Clean Water Act, states are required to list the water quality impaired streams within their borders. Total Maximum Daily Loads (TMDLs) are created after a stream is put on the 303(d) list. The TMDL is developed due to the fact that the bioassessment data of the stream, which is used to generate biological integrity and habitat scores, falls below the states biocriteria statutes. In Tennessee, sedimentation is the primary pollutant impairing stream ecosystems, thus making many streams unable to achieve levels of biological integrity above the states' mandated biocriteria (TMDL, 2005).

Channel instability is one cause for excessive sedimentation in streams. When land is disturbed, it no longer has the ability to absorb the same quantity of water; this increases the amount of runoff that a stream draining the area must transport (Wood, 1997).

Runoff erosion occurs due to land disturbances, and results in sediment-impaired water.

The volume of runoff is also increased due to the land's inability to absorb the same quantity of water as pre-developed conditions allowed (Bledsoe, 2001). Increased runoff

can also increase bank erosion (Jennings, 2003). Through bank erosion, banks can be undercut and fail, depositing large amounts of sediment into the stream. Excess sediment remaining in the stream reach greatly degrades the stream's ability to provide a sustainable habitat for the wide variety of aquatic life that lives there. Habitat is essential to the health of biological communities; therefore, the loss of quality habitat makes it difficult for less tolerant species to survive (TDEC, 2003; U.S. EPA, 2005).

Currently, links between sediment impairment and biological integrity are not well understood. Linking sedimentation and biological integrity could provide a threshold yield for sediment quality that would give an implication of whether the stream is fully supporting (or not supporting) aquatic life. A sediment yield target could be established for watersheds if a significant link could be determined. With a sediment yield target, a better understanding could be established regarding which best management practices (BMP's) are needed to reduce sediment delivery to streams. Effective BMP implementation would improve the biological integrity of impaired streams and keep healthy streams from becoming impaired.

The research objectives of this study were 1) to explore whether there is a level of channel stability that affects biological integrity and 2) to discover if there was a particular sediment size class that predominantly affects biological integrity. The first objective was achieved by correlating biological data provided by Tennessee's Department of Environment and Conservation (TDEC) with channel stability indices. These indices were collected using a Rapid Geomorphic Assessment protocol developed

by Dr. Andrew Simon and his associates at the National Sedimentation Laboratory in Oxford Mississippi. The second objective was accomplished by analyzing particle size distributions, and the modified Wolman pebble count, to the biological data provided by TDEC.

2.0 Background

2.1 Sediment and Habitat Alteration Related to TMDLs

There has long since been a need to protect and restore our nation's water quality. In response to this need, the Clean Water Act was established in 1972. Currently over 40% of the nation's assessed waters do not meet the water quality standards established for them (TMDL, 2005). This accounts for about 300,000 miles of river and shorelines and approximately 5 million acres of lakes. Identified from the 2005 assessment, one of the predominate pollutants is sediment. States are required to develop a list of impaired waters under the 305(b) and 303(d) sections of the 1972 Clean Water Act. TMDLs are to be developed for each of the impaired waterways. According to the Environmental Protection Agency (EPA), a TMDL "specifies the maximum amount of a pollutant that a waterbody can receive and still meet the water quality standards and allocates pollutant loadings among point and non-point pollutant sources".

Even though the TMDL program has been in place since 1972, not until 1996 was substantial progress made to achieve water quality standards for non-point pollution and improve the national TMDL program. The Tennessee Department of Environment and Conservation (TDEC) has the authority and is responsible for implementing the TMDL program among the waters of Tennessee. TDEC must determine which streams are impaired, and then develop TMDLs for those waterways. This is an extremely time and labor intensive process, especially for a state with such an extensive water system.

In fact, Tennessee is ranked only second to Mississippi as having the most sediment polluted waters in the nation (TMDL, 2005). Clearly, a simple, low cost process is needed to determine the level of sedimentation impairment within streams.

Due to the severe impacts of sediment, siltation has become a major priority to the state. Siltation is primarily the result of land use disturbances within a watershed from human activities that supplies streams with excess sediment (Freeman, 2004). However, it is unclear how much sediment is manageable for a stream before it begins to degrade the stream's ecosystem. If a sediment yield threshold were known, management practices could be implemented within a watershed to help control sediment and prevent stream impairment. To do this, a link must be made between sediment data and stream reaches fully supporting or not supporting biological integrity. The state has long since been collecting biological integrity data, which could be utilized to establish this link. The biological data is dependent on both the time of year and ecoregion in which the data was collected. (TDEC, 2003)

2.2 Ecoregions of the United States

Overview

In 1987, Omernik developed ecoregions to classify streams for an effective way to manage water quality. He was motivated in this work by the philosophies of Bailey (1976) and Warren (1979) which promoted the ideas that ecoregion maps should consist

of homogeneous areas involving climate, vegetation, soils, land form, and aquatic and terrestrial ecosystems (Omernik, 1987). The primary goal in developing ecoregion maps was to provide a geographic structure for organizing an ecosystem's resource information. These maps allow individuals to compare land and water relationships, establish realistic water quality standards that relate to regional patterns of tolerances to human impacts, locate monitoring or reference sites, utilize existing site-specific studies, and better understand the effects of changes in land use and pollution controls (Omernik, 1987). This means ecoregions provide a framework to organize the spatial distribution of aquatic organisms across the country. This framework is important for studies that use organisms as indicators of water quality degradation, sediment impairment, and reduction in biodiversity.

Ridge and Valley Ecoregion Physiography

Geology

The study area was located within the Ridge and Valley ecoregion, (Ecoregion 67), and predominantly within east Tennessee. The area stretches from the northeast to the lower southeast portion of the state; the specific site locations are shown in Figure 1. This ecoregion lies between the Blue Ridge Mountains and the Cumberland Plateau and has a unique and diverse topography. The Ridge and Valley ecoregion consists of a 60 to 90 km wide belt of ridges and valleys that run northeast to southwest across Tennessee (Etnier, 1993). The ridges vary in height from less than 300 meters to over 790 meters, and the valley floors range from 200 to 300 meters in elevation (Figure 2). It is thought

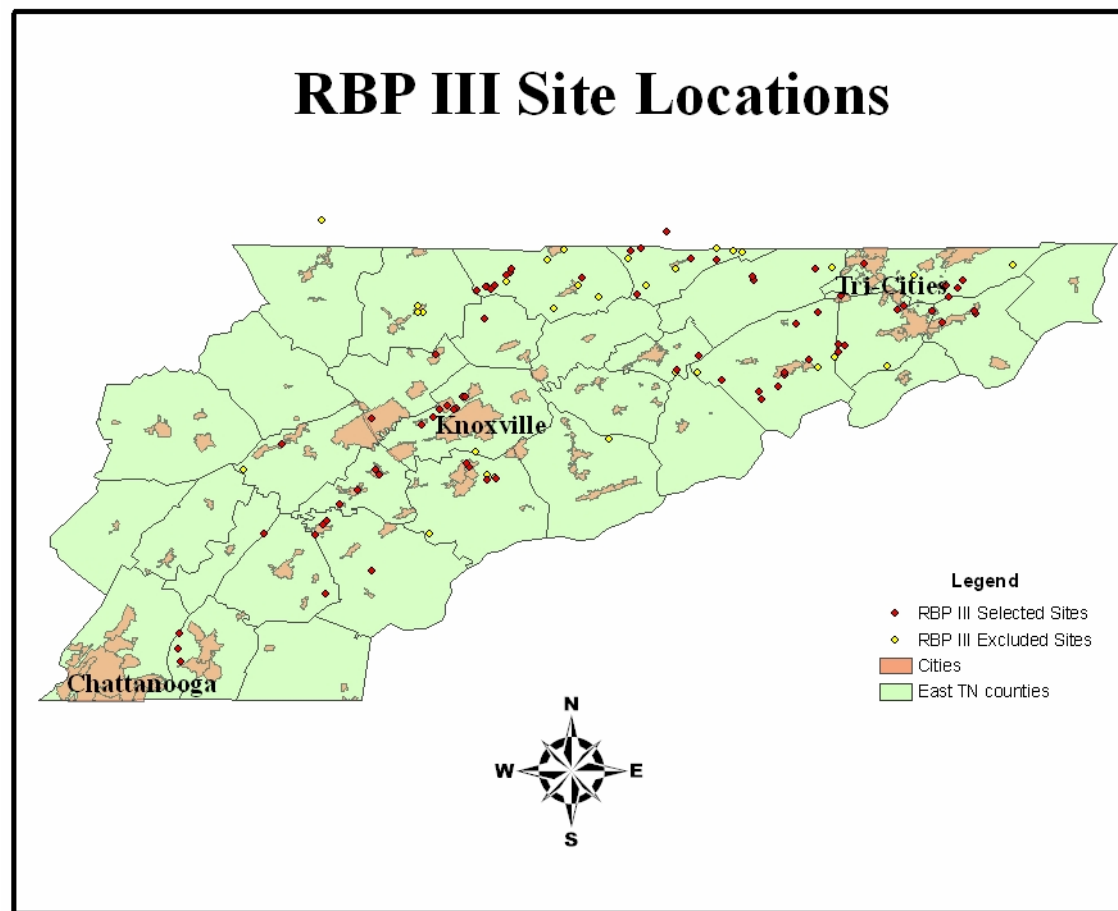


Figure 1: RBP III Site Locations



Figure 2: Ridge and Valley Terrain

that extreme folding and faulting events of the late Paleozoic Era around 250 million years ago formed the features of the Ridge and Valley.

As a result of the topography, larger streams are structurally guided by ridges and run parallel through the valley floors. Smaller tributaries enter the larger streams at near right angles due to the drainage of the ridge slopes. Limestone rubble, bedrock riffles, and silty sand pool areas characterize smaller streams, although there can also be chert gravel areas in these streams.

Climate

The climate of this region varies from the tops of ridges to the floors of the valley. Generally, the winters are mild beginning in late October and lasting until early April with approximately 71 days at or below 32°F (NOAA, 2000). The summers are warm and short, averaging approximately 31 days at or above 90°F. The annual precipitation

ranges from approximately 1,016 to 1,397 millimeters (40 to 55 inches) and also varies by elevation and location.

Vegetation

The portion of the Ridge and Valley ecoregion relevant for this study is located within the Southern Appalachian region; this area is considered to have the greatest biological diversity within the Appalachian chain (Summerlin, 2003). This diversity includes hundreds of different plant species as well as fauna unique only to this region. The mild climate and adequate precipitation enables this region to support a wide variety of vegetation, including 400 moss species, over 2,500 species of flowering plants, and 130 different tree species. The undisturbed riparian floodplains of Ecoregion 67 are also productive and have an abundant supply of vegetation in shallow areas, such as water willow and riverweed (Figure 3).



Figure 3: Stream Vegetation, Site Number CAWOO000.2CL

2.3 Sediment Impairment

Overview

Excessive sediment suspension and deposition can impair aquatic organism communities by affecting their productivity, diversity, and abundance within a stream (Wood, 1997). Major factors that affect the degree of degradation include the variety and quantity of aquatic plant life (primary producers), particle size of the sediment, and the amount of suspended and deposited sediment. A challenge for any study that relates sediment characteristics to biological data is that all factors are interrelated and, therefore, difficult to discuss separately.

The abundance and diversity of a macroinvertebrate community structure provides a good indicator of the quality of a stream. All macroinvertebrates discussed in this study are benthic macroinvertebrates, which comprise a family of macroinvertebrates that live on the streambed and in the sediment substratum. Some macroinvertebrates such as the Ephemeroptera, Plecoptera, and Trichoptera taxa are very sensitive to fine sediment (Kaller, 2004), while others such as Diptera and Chironomidae, are very resilient to pollution (Maul, 2004). Most macroinvertebrates have a life cycle of one or more years, where some life stages are more sensitive than others (Barbour, 1999). During these sensitive stages, some biota will respond quickly to environmental stress while the overall community will have a slower response. These aspects of macroinvertebrates will, in turn, integrate the effects of short-term environmental quality. The implication of this information is that with an understanding of which macroinvertebrates are sensitive

and present within a stream, one can make a fairly accurate estimation regarding how sediment or contaminants may be affecting the stream's biota.

Macroinvertebrates are good indicators of stream health because they are relatively stationary (Barbour, 1999). This characteristic makes them easy to locate and sample. Macroinvertebrates immobility is also important to analyses because they cannot simply move locations depending upon the habitat quality they desire.

Macroinvertebrates can be classified into families, where vulnerable taxa can be identified into more specific groupings with relative ease. Together, the different species of macroinvertebrates cover a broad range of feeding habits and tolerance levels. This characteristic is significant because it provides a strong foundation to interpret collective conditions. Degraded conditions can easily be determined with general information of the families and abundance of the macroinvertebrates present.

Another advantage of using macroinvertebrates as biological integrity indicators is that the sampling process is easy, has minimal detrimental effect on the species, and requires only minimal people and inexpensive gear. (Barbour, 1999) Therefore, using macroinvertebrates is an effective and efficient means to conduct bioassessments.

Discussion of Sediment Size

Fine particles are defined as those less than 2-mm in diameter. This includes fine sand, silt, and clay. While there are conflicting view points regarding which of these particle types is the one most damaging to a stream, there is consensus that the fine particle class is the most detrimental (Haan,1994). Each of these fine particle types have differentiating qualities that affect channel characteristics.

Sand

Sand is the larger of the fine materials with diameters ranging from 2 to 0.02-mm and therefore has the fastest settling rate (Haan, 1994). The settling rate is associated with the time it takes a particle to fall from suspension to the streambed. Sand also has very low cohesive tendencies, meaning it does not have the tendency to bind to other materials. These factors make sand very easy to detach from a surface, but less competent to transport due to its size. Excess sand will quickly settle and generally does not have a harmful turbidity affect. However, due to the inherent non-cohesive properties, the fluvial transport of sand will provide a very instable substrate.

Silt

Silt particles have a diameter ranging from 0.02 to 0.002-mm (Haan, 1994). It is more cohesive than sand, but silt will detach from a surface more easily than clay. Once detached, it will be transported with minimal energy due to its size (Haan, 1994).

Clay

Sediment with a diameter less than 0.002-mm is a clay particle and has quite opposite characteristics to that of sand. Clay has very high cohesive properties and is therefore very hard to detach from a consolidated surface. However, once detached it is extremely easy to transport due to its small size. Because of the strong cohesive forces, clay can bind together on a substrate and create hardpan clay through consolidation. (Haan, 1994)

Ecological Impacts from Sedimentation

Problems with stream ecology arise when an excessive amount of sedimentation takes place in a channel. Naturally occurring sedimentation provides nutrients to floodplain areas and is an important process within a stream. However, excessive sedimentation, usually due to poor land management within a watershed or an uncontrolled increase in flow, adversely affects less pollutant tolerant species of macroinvertebrates (Freeman, 2004). Each size class (sand, silt, and clay) plays a different role in impacting degradation of a stream, where each class can cause numerous problems within the overall system. Sediment composition in a stream is highly variable. While there can be a predominate material within a stream, it is often the combination of size classes that affect the stream and introduce additional complexities.

Effects of Sand

Sand can alter the composition of the substrate and, as a result, change the suitability of the substratum for some taxa or species (Wood, 1997). Due to the lack of cohesive forces

it can provide a very instable substrate, causing an increase in drift for macroinvertebrates. This may reduce the productivity of some macroinvertebrates by hindering their upstream migration. Other macroinvertebrates thrive best when relatively stationary, so the accumulation of sand deposition can increase their drift downstream. Because of its lack of cohesiveness, sand will not smother the channel bed in the same way silt or clay might, unless a very thick sand layer is deposited.

Effects of Silt

Silt can be especially damaging because it can have negative impacts similar to both sand and clay. Silt is small, and easily transportable, and has cohesive properties that fall between those of sand and clay. Respiration is the process by which an organism exchanges gases with its environment to breathe (Wood, 1997). Due to silt's cohesive property, this gas exchange can be hindered when silt deposits form on the organism's respiration structures, thus leading to suffocation. Sedimentation can also cause a decrease in dissolved oxygen concentrations.

Effects of Clay

When clay is deposited on a substrate, it can bind together and virtually clog the areas in which macroinvertebrates live, feed, and grow (Wood, 1997). Clay is known to impair respiration by covering and clogging the breathing mechanism for plants and invertebrates. Clay can also disturb feeding activities by corrupting filter feeding due to high levels of suspended sediment. Due to clay's particle size and its inherent ability to

stay suspended, clay can greatly increase turbidity, reduce photosynthesis, and therefore damage aquatic plant life.

Overall Fine Sediment Effects

Excessive sediment deposits can change channel morphology, block places for organisms to attach and grow, and reduce the suitable habitat for benthic organisms. High concentrations of suspended sediment interfere with feeding activities of periphyton by obstructing the filter feeding process (Wood, 1997). Consequently, this minimizes the food value of periphyton, thus reducing the plant density and leading to a reduction in these primary producers. In severe cases, fine sediment can cover the entire riverbed destroying all plant life; this disrupts the food chain for the stream's entire ecosystem.

Plant life, such as periphyton and aquatic macrophytes, are highly affected by fine depositing sediments and suspended sediments (Wood, 1997). Periphyton is a sessile organism, such as algae, that attaches and lives on a streambed, and macrophytes are macroscopic plants that live within a stream. The turbidity caused by suspended sediments reduces light and consequently photosynthesis. Likewise, sedimentation can damage the leaves and stems by colliding into these plants causing abrasions and ultimately reducing photosynthesis as well. These aquatic plants are the base of the food chain, so a reduction in the diversity and productivity of these plants affects the entire aquatic system.

Conflicting Views on Sediment Impairment

There are conflicting view points among several scientific studies regarding which particle size class (sand, silt, or clay) is most degrading to a stream's biota. For instance, one study stated that invertebrates were more abundant when the primary substrate material was sand rather than clay or gravel (Maul, 2004). Another study found a higher density and diversity of macroinvertebrates correlated to cobble and pebble substrates, while the opposite affect on macroinvertebrates was found with sand and silt dominated substrates (Kaller, 2004). It is stated that sand deposition on the substrate layer can be a particular problem, suggesting that the sand creates an instable substrate that indirectly affects the benthic invertebrates by making their upstream migration more difficult (Wood, 1997). An additional study related anthropogenic influences on macroinvertebrates finding the main effect of degradation was from the silt and sand components (Buss, 2004). Another study theorized that the most degrading sediment was the smallest particles, particularly those that occur from road runoff. The size they studied were interested in was less than 0.004-mm, which would be in the clay category (Kaller, 2004). In addition, it is unclear what part organic material plays in this issue. Organic material is often ignored even though it seems that the organic matter is a major contributor to benthic sediments; this was corroborated in (Rempel, 2000; Wood, 1997).

It is important to understand how different sediment compositions of sand, silt, and clay impact stream habitat for benthic macroinvertebrates, and thus biological integrity. At first, all of these studies seem to be conflicting; however, once analyzed, some patterns begin to emerge. When studying these differences, it seems that while any type of

excessive sediment is destructive, the degree of devastation depends upon the focus of the study. For instance, when concerned with an increase in the drift of macroinvertebrates, sand is the largest contributing factor; however, if concerned with plant life deterioration and filter feeding disruptions due to heavy turbidity, then clay is the culprit.

2.4 Channel Adjustment and Stability

There are several variables that affect channel morphology. Secondary integrated parameters of channel adjustments are climate, vegetation, soils geology and physiography (Knighton, 1998). The predominant controllers of channel form adjustment are discharge and the bed-material of the sediment load. This is significant because land disturbances largely affect both the flow and sediment load within a stream. These effects from land changes can include a dramatic increase in flow and sediment load depending on the type and severity of the disturbances. For example, clearing a large, steep, well-vegetated slope, and leaving the land exposed for a long period of time, will greatly increase flow and sediment load. Conversely, clearing a small, flat, non-vegetated area, which is immediately covered with seed and straw, will not have such dramatic influences.

The slope of the valley and channel is a natural characteristic that determines the overall rate of energy supplied, and can modify the relationship between channel form, discharge, and sediment load (Knighton, 1998). Geology controls geomorphology; therefore stream adjustment patterns behave differently depending on the geology of the

stream reach. For example, in the Ridge and Valley ecoregion, bedrock can be the predominant bed material and therefore control the amount of possible degradation and widening. The geology of a valley-constricted stream will also affect how the morphologies of streams change because the channel has little choice of where it can meander.

Factors that negatively affect a stream's stability include, but are not limited to, channelization, increased runoff, and decreases or removal of streamside vegetation (Jennings, 2003). A declining stability will increase sediment load in the system through mass wasting and/or fluvial erosion of the banks.

Streams naturally strive for equilibrium after a disturbance (Knighton, 1998). Small negative effects can influence a stream, but the stream can regain stability and equilibrium if the disturbance is mitigated. Large single impacts will cause a stream to become unstable; however, it is possible to regain stability at a different equilibrium position as shown in Figure 4.

One of the conceptual models used to describe the process of physical adjustments for a stream reach is the Channel Evolution Model (Simon, 1995). In this model an evolutionary process begins when an undisturbed stable channel is affected by land disturbances or direct modification. For urbanizing watersheds, disturbances cause an increase in peak flows, possibly leading to channel incision (Jenning, 2003). Over-

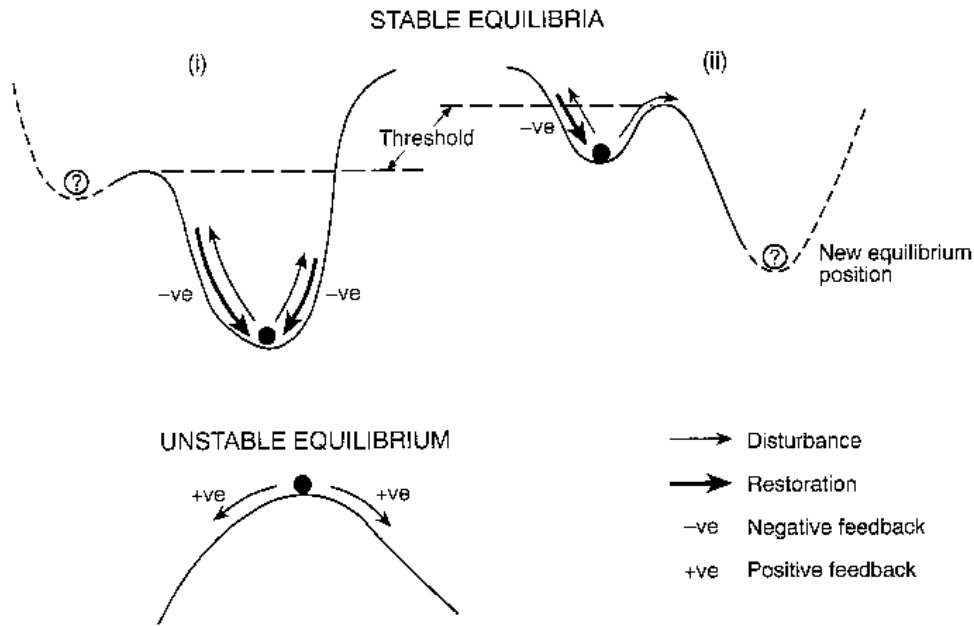


Figure 4: Diagrammatic Representation of Stable and Unstable Equilibria (Knighton, 1998 (p159))

steepened stream banks leading to bank failures is one of the effects of incision (Figure 5). When the stream banks fail, bank material is transported downstream causing widening of the channel; the excess sediment degrades the aquatic habitat. Headcutting, a process where incision and widening continue to move upstream, continues to occur. Eventually the mass wasting slows and the streambed begins to aggrade. In time a new streambed will form in the sediment deposits (Figure 6). At the end of the process, the stream regains stability in the deposited alluvium. The process of channel adjustment is very dependent on how and if the prior disturbances in the watershed are mitigated. Most urban streams are in one of these stages of this evolutionary process. However, the time it takes to reach the Restabilization Stage, if attainable at all, is very dependent on the watershed disturbances, particularly if they are ongoing (Jennings, 2003).



Figure 5: Mass Failure Due to Insision, Site Number STEEK000.7LO



Figure 6: Flow within Sediment, Site Number DAVIS024.1CL

2.5 Channel Morphology, Bed Sediment and Habitat Characteristics

Benthic macroinvertebrates live very near, or in the upper layers of, the channel bed; therefore, they are greatly affected by channel morphology and bed sediment characteristics. Figure 7 shows a macroinvertebrate attached to the streambed. As discussed in prior sections, aquatic macroinvertebrates have a limited, if any, migration pattern; thus, they are locally very habitat dependent (Barbour, 1999). Changing sediment loads in a stream can decrease light penetration, which can affect the food chain. In addition, it can clog small spaces between rocks that are utilized as habitat by macroinvertebrates (Freeman, 2004). The causes of the increase in sedimentation often stem from land disturbances within a watershed, including an increase in stormwater runoff, road crossings, changes in sediment loads, and decreases in riparian vegetation (Jennings, 2003). Likewise, the detrimental effects of channelization can occur in disturbed areas. According to Jennings, 2003, the impact on a stream from these changes



Figure 7: Macroinvertebrate on Streambed (Caddis Larva, *Brachycentrus*)

includes stream bank erosion, channel incision, aggradation, and flooding. Each of these is a response from the stream and can ultimately change the stream's channel form, stability, and general geomorphology.

2.6 Rapid Geomorphic Assessment Protocols

The Rapid Geomorphic Assessment (RGA) is a method developed by Dr. Andrew Simon and his associates at the USDA National Sedimentation Laboratory in Oxford Mississippi. It was designed to evaluate channel stability based on the Channel Evolution Model. This method assesses several parameters of a stream reach and identifies the stream's stage of evolution. A Channel Stability Index, which is the result of the RGA process, ranks the stream reach in question and assists in analysis.

RGA Parameters

The RGA field data sheet and guidelines are located in Appendix A. As one protocol for conducting an RGA, bed material is located on a bar or across a riffle where a particle count of the bed sediment sizes is preformed (Simon, 2004). The bed material is characterized into five different categories: bedrock, boulder/cobble, gravel, sand, and silt-clay. Bedrock is a parent material that can appear as large slabs of rock when exposed. Boulder/cobble is material with a median diameter greater than 64-mm. Gravel is considered material with a median diameter between 64-mm and 2-mm. Particles with a median diameter between 2-mm and 0.63-mm are considered sand. Silt-clay is

associated with a median diameter less than 0.63-mm. The slope of the selected reach is found using a hand-held clinometer or survey equipment. The other parameters are bed or bank protection, degree of incision, degree of constriction, bank erosion, stream bank instability, established riparian woody-vegetative cover, occurrence of accretion, and stage of evolution. These are explained in more detail in the *Methods* section of this document. The stages of evolutions are divided into six categories: pre-modified, constructed, degradation, threshold, aggradation, and restabilization. There is a number assigned to each parameter; the total score is the addition of the responses to the nine questions. This in turn is the overall channel stability index for that reach of the stream.

Stages of Channel Evolution

The stage of evolution is an important aspect of this method, and therefore deserves more attention and clarification. A diagram of the stages of evolution is shown in Figure 8. As stated in (Simon, 2004), the different stages are defined as the following:

- I. *Pre-modified* –Stable bank conditions exist in this stage, meaning no mass wasting, and small, low angle bank slopes. Established woody vegetation is also present on the banks, and the bank shape often consists of a convex upper bank and a concave lower bank.
- II. *Constructed* – Artificial reshaping of existing banks has occurred in this stage. Vegetation is often removed and the banks are steepened, heightened, and made linear.

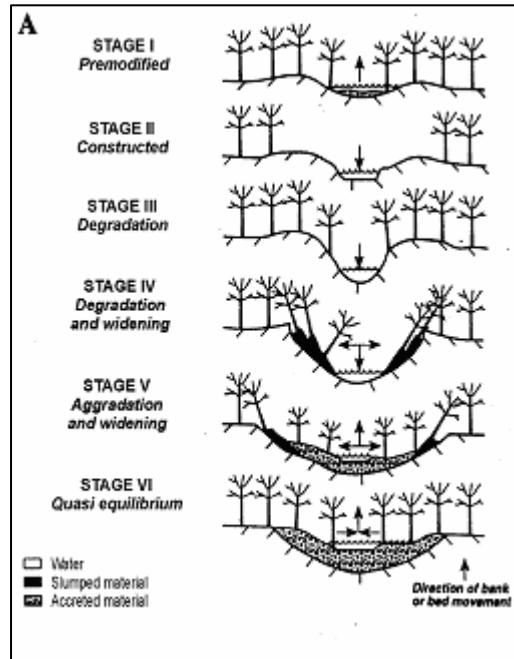


Figure 8: Stages of Evolution (Simon, 2004)

- III. *Degradation* –The channel bed is lowering and, consequently, there is an increase in bank height. Incision occurs without widening. Bank toe material is often removed causing an increase in bank angle.
- IV. *Threshold* – Degradation and basal erosion occurs, which results in incision and active channel widening, as well as mass wasting and extensive undercutting of banks. Due to the bank failures, trees and vegetation tend to lean and fall from the banks. A vertical bank face may even be present.
- V. *Aggradation* – Deposition of material, often sand, occurs on the bed. The channel widens due to bank retreat, not incision. The bank profile has a concave shape and filed material is reworked and deposited. Floodplain terracing and channel meandering is also a trait of this stage.

VI. *Restabilisation* – Reduction in bank heights and aggradation of the channel bed often occurs. There is also deposition on the upper bank that visibly buries vegetation. The banks have a convex shape, and floodplain terraces may occur.

Stages I and VI are considered the “reference” stream condition according to Simon, 2003. The pre-modified stage, or stage I, is the reference condition in pristine areas where disturbances either have not occurred or are not harsh. The Restabilization stage is considered the reference stream for areas where disturbance or land clearing has been severe. Reference streams constitute stability, therefore stages I and VI are important in the determination of appropriate natural channel design parameters.

2.7 Rapid Bioassessment Protocol, (third protocol)

Rapid Bioassessment Protocol (third protocol), also known as RBP III, is meant to be a simple method to assess whether or not a stream is supporting healthy aquatic life (Barbour, 1999). Due to declining resources for monitoring and assessment in the mid-1980's and the extensive miles of un-assessed stream segments, the need for a cost-effective biological survey method was realized. Another realization was the need for more biological data, which was desperately lacking, in order to make informed decisions relevant to the nation's waters. Consolidated methods from several different state water resource agencies developed the original RBP's. RBP I was based on a screening protocol. The second, RBP II, was more time and labor intensive and incorporated field sampling and family-level taxonomy. The third version, RBP III, is the most stringent

and rigorous due to the incorporation of certain aspects of metric criteria developed by the North Carolina Division of Environmental Management and the New York Department of Environmental Conservation (Barbour, 1999). In this study, all RBP III data was collected and performed by TDEC within the last six years.

3.0 Methods

3.1 Study Design

Overview

The driving force behind this study was the need for better TMDL assessment tools. TDEC must implement TMDL requirements as promulgated by the Federal Clean Water Act, and state water pollution control statutes. Many streams on the 303(d) list are degraded due to siltation and habitat alteration lowering biological integrity. However, there is no direct causative link between the sedimentation and biological integrity, although it is often inferred from RBP III bioassessments. The objective of this study was to explore potential relationships between channel stability, bed sediment characteristics, and biological integrity.

TDEC biologists have conducted surveys for biological integrity data throughout Ecoregion 67. These surveys were termed RBP III's referring to the U.S. Environmental Protection Agency's Rapid Bioassessment Protocols (Barbour, 1999). The RBP III's were all performed in accordance with the state protocols (State of Tennessee, TDEC, Division of Water Pollution Control, Quality System Standard Operating Procedure for Macroinvertebrate Stream Surveys) and the EPA document *Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, Periphyton, Benthic Macroinvertebrates, and Fish*. As part of this study, data for channel stability and bed sediment characteristics were collected at the same locations in which TDEC collected

RBPIII data. The data was then compiled for a correlation analysis in order to examine relationships between both channel stability and bed sediment characteristics, and how they relate to biological integrity.

General Design Development

The first step of the study was to locate all the sites where TDEC had assessed the streams biological integrity with the RBP III protocols. Each location was then evaluated to ensure it was applicable for this study. After this process it was found that out of 109 possible sites, 76 were applicable for this study (Figure 1).

The field approach was to locate the stream reach using a GPS receiver with coordinates provided in the TDEC database. Once located, a team walked the stream segment and took digital photographs. During this time, a proper place to perform the pebble count and collect sediment was identified. Then the RGA, pebble count, and sediment collection was conducted. When returned to the lab, the data was entered and the particle size distributions were performed according to ASTM standards (ASTM Standards, 2003). Later, the TSS was conducted with the decant from the Hydrometer method and was performed according to Standard Methods (AWWA, 1995).

3.2 Field Methods

Site Selection

The sites were chosen specifically for locations containing RBP III data. TDEC provided GPS coordinates for each site, see Appendix B for site coordinates. The sites were located and mapped as shown in Figure 1. From this data and collaboration with Jonathon Burr of TDEC, proper site locations were selected. Sites were discarded if any of the following conditions were determined:

- there was water running through the stream predominantly from a different ecoregion
- there was discharge from a sewer treatment plant just upstream
- the site was near a confluence
- the stream was simply too large or too deep.

From these restrictions, the sites located in Figure 1 were the final selected sites, which comprise a total of 76 stream reaches.

Study Area

The research was concentrated in the Ridge and Valley area predominantly in East Tennessee. Ecoregion 67 is located between the Blue Ridge Mountains and the Cumberland Plateau and is relatively low-lying compared with the surrounding ecoregions (Etnier, 1993).

3.3 Rapid Geomorphic Assessment

The Rapid Geomorphic Assessment (RGA) is a method developed by Dr. Simon and colleagues at the USDA National Sedimentation Laboratory located in Oxford, Mississippi. The RGA provides a quick assessment of the channel stability of a particular stream reach. When the RGA is complete, an index metric for channel stability is generated. Examples of the forms used are located in Appendix A.

There are several dependent parameters of the channel's geomorphic characteristics that are combined to generate an index metric for channel stability. Following are the nine parameters needed:

- *Primary bed material* – found by performing a modified Wolman Count: along the stretch of a tape measure, the sediment is categorized as bedrock, boulder/cobble, gravel, sand, or silt clay for 100 specific tape intervals. All boulder/cobble and gravel materials are measured and recorded during this process.
- *Bed/bank protection* – marked if the bed or banks are artificially protected, and whether it is one or both banks that are protected.
- *Degree of incision* – found by measuring the water depth in the thalweg of the channel and dividing that by the bankfull height, which is from bank top to bank base.

- *Degree of constriction* – only found where obstructions are present within the channel making the upstream width differ from the downstream width of the stream.
- *Stream bank erosion* – broken into three categories: None, Fluvial, and Mass Wasting. Fluvial processes indicate undercutting of the bank toe or small amounts of surface erosion. Mass wasting is the worst kind of erosion where a large portion of material is dislodged into the stream. For this process stream bank erosion is separated into two sides, left and right when looking downstream.
- *Stream bank instability* – characterizes the percent each bank is failing.
- *Established riparian woody-vegetative cover* – the amount of permanent vegetation growing on the stream banks is estimated by the amount of vegetation with woody stems.
- *Occurrence of bank accretion* – the percentage of the reach with fluvial deposition of material.
- *Stage of evolution* – determined by consulting the stage of evolution figure and estimating what stage the channel represents. The stages of evolutions are divided into six categories: pre-modified, constructed, degradation, threshold, aggradation, and restabilization. (Simon, 2004)

In this study, each parameter represented a score between zero and four for a composite metric for channel stability. The total score was the addition of the nine parameter scores. Other prevalent pieces of information, such as the site location, date, and crewmembers, were documented. The slope of the channel was found with a Suunto

hand-held clinometer. See Appendix A for the actual form used. All RGA protocols were conducted in accordance with the procedures and training provided by the National Sedimentation Laboratory personnel.

Once a field site was located, the entire stream reach was walked. The stream reach was approximately six to ten times the stream width, straddling the actual location of the riffle that the RBP III was conducted. While walking, the features of the stream and surrounding area were noted, and locations for the modified Wolman pebble count and sediment collection were identified. Photographs were taken of the upstream and downstream ends of the reach, as well as unique features of the stream channel or banks. The sediment was promptly collected in the specified area to insure the area was not disturbed. The particle count was then performed using a 30-meter tape measure; in which particles were measured at consistent length intervals. This is modified from the original Wolman method in which a ten by ten grid is used. All particles two millimeters and larger were measured. Immeasurable items were classified as a silt clay, sand, or bedrock. The parameters of the RGA were assessed and the RGA form completed, including determination of the slope. Channel slope was estimated by a hand-held Suunto clinometer to the nearest 0.5-degree.

3.4 Bed Sediment Collection

There are two methods to characterize bed sediment. The first was the modified Wolman Count, which was described and used in the RGA method above. The second method

was to collect bed sediment and run laboratory analysis on the sample. Data from both methods were used in the study's correlation analyses.

Collection Location

Special protocols for the second sediment characterization method were used to collect and prioritize bed sediment. Once a collection area was located, special attention was made to avoid disturbing the area until the sediment was collected. If possible, the sediment was collected on a point bar. If there was not a point bar, then collection was on a side bar. If neither a point nor side bar was available, then collection was made behind any structure creating lateral flow and, therefore, creating a depositing area. This process was developed to collect the sediment that would show the history of the type of material the stream transports during a flood event.

Collection Process

When the location was determined, the sediment was collected with the stainless steel (SS) sampler (Figure 9). The metal sampler is 20.2-cm long and has an inside diameter of 7.1-cm. The sampler was slowly inserted into the sediment with the top moving against the direction of flow. A SS flat plate was used to seal the contents inside the container while removing the sampler from the stream. This was all done to ensure that fine sediment was collected in the process. The sediment, including any liquid, was then placed in a safe container and labeled with the site location and date. The sampler was



Figure 9: Sediment Sampler and Flat Plate

rinsed into the container to include any remaining sediment. The sample was then taken to the laboratory where the particle size distribution and total suspended solids tests were performed.

3.5 Laboratory Methods

When the sample was received at the laboratory, it underwent a series of procedures to produce a particle size distribution according to ASTM Standards (ASTM Standards, 2003). The total suspended solids procedure was performed on the decant from the hydrometer (AWWA, 1995). To view the laboratory forms used, see Appendix A.

Particle Size Distribution Method

The particle size distribution is a four-fold process that begins with the # 10 Sieve, separating the larger material that is retained, and the smaller material that passes the # 10 Sieve. The details of the process are described below, and the PSD's and raw data are located in Appendix B.

10 Sieve

First, the sample was air-dried in a disposable aluminum-baking pan until the entire sample was completely dry. The procedure for the # 10 Sieve was as follows:

- weigh the original sample and the #10 sieve
- dump material into the sieve carefully brushing and scraping to be sure no material is lost
- weight the empty aluminum container
- put the #10 sieve in a sieve shaker (Humboldt H-4330-1) and shake for 10 minutes
- put the large remaining material from the #10 sieve in a bowl and using a mortar and pestle break up aggregates as needed
- put the sample back in the #10 sieve and shake for another 10 minutes
- weigh sieve and retained material
- with the passing material, weigh a small tare and add 10-15 grams of material for the Hygroscopic Moisture test

- put the tare in the oven (110°C) and dry for 12-24 hours to get a moisture correction factor
- weigh another small container and add 110g for sandy material or 65g for clay material, cover and set aside for hydrometer
- put the remaining material in container and label for storage (Site Name, % passing #10)
- with the retained material, wash the material on the # 10 sieve for about 10 minutes
- weigh an extra large tare to collect the washed material by carefully brushing and scraping the material out of sieve and into tare
- oven dry the material over night (110°C).

Hydrometer

For the hydrometer method, these procedures were followed:

- wash and rinse the hydrometer cylinder with distilled water
- fill one hydrometer to the etched line with distilled water and insert the Celsius thermometer to record the temperature
- fill another hydrometer 1/3 full and label it with the site name
- re-weigh the sample, set aside for the hydrometer, and fill out hydrometer sheet, see Appendix A
- put the sample in the hydrometer and fill cylinder to just below the line with distilled water

- insert a stopper and shake for one minute (time according to when first time should be taken)
- carefully rinse the stopper and top of cylinder to avoid losing any material
- add distilled water as needed to bring the water level up to the etched line on the hydrometer
- take the hydrometer readings at specified times (taking 20 sec to slowly put hydrometer in sample so as not to create turbulence)
- continue to take readings until hydrometer reads zero
- once the hydrometer method is complete, siphon the sediment filled liquid into a plastic bottle and label the site indicating that it is the decant from the hydrometer
- prepare a tare by weighing and noting the tare number on Hydrometer sheet
- wash the remaining sediment on the #200 sieve and put into prepared tare
- oven dry 12-24 hours.

Dry Sieve Greater than #10

With the oven-dried material that was retained on the #10 sieve, these steps were followed:

- weigh the material and note on both the original sheet and on dry sieve greater than #10 sheet
- retrieve the 1/2, 3/8, #4, and #8 sieves and weigh each sieve separately
- combine the sieves with the bottom pan and add the material
- put in the shaker for 10 minutes (Humboldt H-4330-1)

- weigh and note each sieve with material, then collect all the material in container to store
- label site name and that the material was retained on the #10 sieve.

Dry Sieve from Wash 200

The procedure for this process was as follows:

- weigh the oven-dried material from the wash 200 and note on both the hydrometer sheet and dry sieve sheet
- weight each sieve separately and add the dried material from the wash 200 and sieve in a small shaker (Humboldt H-4326) for a minimum of 10 minutes
- once completed, weigh each sieve with material and collect all the material in a labeled container to store.

Total Suspended Solids Procedure

The Total Suspended Solids (TSS) procedure is not a standard procedure for the PSD analysis; it was done as a surrogate to parameterize the very fine material still suspended in the sample after the hydrometer test was complete. The TSS method was conducted on the decant from the hydrometer and was performed according to Standard Methods (AWWA, 1995, procedure No. 2540D).

The liquid remaining from the hydrometer was siphoned from the cylinder to a properly labeled liquid safe container. The TSS process was performed as follows. (AWWA, 1995)

Glass-Fiber Filter Disk Preparation

- insert filter disk (Gelman type A/E - 1.5 micron pore size) in filtration apparatus with wrinkled side up
- apply vacuum and, using distilled water, wash disk three times each with 20 ml portions
- continue suction to remove all traces of water, then place filter in inert planchet oven dry for one hour at 103 to 105°C
- cool in a desiccator to balance the temperature and weigh
- repeat cycle until the weight change is less than 4% or 0.5mg of the previous weighing, whichever is less; store in desiccator until needed.

Sample Analysis

- assemble filtering apparatus, filter, and then begin suction; wet filter with a small amount of distilled water to seat it
- stir sample with a magnetic stirrer continuously while the measured volume is extracted with a pipet into the seated glass-fiber filter
- wash with three successive 10-ml volumes of distilled water being careful to allow complete drainage between washings, and continue suction for three

minutes after filtration is complete (samples with high concentrations of dissolved solids may require additional washings)

- remove filter with tweezers and transfer to aluminum planchet
- oven dry for one hour at 103 to 105°C, cool in a desiccator, and weigh; repeat drying and cooling cycle until the weight change is less than 4%
- duplicate determinations should agree within 5% of their average.

3.6 Study Analysis

Data was compiled into two spreadsheets with rows representing the 76 study sites.

Columns included the following variables: RBP III score, RGA score, predominate material, channel slope, percent finer, and TSS. The percent finer was further broken into sub-categories of material finer than 2-mm, 0.425-mm, 0.15-mm, 0.075-mm, 0.016-mm, and 0.004-mm.

The particle size distribution information was broken up into similar categories as shown in the procedure above. An example of the spreadsheet created for the PSD analyses is presented in Appendix A. The different sediment size ranges are shown in Figure 10. This figure shows the location of each sediment size class (clay, silt, sand, and gravel). Larger materials can be present on PSD curves; however, the focus for this analysis was the material from the smaller size classes.

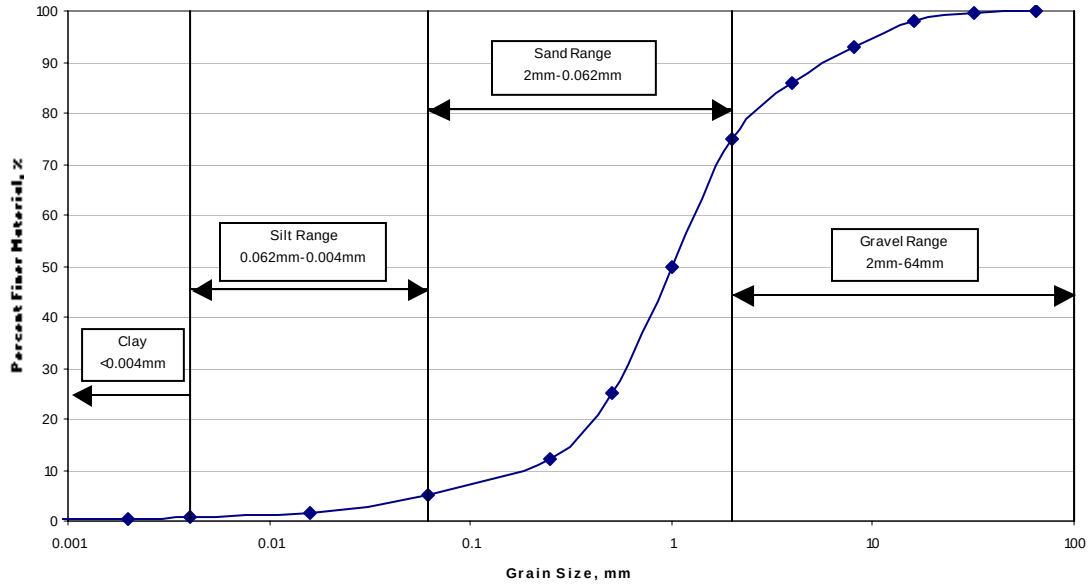


Figure 10: Particle Size Distribution Curve with Sediment Size Ranges

Column variables for this part of the analysis were: RBP III, RGA score, and information from the modified Wolman pebble count. The data from the Wolman procedure was reported as the percent below 2-mm, the Phi (ϕ) diameter at 50% and 16% (D_{50} and D_{84} respectively), and the amount of bedrock present. The Phi diameters were found using the equation as follows:

$$\phi = -\log_2 d, \text{ where } \log_2 d = \frac{\log_{10} d}{\log_{10} 2}, \text{ therefore } \phi = -\frac{\log_{10} d}{\log_{10} 2},$$

where ϕ = Phi diameter, and d = grain size diameter, mm (Wentworth, 1922).

The more negative the Phi value the larger the grain size. Cumulative frequency plots were formed by assigning each Phi diameter to a range then accumulating the values into cumulative percents associated with each Phi range. These plots are located in Appendix B and represent the percentage of particles larger or smaller than a given diameter. The

D_{50} indicates the median particle size where 50% of the particles are smaller or larger than that size. D_{84} represents the Phi diameter where 84% of particles are smaller. The *Result* section shows the result summaries of the collected data in tabular form.

Correlation and comparison analyses were preformed. The RBP III was the dependent variable and the RGA, channel slope, percent finer particles, TSS test, % below 2-mm, D_{50} and D_{84} Phi diameters were the independent variables. All statistical analyses were preformed using the JMP 5.1.2 Statistical Discovery Software.

4.0 Results

The results of the field and laboratory procedures are displayed in Tables 1 and 2. In both tables, the rows represent the data collected for each sample location. In Table 1, the columns correspond to the site location identification, RBP III score, RGA score, channel slope, and the Wolman count analysis (predominate material, % below 2-mm, D_{50} , D_{84} and D_{50} , D_{84} converted to millimeters). Table 2 displays the site location identification, RBP III score, and PSD information from the bed sediment collection (2-mm, 0.425-mm, 0.075-mm, 0.016-mm, 0.004-mm, TSS Test, including slopes from the percent finer PSD ranges).

A nonparametric statistical procedure was utilized due to the non-normality of the data. Table 3 shows the data analysis results, where each of the seventeen independent parameters was separately correlated with the RBP III data (biological data). The data in Table 3 was sorted in descending order according to the correlation coefficient (Spearman's Rho). The Spearman method was implemented using the JMP statistical software package to analyze the data.

The overall analysis did not yield strong correlations, but the relationships did show strong significance levels indicating confirmation that relationships do exist between RBP III data and several of the independent variables. Of the seventeen variables examined, nine had a correlation above 20% and are considered significant.

Table 1: Result Summery RGA Data

Location	RBPIII Score	RGA Score	Channel Slope	Cumulative Frequency Wolman Count					
	Range 0-42	Range 0-35		Predominate Material	Below 2mm, %	D ₅₀ (Phi)	D ₈₄ (Phi)	D ₅₀ , mm	D ₈₄ , mm
ALEXA000.2HS	32	6	4.0	Gravel	22.45	-3.92	-6.77	15.14	109.14
BARM000.5SU	28	9.5	1.5	Gravel	32.00	-3.75	-5.47	13.45	44.32
BLIME004.0WN	24	13.5	0.5	Gravel	16.00	-3.70	-4.46	13.00	22.01
BOONE001.7WN	24	17	1.7	Gravel	43.66	-3.06	-4.08	8.34	16.91
BOONE003.7WN	30	18	1.0	Gravel	29.87	-5.01	-6.23	32.22	75.06
BRUSH000.7WN	30	13	1.8	Boulder/Cobble	10.29	-6.33	-7.21	80.45	148.06
BSPRI000.2CT	36	17.5	1.8	Boulder/Cobble	6.38	-7.06	-7.88	133.44	235.57
BUFFA000.2CT	36	16	1.0	Gravel	42.86	-4.63	-5.96	24.76	62.25
CANEY004.3RO	24	16	2.0	Silt/Clay	52.00	-5.17	-6.06	35.95	66.72
CARSO000.1WN	24	19.5	1.0	Gravel	53.00	-3.56	-4.62	11.79	24.59
CAWOO000.2CL	34	15	5.0	Gravel	24.66	-2.37	-4.92	5.17	30.27
CROOK001.1BT	32	29	0.2	Silt/Clay	91.75	-2.50	-3.29	5.66	9.78
DAVIS011.6CL	38	15.5	1.0	Gravel	22.67	-3.81	-6.12	14.03	69.55
DAVIS014.6CL	34	17	1.0	Gravel	40.00	-2.65	-3.45	6.28	10.93
DAVIS016.2CL	30	18.5	0.5	Bed Rock	12.50	-4.60	-6.74	24.25	106.89
DAVIS018.1CL	28	18	0.8	Gravel	4.00	-3.95	-4.94	15.45	30.70
DAVIS020.5CL	26	16	1.0	Gravel	0.00	-4.22	-5.19	18.64	36.50
DAVIS022.6CL	16	17	0.0	Silt/Clay	100.00	0.00	0.00	1.00	1.00
DAVIS024.1CL	12	10.5	2.2	Gravel	0.00	-4.36	-5.14	20.53	35.26

Table 1: Continued

Location	RBPIII Score	RGA Score	Channel Slope	Cumulative Frequency Wolman Count					
	Range 0-42	Range 0-35		Predominate Material	Below 2mm, %	D ₅₀ (Phi)	D ₈₄ (Phi)	D ₅₀ , mm	D ₈₄ , mm
DRY001.3SU	40	19	2.2	Gravel	24.00	-5.57	-6.62	47.50	98.36
ECO6701	37.33	9.5	1.0	Bed Rock	41.51	-6.65	-7.50	100.43	181.02
ECO6702	36.67	9	4.0	Bed Rock	42.42	-4.06	-5.16	16.68	35.75
ECO6707	37.5	5.5	0.4	Boulder/Cobble					
ECO67F06	39.3	11	1.0	Gravel	6.00	-3.63	-4.84	12.38	28.64
ECO67F13	37.6	9	2.0	Gravel	12.12	-5.37	-6.82	41.36	112.99
ECO67F16	39.33	13.5	3.0	Gravel	2	-5.59	-6.18	48.17	72.5
ECO67F17	37.43	5.5	3.0	Boulder/Cobble	1.10	-6.17	-8.04	71.75	263.20
ECO67F23	36	12.5	3.0	Boulder/Cobble	8.82	-6.38	-8.81	83.29	448.82
ECO67G01	34.86	20	1.0	Gravel	13.16	-4.69	-5.80	25.81	55.72
ECO67G05	38.8	19.5	1.0	Boulder/Cobble	11.00	-6.32	-7.40	79.89	168.90
ECO67G08	38	14	0.7	Bed Rock	24.56	-4.55	-6.13	23.43	70.03
ECO67G09	40	9.5	1.1	Gravel	19.44	-4.41	-5.62	21.26	49.18
ECO67H04	30.67	8.5	1.8	Gravel	10.00	-4.63	-6.35	24.76	81.57
ECO67H06	39.33	12	0.8	Gravel					
ECO67I12	39.33	7.5	2.5	Gravel	16.00	-3.37	-4.34	10.34	20.25
ELLEJ000.1BT	39	6	0.5	Bed Rock					
FALL000.6WN	36	16.5	3.8	Gravel	20.22	-5.25	-8.29	38.05	313.00
FLAT001.HA	38	16.5	1.0	Gravel	2.00	-4.79	-6.13	27.67	70.03

Table 1: Continued

Location	RBPIII Score	RGA Score	Channel Slope	Cumulative Frequency Wolman Count					
	Range 0-42	Range 0-35		Predominate Material	Below 2mm, %	D ₅₀ (Phi)	D ₈₄ (Phi)	D ₅₀ , mm	D ₈₄ , mm
FOURM000.1HK	38	9.5	3.0	Boulder/Cobble	10.00	-6.09	-7.41	68.12	170.07
INDIA001.0SU	20	15	0.3	Gravel	18.95	-3.94	-5.31	15.35	39.67
JOCKE000.1WN	28	12	4.0	Gravel	19.00	-4.20	-5.29	18.38	39.12
LICK052.3GE	38	12	2.2	Bed Rock	8.33	-6.65	-8.23	100.43	300.25
LICK061.0GE	30	15.5	2.0	Gravel	34.34	-2.34	-3.16	5.06	8.94
MADD001.2SU	10	15	0.2	Gravel	18.00	-4.25	-5.77	19.03	54.57
MEADO000.4GE	34	14.5	0.5	Boulder/Cobble	9.28	-6.04	-7.19	65.80	146.02
PIGEO001.0GE	34	11.5	2.8	Bed Rock	35.90	-3.81	-6.25	14.03	76.11
PISTO000.2BT	28	14	1.0	Boulder/Cobble					
RICHL001.5GE	32	4	1.5	Bed Rock	28.51	-4.25	-5.26	19.03	38.32
RICHL003.5GE	16	25.5	0.5	Gravel	29.00	-3.90	-4.62	14.93	24.59
RICHL004.2GE	16	13	1.5	Gravel	39.08	-4.75	-7.44	26.91	173.65
RUSSE00.3CL	20	13.5	1.0	Gravel	39.00	-3.35	-4.31	10.20	19.84
RUSSE003.0CL	26	21	0.4	Gravel	38.39	-3.29	-4.30	9.78	19.70
RUSSE003.0CL	35	11.5	2.0	Gravel	0.00	-4.23	-5.93	18.77	60.97
SFLSE001.7MM	30	17	0.9	Gravel	49.48	-3.08	-4.01	8.46	16.11
SINKI003.2GE	37	8	2.8	Bed Rock	12.73	-6.10	-6.96	68.59	124.50
STEEK000.7LO	24	24	0.5	Gravel	13.00	-4.11	-4.78	17.27	27.47
STONY000.3CT	38	4.5	2.0	Boulder/Cobble	3.00	-5.92	-7.19	60.55	146.02

Table 1: Continued

Location	RBPIII Score	RGA Score	Channel Slope	Cumulative Frequency Wolman Count					
	Range 0-42	Range 0-35		Predominate Material	Below 2mm, %	D ₅₀ (Phi)	D ₈₄ (Phi)	D ₅₀ , mm	D ₈₄ , mm
SWEET009.3LO	26	13.5	0.8	Silt/Clay	60.60	-2.30	-3.07	4.92	8.40
SWEET017.3MO	14	24	0.1	Silt/Clay	100.00	0.00	0.00	1.00	1.00
SWEET019.4MO	30	16.5	0.8	Gravel	50.50	-3.42	-4.34	10.70	20.25
SWEET023.3MO	36	22	0.5	Silt/Clay	73.86	-2.79	-3.33	6.92	10.06
THOMP000.6MM	25.33	16.5	1.0	Sand	68.82	-6.19	-8.09	73.01	272.48
TOWN000.5LO	36	11	0.6	Gravel	41.00	-3.10	-4.38	8.57	20.82
TOWN002.1LO	38	20	0.8	Boulder/Cobble	1.10	-7.09	-7.84	136.24	229.13
TURKE000.5HK	42	8	3.5	Gravel	2.02	-5.82	-7.92	56.49	242.19
WFPAN000.1HK	32	18.5	1.0	Gravel	11.00	-3.98	-4.50	15.78	22.63
Beaver Creek at Halls Park	28	13	2.0	Gravel	85.19	-1.97	-3.37	3.92	10.34
Beaver Ck @Beeler Rd	24	20	0.5	Gravel	21.21	-2.90	-3.64	7.46	12.47
Beaver Ck @Brown Gap Rd	32	14.5	1.5	Gravel	11.00	-4.75	-6.13	26.91	70.03
Willow Fork@Willow Fork Ln	28	11	1.0	Gravel	0.00	-4.13	-4.84	17.51	28.64
Hines Branch@Cunningham Rd	22	19	1.5	Gravel	15.00	-3.91	-4.73	15.03	26.54
Knob Fork	24	13.5	1.0	Gravel	5.00	-4.00	-4.71	16.00	26.17
Cox Creek @at Brown Gap Rd	34	10.5	2.0	Gravel	3.00	-4.34	-5.72	20.25	52.71
Breaver Creek@ Stormer Rd	18	13	0.5	Gravel	40.63	-2.91	-3.81	7.52	14.03
Beaver Creek@ Clinton Hwy	34	14.5	0.5	Gravel	6.00	-3.82	-4.67	14.12	25.46
Meadow Creek@Cross Lane	34	15	1.5	Gravel	3.09	-4.00	-4.87	16.00	29.24

Table 2: Result Summery

Location	RBPIII Score*	Percent Finer						TSS Test	Slopes from Percent Finer				
	Range 0-42	2mm	0.425mm	0.15mm	0.075mm	0.016mm	0.004mm		2mm- 0.425mm	0.425mm- 0.15mm	0.15mm- 0.075mm	0.075mm- 0.016mm	0.016mm- 0.004mm
ALEXA000.2HS	32	19.520	11.540	6.690	5.830	0.869	0.335	0.323	11.864	10.723	2.857	7.393	0.888
BARM000.5SU	28	46.420	24.360	8.280	6.290	1.823	0.806	0.332	32.796	35.552	6.611	6.658	1.688
BLIME004.0WN	24	41.670	16.990	7.830	5.870	1.320	0.309	0.581	36.691	20.252	6.511	6.781	1.679
BOONE001.7WN	24	84.840	48.920	18.660	13.780	3.481	1.661	0.088	53.401	66.903	16.211	15.351	3.022
BOONE003.7WN	30	45.930	18.440	3.280	2.670	0.931	0.230	0.076	40.869	33.518	2.026	2.592	1.165
BRUSH000.7WN	30	22.750	5.060	2.790	2.450	0.841	0.243	0.203	26.299	5.019	1.129	2.397	0.994
BSPRI000.2CT	36	66.460	41.430	9.160	4.580	1.922	0.644	0.125	37.212	71.347	15.214	3.962	2.121
BUFFA000.2CT	36	16.770	8.500	3.690	2.630	0.548	0.171	0.180	12.295	10.635	3.521	3.103	0.626
CANEY004.3RO	24	50.250	18.530	4.060	2.050	0.171	0.000	0.717	47.157	31.992	6.677	2.801	0.283
CARSO000.1WN	24	80.900	44.890	18.850	13.570	1.390	0.000	1.104	53.535	57.573	17.540	18.154	2.309
CAWOO000.2CL	34	49.590	18.870	1.980	1.230	0.000	0.000	0.338	45.671	37.343	2.491	1.833	0.000
CROOK001.1BT	32	74.380	30.630	2.810	1.840	0.660	0.000	1.120	65.042	61.508	3.222	1.759	1.096
DAVIS011.6CL	38	53.970	30.480	2.980	1.420	0.000	0.000	0.259	34.922	60.801	5.182	2.116	0.000
DAVIS014.6CL	34	33.350	19.160	4.000	2.270	0.283	0.000	0.925	21.096	33.518	5.747	2.961	0.471
DAVIS016.2CL	30	37.590	9.650	2.440	1.350	0.490	0.000	0.839	41.538	15.941	3.621	1.282	0.814
DAVIS018.1CL	28	46.410	33.680	3.630	2.320	0.348	0.000	0.600	18.925	66.439	4.352	2.940	0.577
DAVIS020.5CL	26	21.860	10.860	6.040	4.680	1.403	0.311	0.368	16.353	10.657	4.518	4.884	1.814
DAVIS022.6CL	16	99.540	77.300	39.960	23.320	4.108	0.189	0.716	33.064	82.556	55.277	28.635	6.508
DAVIS024.1CL	12	9.790	6.080	3.530	2.510	0.901	0.107	1.908	5.516	5.638	3.388	2.398	1.319

Table 2: Continued

Location	RBPIII Score	Percent Finer						TSS Test	Slopes from Percent Finer				
	Range 0-42	2mm	0.425mm	0.15mm	0.075mm	0.016mm	0.004mm		2mm- 0.425mm	0.425mm- 0.15mm	0.15mm- 0.075mm	0.075mm- 0.016mm	0.016mm- 0.004mm
DRY001.3SU	40	38.340	13.450	4.550	3.580	0.680	0.514	0.272	37.003	19.677	3.222	4.322	0.275
ECO6701	37.33	38.700	12.720	1.760	1.300	0.000	0.000	0.925	38.624	24.232	1.528	1.938	0.000
ECO6702	36.67	98.740	48.740	3.680	2.600	0.000	0.000	0.345	74.334	99.625	3.588	3.875	0.000
ECO6707	37.5							0.207	0.000	0.000	0.000	0.000	0.000
ECO67F06	39.3	13.950	6.520	1.970	1.080	0.048	0.000	0.699	11.046	10.060	2.957	1.538	0.080
ECO67F13	37.6	32.870	12.150	0.860	0.480	0.000	0.000	0.393	30.804	24.961	1.262	0.715	0.000
ECO67F16	39.33	68.950	15.860	0.880	0.810	0.000	0.000	0.357	78.928	33.120	0.233	1.207	0.000
ECO67F17	37.43	55.450	16.600	11.000	7.920	1.497	0.000	1.131	57.757	12.381	10.232	9.574	2.486
ECO67F23	36	79.460	54.350	3.610	1.950	0.000	0.000	0.304	37.330	112.183	5.514	2.906	0.000
ECO67G01	34.86	49.440	4.630	2.560	2.290	0.184	0.000	0.951	66.618	4.577	0.897	3.139	0.306
ECO67G05	38.8	69.910	42.640	31.010	30.060	0.000	0.000	1.171	40.542	25.713	3.156	44.803	0.000
ECO67G08	38	33.320	8.800	4.450	3.720	0.848	0.418	0.237	36.453	9.618	2.425	4.281	0.714
ECO67G09	40	15.450	3.960	1.710	1.370	0.303	0.280	0.199	17.082	4.975	1.129	1.590	0.038
ECO67H04	30.67	23.160	2.850	2.110	1.840	0.680	0.218	0.183	30.194	1.636	0.897	1.729	0.768
ECO67H06	39.33							0.760	0.000	0.000	0.000	0.000	0.000
ECO67I12	39.33	61.100	32.160	11.170	7.330	1.680	0.099	0.461	43.024	46.407	12.756	8.421	2.626
ELLEJ000.1BT	39								0.000	0.000	0.000	0.000	0.000
FALL000.6WN	36	38.190	12.510	3.410	2.570	0.350	0.000	0.659	38.178	20.119	2.790	3.309	0.581
FLAT001.HA	38	26.460	9.530	3.470	2.630	0.240	0.000	1.539	25.169	13.398	2.790	3.562	0.399

Table 2: Continued

Location	RBPIII Score	Percent Finer						TSS Test	Slopes from Percent Finer				
	Range 0-42	2mm	0.425mm	0.15mm	0.075mm	0.016mm	0.004mm		2mm- 0.425mm	0.425mm- 0.15mm	0.15mm- 0.075mm	0.075mm- 0.016mm	0.016mm- 0.004mm
FOURM000.1HK	38	40.020	15.860	4.040	3.060	0.338	0.000	0.680	35.918	26.133	3.255	4.056	0.562
INDIA001.0SU	20	27.800	4.410	2.320	2.160	0.743	0.263	0.196	34.773	4.621	0.532	2.112	0.796
JOCKE000.1WN	28	38.100	20.120	8.780	6.500	0.700	0.072	0.225	26.730	25.072	7.574	8.645	1.043
LICK052.3GE	38	71.280	6.670	4.020	2.980	0.000	0.000	0.680	96.054	5.859	3.455	4.442	0.000
LICK061.0GE	30	83.900	30.380	17.560	13.210	1.908	0.780	0.337	79.567	28.344	14.450	16.845	1.874
MADD001.2SU	10	64.840	14.730	1.650	1.370	0.349	0.000	0.133	74.497	28.919	0.930	1.522	0.579
MEADO000.4GE	34	67.670	48.340	14.810	8.030	1.200	0.000	0.869	28.737	74.133	22.523	10.180	1.993
PIGEO001.0GE	34	45.980	29.790	8.890	6.530	1.233	0.042	0.553	24.069	46.209	7.840	7.895	1.978
PISTO000.2BT	28	88.600	13.750	4.180	3.300	0.000	0.000	0.765	111.278	21.159	2.923	4.918	0.000
RICHL001.5GE	32	38.480	19.420	4.850	2.550	0.181	0.000	0.736	28.336	32.213	7.640	3.531	0.301
RICHL003.5GE	16	92.680	54.350	5.650	3.620	0.000	0.000	0.704	56.984	107.672	6.744	5.395	0.000
RICHL004.2GE	16	51.010	4.150	0.880	0.690	0.000	0.000	0.271	69.666	7.230	0.631	1.028	0.000
RUSSE000.3CL	20	41.140	29.820	10.570	6.850	1.096	0.076	0.249	16.829	42.560	12.358	8.576	1.694
RUSSE000.9BT	26	42.130	13.980	2.860	2.470	0.364	0.131	5.908	41.850	24.586	1.296	3.139	0.387
RUSSE003.0CL	35	21.980	9.110	3.160	2.100	0.400	0.000	0.987	19.134	13.155	3.521	2.534	0.664
SFLSE001.7MM	30	37.310	13.740	4.140	2.940	0.746	0.000		35.041	21.225	3.986	3.270	1.239
SINKI003.2GE	37	87.120	16.250	3.960	3.250	0.400	0.000	0.379	105.361	27.172	2.359	4.248	0.664
STEEK000.7LO	24	17.680	12.140	5.320	3.190	0.285	0.082	0.207	8.236	15.079	7.076	4.329	0.338
STONY000.3CT	38	6.360	4.330	1.810	1.100	0.302	0.229	0.144	3.018	5.572	2.359	1.189	0.121

Table 2: Continued

Location	RBPIII Score	Percent Finer						TSS Test	Slopes from Percent Finer				
	Range 0-42	2mm	0.425mm	0.15mm	0.075mm	0.016mm	0.004mm		2mm- 0.425mm	0.425mm- 0.15mm	0.15mm- 0.075mm	0.075mm- 0.016mm	0.016mm- 0.004mm
SWEET009.3LO	26	50.210	34.280	7.870	5.910	1.006	0.268	0.136	23.683	58.391	6.511	7.310	1.225
SWEET017.3MO	14	100.000	99.690	94.770	90.000	56.154	23.410		0.461	10.878	15.846	50.446	54.386
SWEET019.4MO	30	53.660	30.530	3.400	2.280	0.101	0.000	2.101	34.387	59.983	3.721	3.247	0.168
SWEET023.3MO	36	57.380	33.020	5.120	3.170	0.635	0.088	0.208	36.215	61.685	6.478	3.778	0.908
THOMP000.6MM	25.3	92.760	79.530	10.480	5.270	2.103	0.840	0.105	19.669	152.665	17.307	4.720	2.098
TOWN000.5LO	36	54.230	16.460	3.940	2.620	0.490	0.000	1.991	56.152	27.681	4.385	3.175	0.814
TOWN002.1LO	38	26.880	5.300	3.390	2.710	0.611	0.049	4.707	32.082	4.223	2.259	3.128	0.933
TURKE000.5HK	42	25.450	8.610	4.880	3.940	0.330	0.000	1.061	25.036	8.247	3.123	5.381	0.548
WFPAN000.1HK	32	35.540	5.820	3.330	2.910	0.463	0.000	1.233	44.184	5.505	1.395	3.647	0.770
Beaver Creek at Halls Park	28	64.020	6.880	3.640	3.120	0.590	0.000	0.891	84.949	7.163	1.727	3.771	0.980
Beaver Ck @Beeler Rd	24	54.170	18.620	8.160	7.080	0.950	0.048		52.851	23.126	3.588	9.136	1.498
Beaver Ck @Brown Gap Rd	32	17.870	7.290	5.720	5.370	5.671	3.859		15.729	3.471	1.163	-0.448	3.008
Willow Fork@Willow Fork Ln	28	29.980	10.280	1.870	1.600	0.096	0.000		29.288	18.594	0.897	2.242	0.159
Hines Branch@Cunningham Rd	22	50.080	2.370	1.410	1.230	0.053	0.000	0.733	70.929	2.122	0.598	1.754	0.088
Knob Fork	24	25.760	6.200	2.090	1.660	0.190	0.000		29.079	9.087	1.428	2.190	0.316
Cox Creek @at Brown Gap Rd	34	28.650	2.820	1.560	1.330	0.360	0.026	0.565	38.401	2.786	0.764	1.446	0.554
Breaver Creek@ Stormer Rd	18	93.930	40.860	19.190	13.560	3.743	0.344	1.127	78.898	47.911	18.702	14.632	5.645
Beaver Creek@ Clinton Hwy	34	54.030	30.460	5.220	3.200	0.980	0.000	0.967	35.041	55.804	6.710	3.309	1.628
Meadow Creek@Cross Lane	34	15.700	5.340	2.960	2.300	0.207	0.000		15.402	5.262	2.192	3.120	0.343

*All available RBP III data was collected and averaged for sites with multiple scores

Table 3: Data Analysis Results (Sorted by Spearman Rho)			
Variable (Against RBP III)	Spearman Rho		Prob> Rho
	Sign	Value	
D84	-	0.4926	<0.0001
D50	-	0.4615	<0.0001
0.016-0.004-mm	-	0.399	0.0004
RGA	-	0.357	0.0015
Channel Slope	+	0.3461	0.0022
Below 2-mm	-	0.3425	0.0032
0.016-mm	-	0.3144	0.0067
0.15-0.075-mm	-	0.2678	0.0193
0.075-0.016-mm	-	0.2292	0.0464
0.004-mm	-	0.2193	0.0623
2-mm	-	0.1956	0.0972
0.15-mm	-	0.1888	0.1097
0.075-mm	-	0.1851	0.117
0.425-0.15-mm	-	0.1834	0.1129
0.425-mm	-	0.1655	0.1617
2-0.425-mm	-	0.1099	0.3448
TSS Test	+	0.0759	0.5387

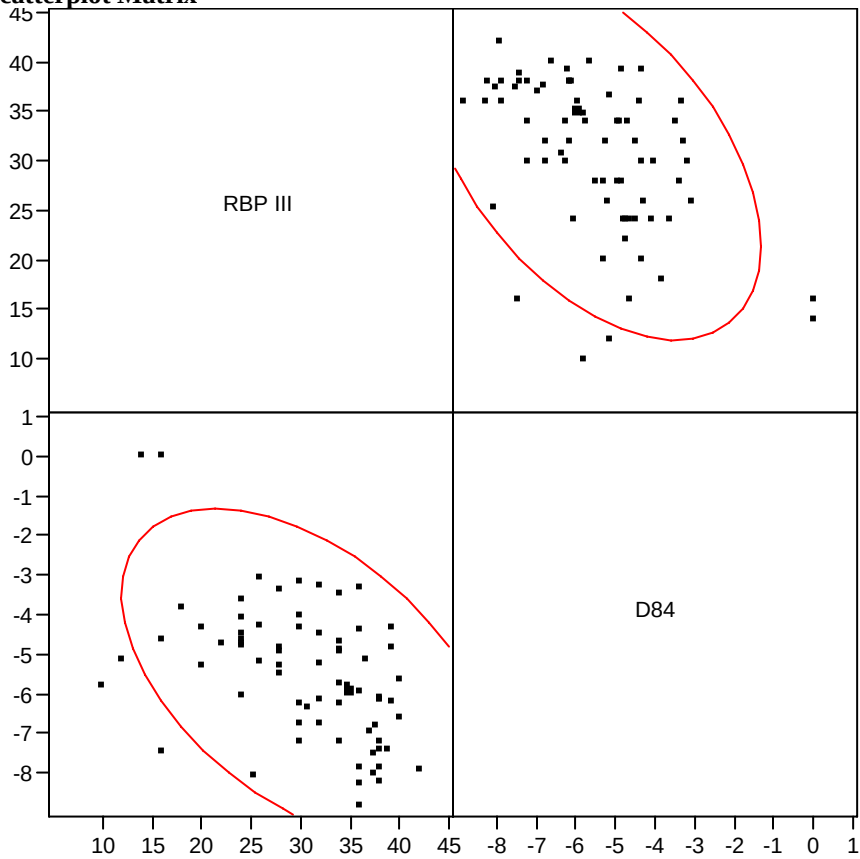
The strongest relationship to the RBP III data was the D_{84} from the pebble count, which had a correlation of 49.3% and a significance value less than 0.0001 (Figure 11). The D_{50} also had a strong relationship with a correlation of 46.2% and a significance value also less than 0.0001 (Figure 12). The slope between the percent finer values of 0.016-mm and 0.004-mm resulted in a correlation value of 39.9% with a significance value of 0.0004 (Figure 13). The RGA procedure produced a similar correlation of 35.7% and significance of 0.0015 (Figure 14). The channel slope resulted in a correlation of 34.6% with a significance of 0.0022 (Figure 15). The percent below 2-mm was found to have a correlation of 34.3% with a significance of 0.0032 (Figure 16). The 0.016-mm variable of the percent finer material produced a correlation coefficient of 31.4% and a significance value of 0.0067 (Figure 17). The slope between the percent finer values of 0.15-mm to 0.075-mm resulted in a correlation value of 26.8% with a significance value of 0.0193 (Figure 18). The last of the significant relationships is the slope between the 0.075-mm and the 0.016-mm of the percent finer material, which had a 22.9% correlation with a 0.0464 significance value (Figure 19). The remaining variables were not found to have strong enough relationships to be considered statistically significant. In order of correlations, these variables include 0.004-mm, 2-mm, 0.15-mm, 0.075-mm, 0.425 to 0.15-mm, 0.425-mm, 2 to 0.425-mm, and finally the TSS test (Figures 20-27).

Two outliers were found with the JMP statistical software during the analysis; the sites were DAVIS024.1CL and MADD001.2SU. Jonathon Burr and Tina Robinson from TDEC were contacted to discuss the site conditions. Based on these discussions, the decision was made to exclude these points from the data analyses, due to the effects of

Multivariate Correlations

	RBP III	D84
RBP III	1.0000	-0.4892
D84	-0.4892	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

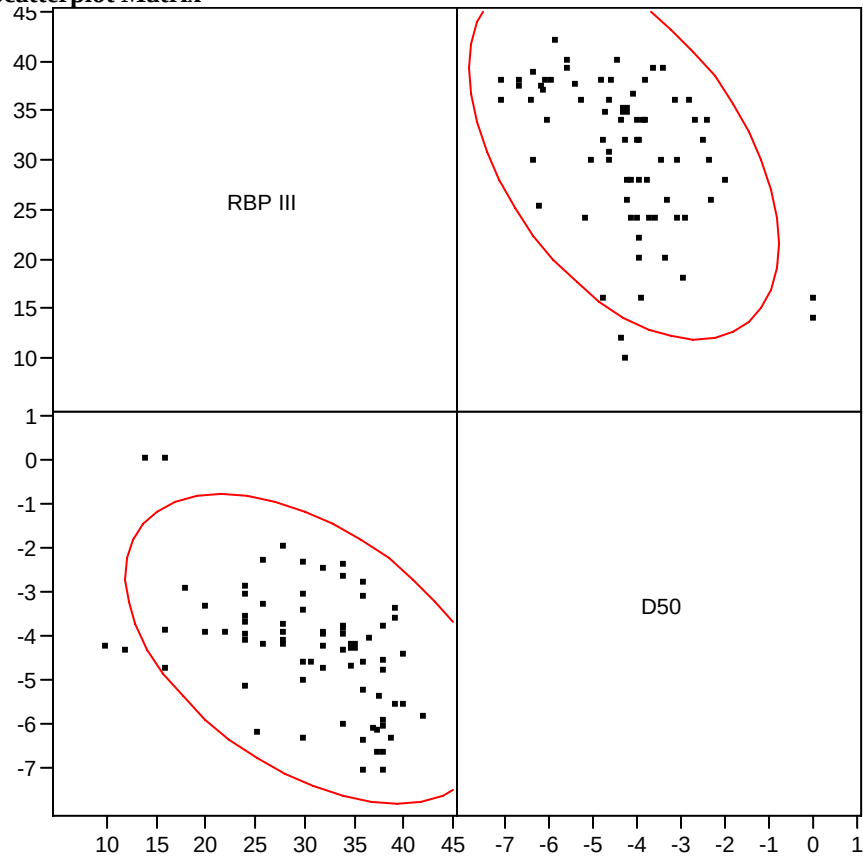
Variable	by Variable	Spearman Rho	Prob> Rho
D84	RBP III	-0.4926	<.0001

Figure 11: RBP III and D84 Correlations

Multivariate Correlations

	RBP III	D50
RBP III	1.0000	-0.4765
D50	-0.4765	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

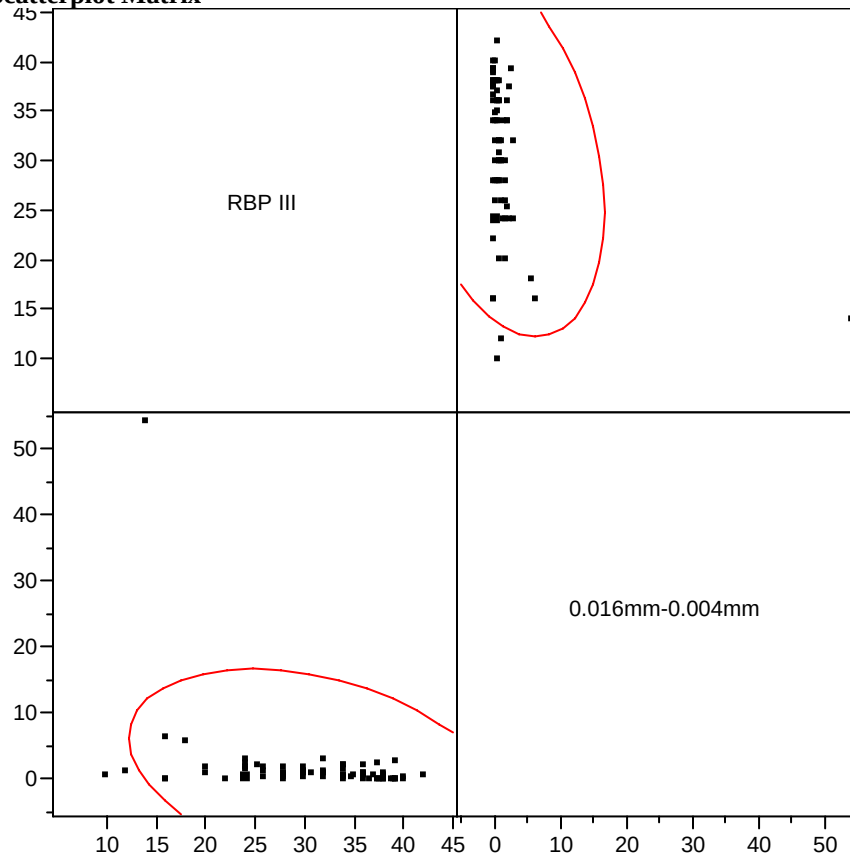
Variable	by Variable	Spearman Rho	Prob> Rho
D50	RBP III	-0.4615	<.0001

Figure 12: RBP III and D50 Correlations

Multivariate Correlations

	RBP III	0.016-0.004-mm
RBP III	1.0000	-0.3199
0.016-0.004-mm	-0.3199	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

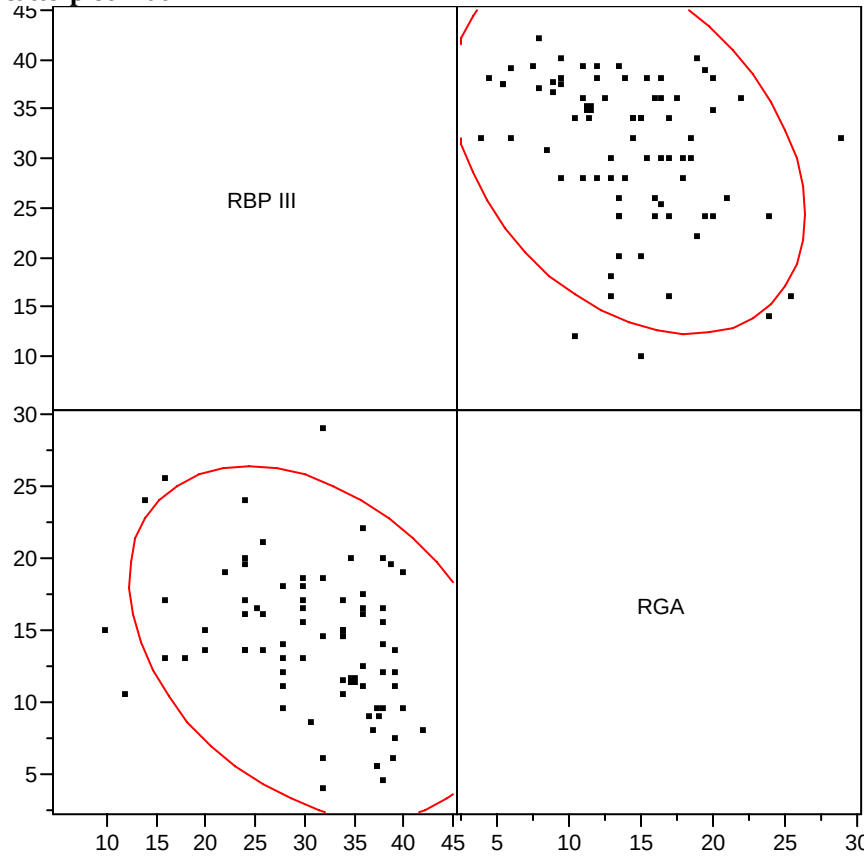
Variable	by Variable	Spearman Rho	Prob> Rho
0.016-0.004-mm	RBP III	-0.3990	0.0004

Figure 13: RBP III and 0.016-0.004-mm Correlations

Multivariate Correlations

	RBP III	RGA
RBP III	1.0000	-0.3453
RGA	-0.3453	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

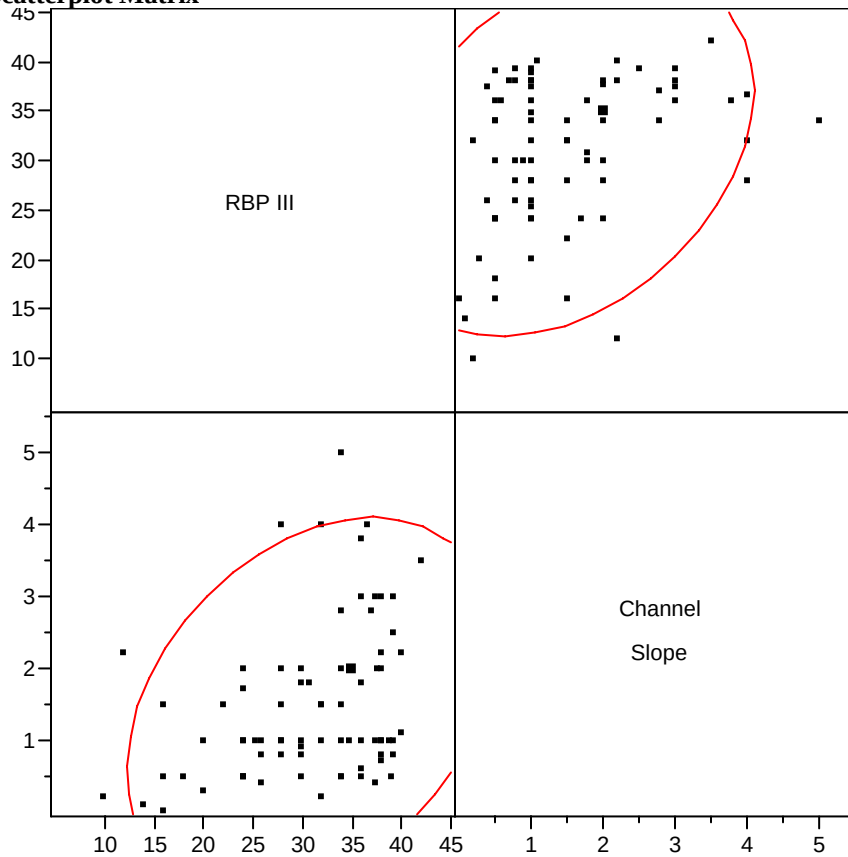
Variable	by Variable	Spearman Rho	Prob> Rho
RGA	RBP III	-0.3570	0.0015

Figure 14: RBP III and RGA Correlations

Multivariate Correlations

	RBP III	Channel Slope
RBP III	1.0000	0.3426
Channel Slope	0.3426	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

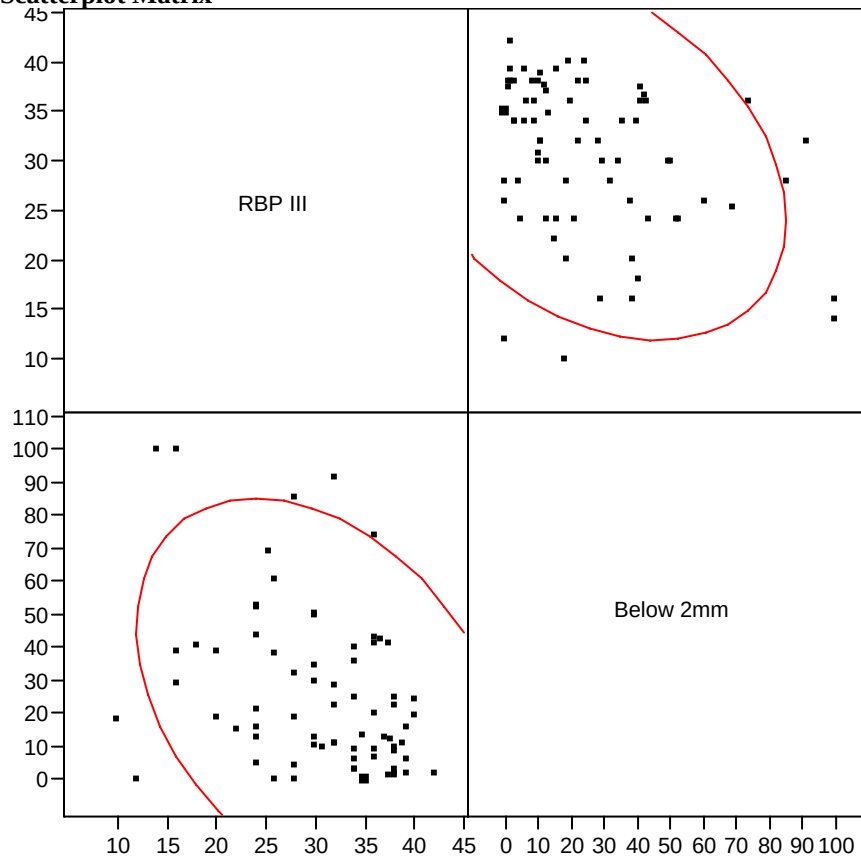
Variable	by Variable	Spearman Rho	Prob> Rho
Channel Slope	RBP III	0.3461	0.0022

Figure 15: RBP III and Channel Slope Correlations

Multivariate Correlations

	RBP III	Below 2-mm
RBP III	1.0000	-0.3498
Below 2-mm	-0.3498	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

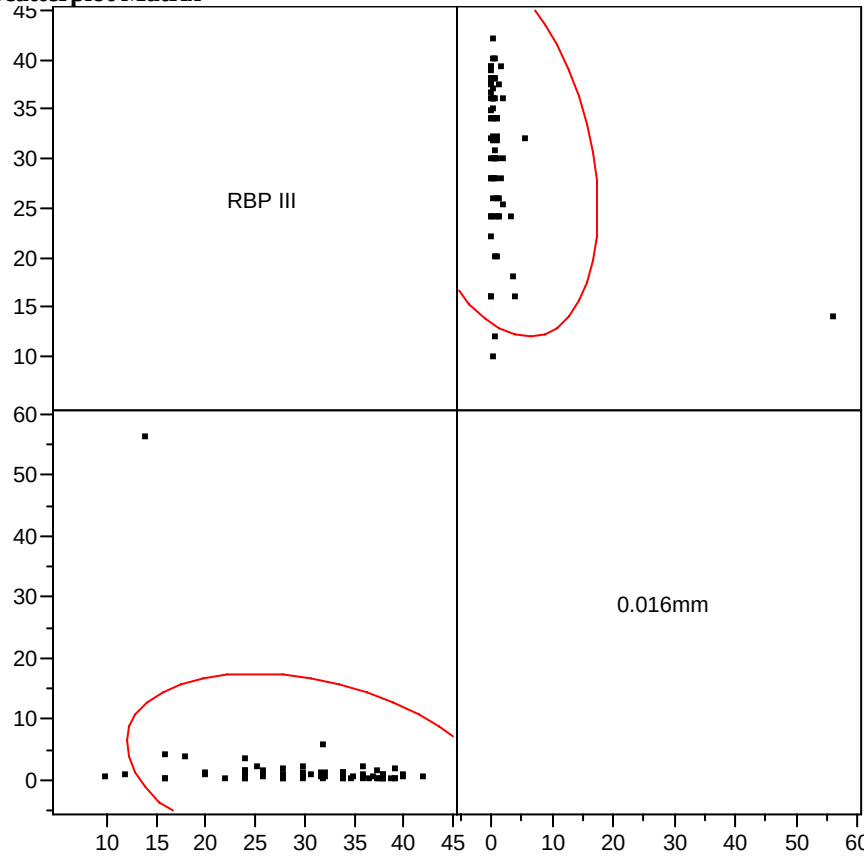
Variable	by Variable	Spearman Rho	Prob> Rho
Below 2-mm	RBP III	-0.3425	0.0032

Figure 16: RBP III and Percent Below 2-mm Correlations

Multivariate Correlations

	RBP III	0.016-mm
RBP III	1.0000	-0.2965
0.016-mm	-0.2965	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

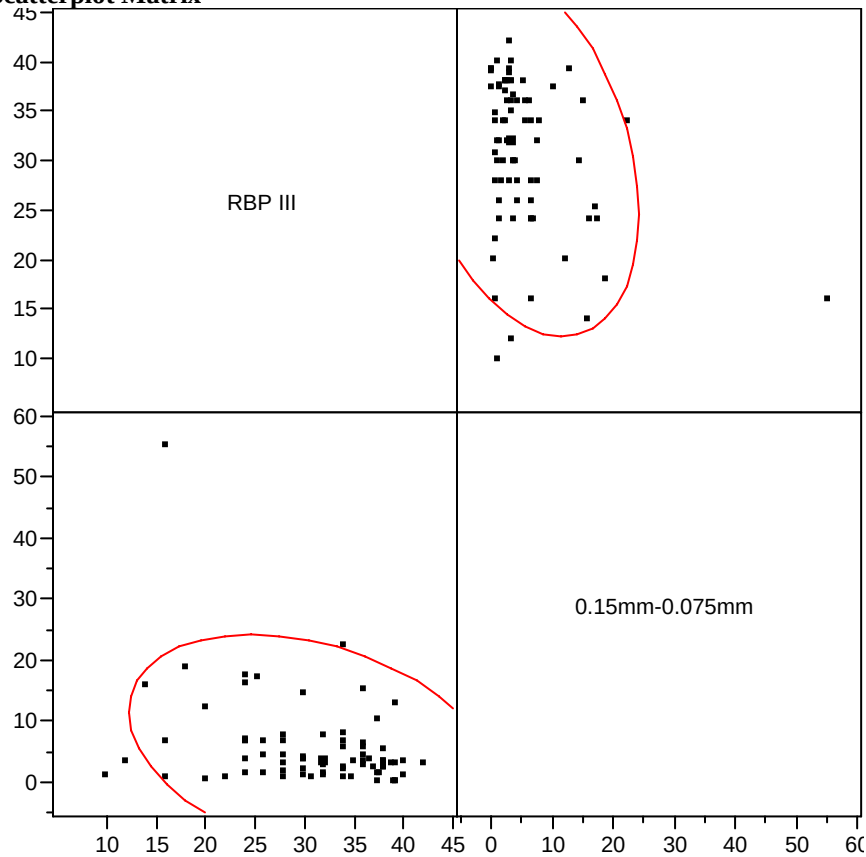
Variable	by Variable	Spearman Rho	Prob> Rho
0.016-mm	RBP III	-0.3144	0.0067

Figure 17: RBP III and 0.016-mm Correlations

Multivariate Correlations

	RBP III	0.15-0.075-mm
RBP III	1.0000	-0.3283
0.15-0.075-mm	-0.3283	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

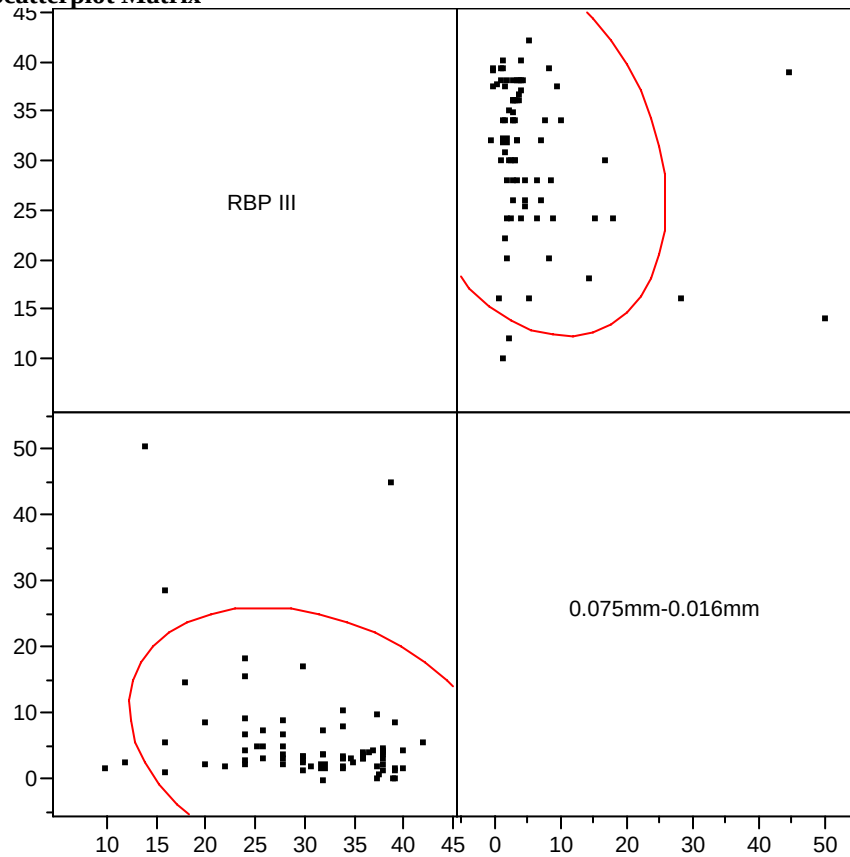
Variable	by Variable	Spearman Rho	Prob> Rho
0.15-mm-0.075-mm	RBP III	-0.2678	0.0193

Figure 18: RBP III and 0.15-0.075-mm Correlations

Multivariate Correlations

	RBP III	0.075-0.016-mm
RBP III	1.0000	-0.2709
0.075-0.016-mm	-0.2709	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

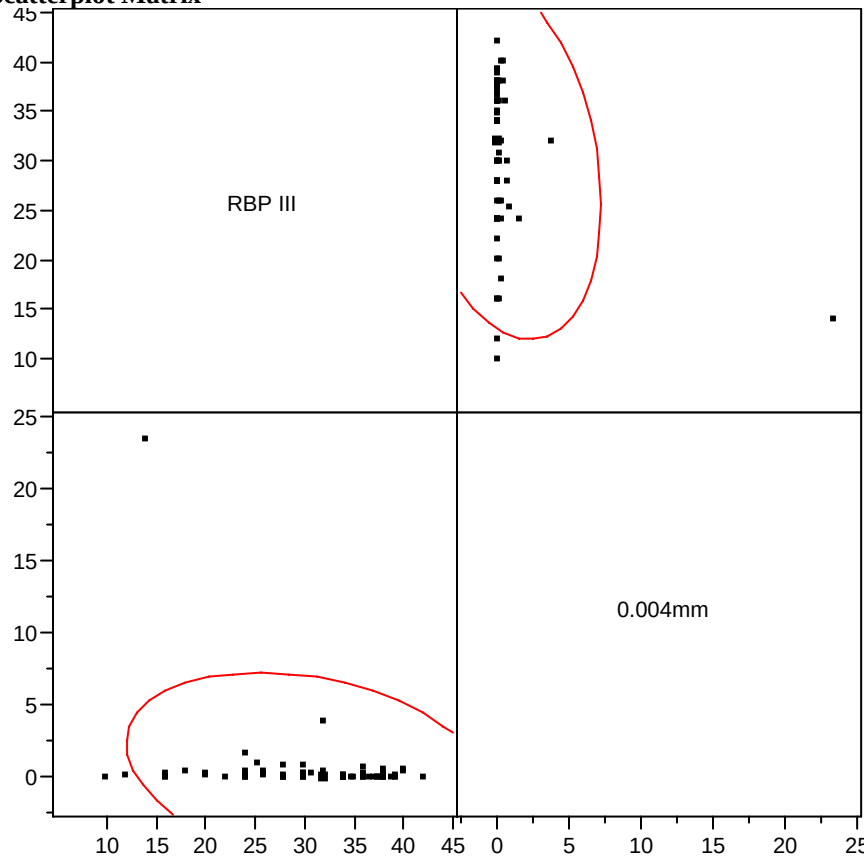
Variable	by Variable	Spearman Rho	Prob> Rho
0.075-mm-0.016-mm	RBP III	-0.2292	0.0464

Figure 19: RBP III and 0.075-0.016-mm Correlations

Multivariate Correlations

	RBP III	0.004-mm
RBP III	1.0000	-0.2658
0.004-mm	-0.2658	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

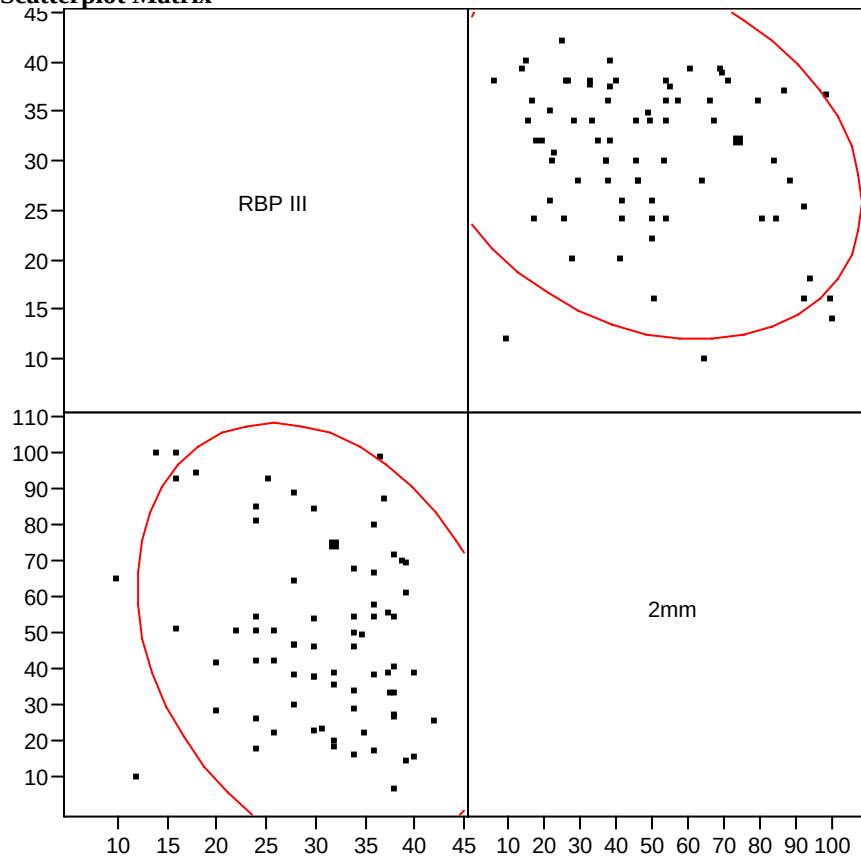
Variable	by Variable	Spearman Rho	Prob> Rho
0.004-mm	RBP III	-0.2193	0.0623

Figure 20: RBP III and 0.004-mm Correlations

Multivariate Correlations

	RBP III	2-mm
RBP III	1.0000	-0.2514
2-mm	-0.2514	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

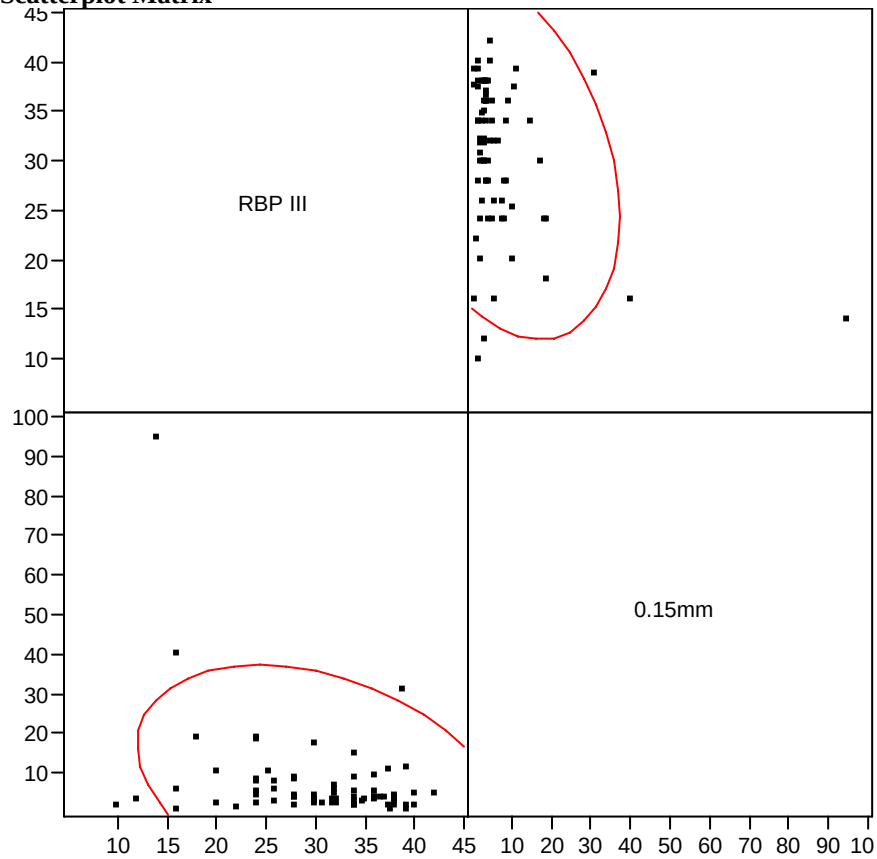
Variable	by Variable	Spearman Rho	Prob> Rho
2-mm	RBP III	-0.1956	0.0972

Figure 21: RBP III and 2-mm Correlations

Multivariate Correlations

	RBP III	0.15-mm
RBP III	1.0000	-0.3312
0.15-mm	-0.3312	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

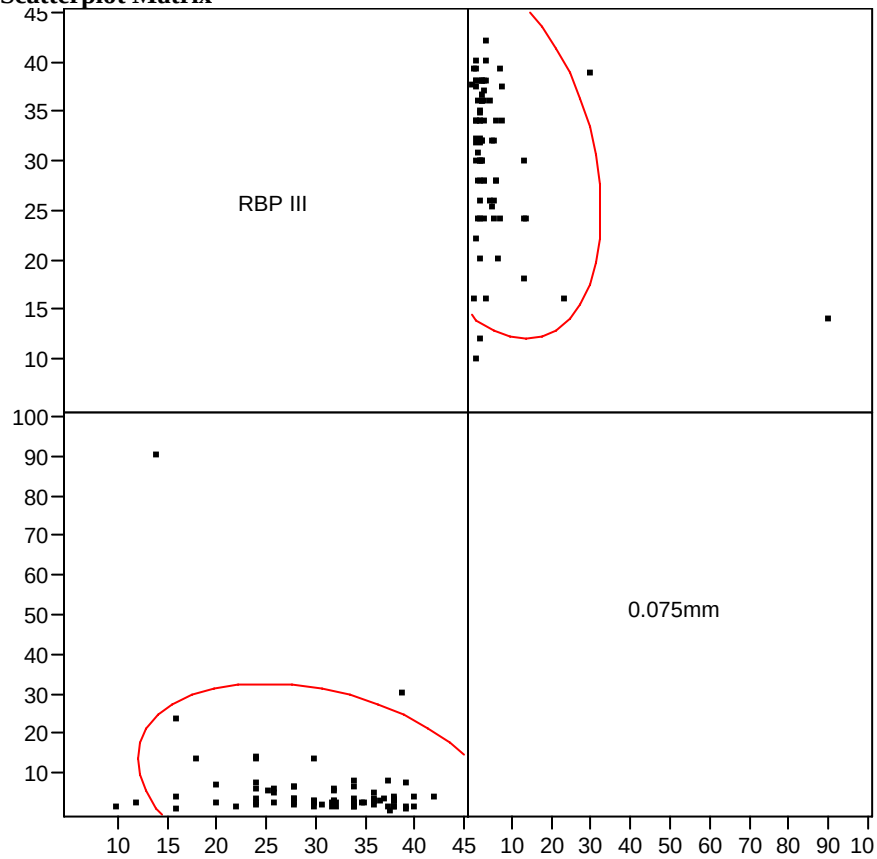
Variable	by Variable	Spearman Rho	Prob> Rho
0.15-mm	RBP III	-0.1888	0.1097

Figure 22: RBP III and 0.15-mm Correlations

Multivariate Correlations

	RBP III	0.075-mm
RBP III	1.0000	-0.3014
0.075-mm	-0.3014	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

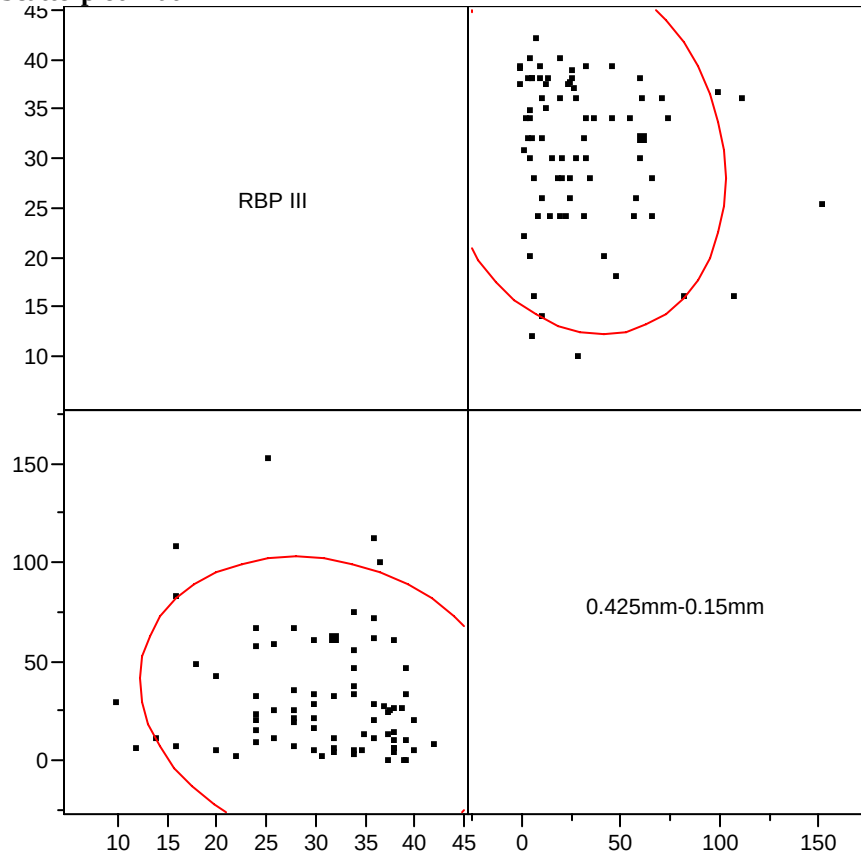
Variable	by Variable	Spearman Rho	Prob> Rho
0.075-mm	RBP III	-0.1851	0.1170

Figure 23: RBP III and 0.075-mm Correlations

Multivariate Correlations

	RBP III	0.425-0.15-mm
RBP III	1.0000	-0.1492
0.425-0.15-mm	-0.1492	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

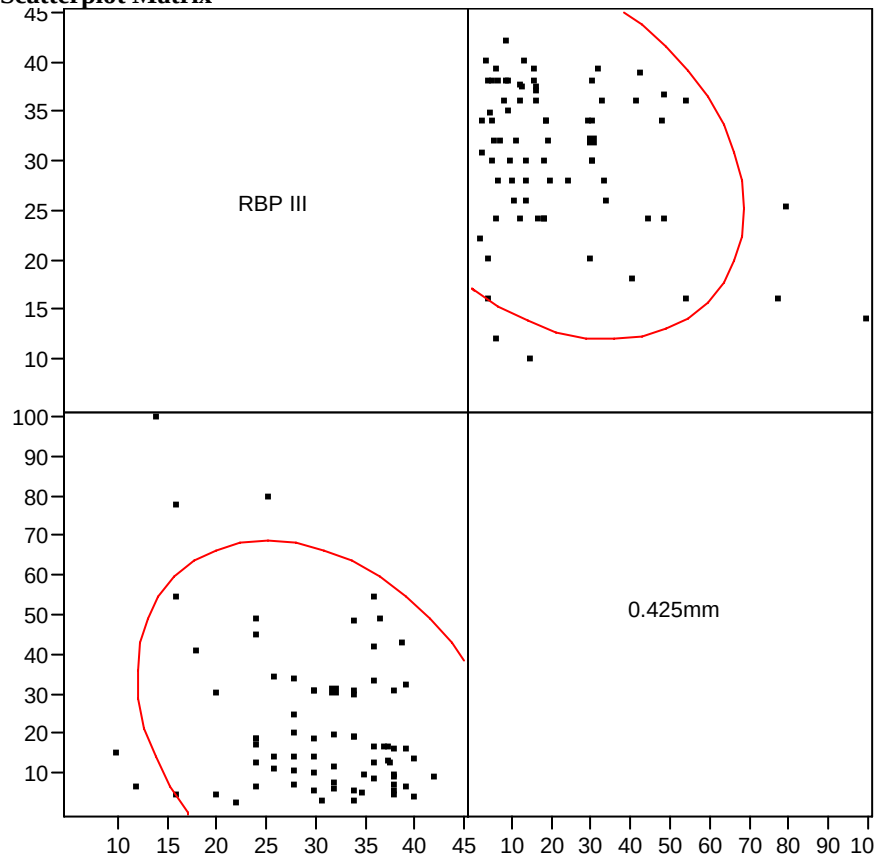
Variable	by Variable	Spearman Rho	Prob> Rho
0.425-0.15-mm	RBP III	-0.1834	0.1129

Figure 24: RBP III and 0.425-0.15-mm Correlations

Multivariate Correlations

	RBP III	0.425-mm
RBP III	1.0000	-0.2881
0.425-mm	-0.2881	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

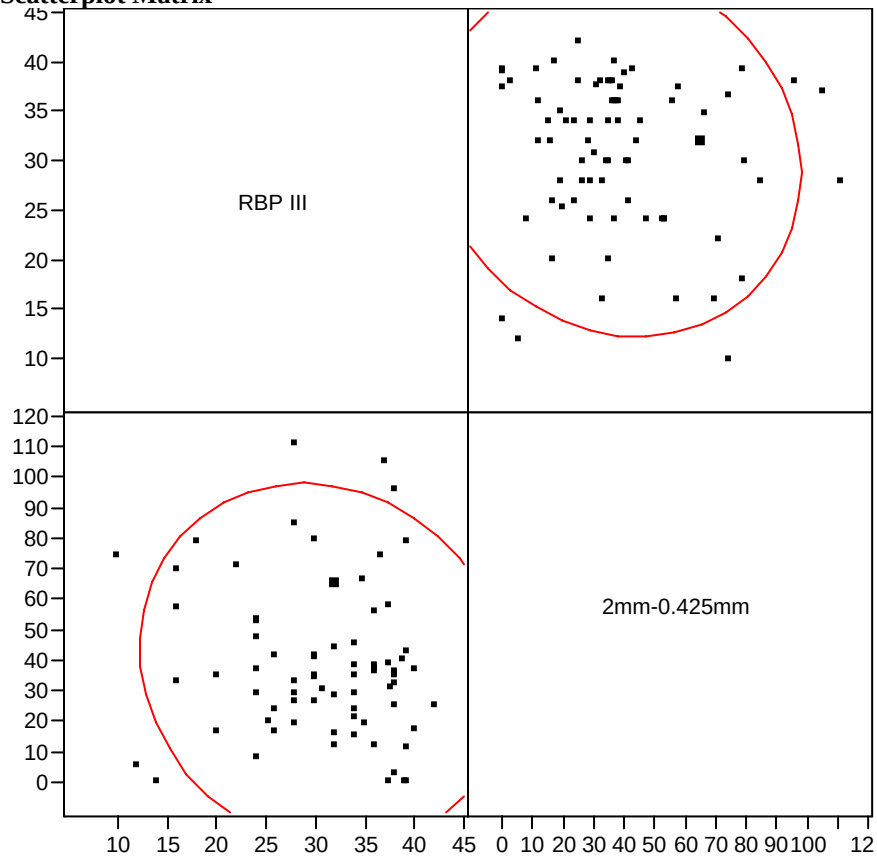
Variable	by Variable	Spearman Rho	Prob> Rho
0.425-mm	RBP III	-0.1655	0.1617

Figure 25: RBP III and 0.425-mm Correlations

Multivariate Correlations

	RBP III	2-0.425-mm
RBP III	1.0000	-0.1018
2-0.425-mm	-0.1018	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

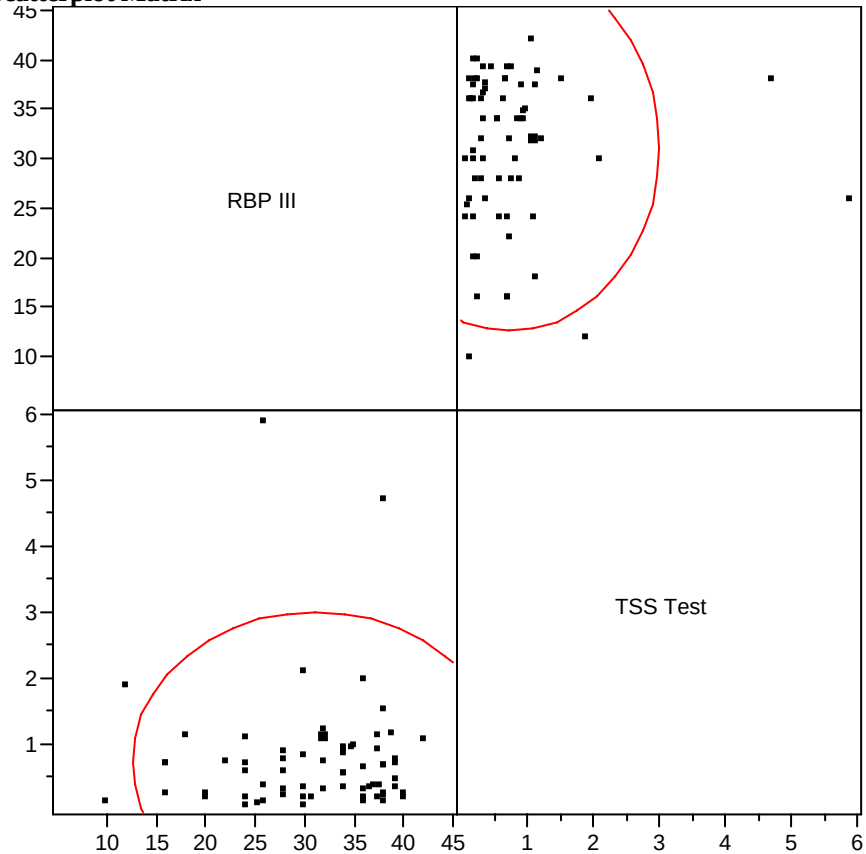
Variable	by Variable	Spearman Rho	Prob> Rho
2-0.425-mm	RBP III	-0.1099	0.3448

Figure 26: RBP III and 2-0.425-mm Correlations

Multivariate Correlations

	RBP III	TSS Test
RBP III	1.0000	0.0025
TSS Test	0.0025	1.0000

Scatterplot Matrix



Nonparametric: Spearman's Rho

Variable	by Variable	Spearman Rho	Prob> Rho
TSS Test	RBP III	0.0759	0.5387

Figure 27: RBP III and TSS Test Correlations

nutrient water quality issues at both sites. This is the same justification used in the initial site selection where sites directly downstream from a sewer treatment plant were excluded.

5.0 Discussion

The most interesting observation was that positive correlations of the RBP III score (biological integrity) to the larger particles were far greater than any other negative correlations and their related significance values. The D_{84} and D_{50} from the modified Wolman pebble counts represents the percentages of large particles in a stream where D_{84} particles are larger than D_{50} . The Phi diameters for large particles have negative values, meaning the larger the particle the more negative the Phi diameter. When comparing the two variables, the D_{84} is more closely correlated to RBP III than the D_{50} , and the significance values for both are below 0.0001. To be considered significant, the $\text{Prob} > |\text{Rho}|$ value must be below 0.05; therefore, the D_{84} and D_{50} variables are significant. In addition, the correlation coefficients for D_{84} and D_{50} are 49.3% and 46.2%, respectively. Given the natural variability in the data, this level of correlation is considered significant. To a degree, this shows that the presence of larger particles is likely more pertinent than the presence of fine material when relating these measures to a streams biological integrity. This phenomenon was also found in a study conducted by Negishi and Richardson, 2003, where boulder clusters were placed within a stream. The findings in their study indicated that when habitat heterogeneity was increased, macroinvertebrate abundance was improved (Negishi, 2003). In another study a higher density and diversity of macroinvertebrate communities were reported in cobble and pebble substrates (Kaller, 2004).

The PSD slope ranging from 0.016 to 0.004-mm represented the relative amount of material in the medium to fine silt size class. This variable was found to have a correlation of 39.9% and a significance value of 0.0004. This slope (0.016 to 0.004-mm) parameter was expected to have an even stronger relationship with biological integrity due to the vast amount of supporting literature. Very fine material, such as fine silt, is emphasized to be extremely hazardous to macroinvertebrates (Wood, 1997; Kaller, 2003).

The RGA had a 35.7% correlation with a significance value of 0.0015 when analyzed against the biological data. Initially, this was expected to be higher; however, during the data collection process it was found that 30 of the 76 sites contained some portion of bedrock. This accounts for nearly 40% of the site locations, which for the Ridge and Valley ecoregion is not surprising. Bedrock prevents incision and vegetation growth along banks, and/or degradation of the streambed depending on the amount and location of bedrock. These factors directly affect four parameters of the RGA and indirectly affect the stage of evolution due to the inability of the channel to experience the degradation and/or widening processes. Further studies should investigate the impacts of bedrock on RGA scores to determine if the relationship between the RGA and biological integrity data would improve. Figures 28 and 29 are examples of the bedrock encountered. Due to instances such as these, it often was difficult to assign a stream to a particular stage of evolution under existing protocols.



Figure 28: Bedrock Streambed, Site Number Richl001.5GE



Figure 29: Bedrock Folds, Site Number ALEX000.2HS

Channel slope was found to have a correlation of 34.6% with a significance value of 0.0022 to support confidence in its relationship to RBP III data. This result was logical since the channel slope is inherently related to the overall rate of energy supplied, which can modify channel form, discharge, and sediment load as discussed in the *Background* section (Knighton, 1998). In addition, often streams with steeper slopes have larger particle sizes, which is significant as stated above. The instrument used to determine the channel slope in this study was a hand-held Suunto clinometer. Although effective, the accuracy is less than desirable. With the knowledge that channel slope has a good relationship to biological integrity, a more accurate device should be utilized in future studies.

The correlation between the percent below 2-mm from the pebble count was 34.3% with a 0.0032 significance value. This was better than the results from most of the bed sediment PSD's. Both of these methods represent the fines of a stream reach, however the location is different. The bed collection was from a localized depositing area, where the pebble count was across a riffle. This may also relate to the significance of larger particles since often they are located near the riffles and, therefore, the distribution of the fines would be different in these locations. In addition, macroinvertebrates can be protected by the larger particles of the riffles, so high or low amounts of fines in those areas may directly impact the macroinvertebrates.

The last variable with a correlation above 30% was the 0.016-mm parameter from the PSD's, which had correlation and significance values of 31.4% and 0.0067 respectively.

This is a fairly strong relationship especially when related to the slope variable 0.016 to 0.004-mm discussed prior. A unique observation was that the variable 0.004-mm had only a correlation of 21.9% and was not found to be significant (0.0623). This may imply that the more relevant size within the slope range is the material closer to the 0.016-mm size class, which is the lower boundary of the medium silt according to Julian (1998).

There were two variables from the PSD that showed some correlation and significance, although the relationships were not very strong. The first variable ranged from 0.15 to 0.075-mm with a correlation of 26.8% and significance of 0.0193. The second is the slope ranging from 0.075 to 0.016-mm with correlation and significance values of 22.9% and 0.0464 respectively. These two slopes both have negative correlations indicating that the more material between 0.15 to 0.016-mm, the lower the RBP III score. The range in data represents the quantity of material collected ranging from fine sand to medium silt (Julian, 1998). It should not be overlooked that the medium silt (0.016-mm) is once again present and considered significant. These relationships are supported by the literature discussed in the *Background* section concerning the fine materials, but the relationships were not as strong as anticipated.

The general lack of correlations and significance from the remaining PSD's and the TSS test was surprising due to the wealth of literature indicating the effect of fine material. There were seven PSD variables that showed not only a poor correlation, but are also considered insignificant. These parameters were 0.004-mm, 2-mm, 0.15-mm, 0.075-mm,

0.425 to 0.15-mm, 0.425-mm, and 2 to 0.425-mm. Their correlation and significance values ranged from 21.9% to 11.0% and 0.0623 to 0.3448 respectively (Table 3).

The TSS test was performed to find the effects of turbidity or clay material in the sediment. Surprisingly, the TSS test showed no relationship with a correlation of 4.6% and significance of 0.7133. One possible explanation may be that the clay material is simply being washed through the system. As discussed in the *Background* section, once clay is detached, it is very easy to transport. In fact, due to the very small settling velocity, once detached clay is extremely difficult to separate from the water column, even in quiescent waters (Haan, 1994). Therefore, it is reasonable to hypothesize that clay particles are moving through the system during high turbulent flow events.

When analyzing variables separately, it is possible for related lurking variables to be overlooked. This is an initial study that revealed strong, solid relationships between biological data and large particles, 0.016 to 0.004-mm, RGA processes, channel slope, the percent of material below 2-mm (from the pebble count) and 0.016-mm. Stronger relationships may be found in further studies of these variables, particularly when their interactions with one another are analyzed.

Generally, the results of this study suggest that more attention should also be given to the positive biological effects of the larger particle sizes in conjunction with the negative impacts of the fine material. An increase of the heterogeneity in a system to include larger material may increase the habitat size and quality, and therefore increase the

abundance and diversity of biota; this concept could be applied to improving stream restoration projects. Restoration of impaired streams on the 303(d) list may focus on introducing larger particle sizes to increase heterogeneity and habitat availability, in addition to removing the fine material. The introduction of large materials, coupled with the reduction of fine particles may greatly assist in sediment induced restoration projects.

Secondly, the results found that medium to fine silt has a strong negative relationship with biological integrity. Since BMP's focus on controlling finer particles, this notion could be applied to improve BMP effectiveness. Clearly, BMP's should continue to limit all fine material from the streams; however, special concentration should be given to the medium to fine silts. Unfortunately, this size class is cumbersome to remove for most BMP's, although it can be done with proper planning and implementation. For example, if the BMP's were to focus on erosion protection, insuring that sediment remains on the hillslopes, this process would work much more efficiently (Haan, 1994). Providing as little as 10% cover to exposed soil prior to precipitation would prove to be rather effective (Haan, 1994).

Overall, the results of this research were very enlightening. The relationships discovered may prove to greatly increase the effectiveness of both stream restoration and watershed BMP programs. Through further investigative studies of the strong relationships found in this initial analysis, more effective methods can be discovered to restore and protect our nation's waterways.

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Appendices

Appendix A

CHANNEL-STABILITY RANKING SCHEME

Station # _____ Station Description _____

Date _____ Crew _____ Samples Taken _____

Pictures (circle) upstream downstream cross section

Slope _____

1. Primary bed material

Bedrock	Boulder/Cobble	Gravel	Sand	Silt Clay
0	1	2	3	4

2. Bed/bank protection

Yes	No	(with)	1 bank protected	2 banks
0	1		2	3

3. Degree of incision (Relative ele. Of "normal" low water; floodplain/terrace @ 100%)

0-10%	11-25%	26-50%	51-75%	76-100%
4	3	2	1	0

4. Degree of constriction (Relative decrease in top-bank width from up to downstream)

0-10%	11-25%	26-50%	51-75%	76-100%
0	1	2	3	4

5. Streambank erosion (Each bank)

	None	fluvial	mass wasting (failures)
Left	0	1	2
Right	0	1	2

6. Streambank instability (Percent of each bank failing)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	0	0.5	1	1.5	2
Right	0	0.5	1	1.5	2

7. Established riparian woody-vegetative cover (Each bank)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

8. Occurrence of bank accretion (Percent of each bank with fluvial deposition)

	0-10%	11-25%	26-50%	51-75%	76-100%
Left	2	1.5	1	0.5	0
Right	2	1.5	1	0.5	0

9. Stage of channel evolution

I	II	III	IV	V	VI
0	1	2	4	3	1.5

TOTAL

CHANNEL-STABILITY PARTICLE COUNT FORM

Station # _____ Station Description _____

Date _____ Crew _____

Location/Description _____
(pool, riffle, 1 of 3, additional samples?)

1	26	51	76
2	27	52	77
3	28	53	78
4	29	54	79
5	30	55	80
6	31	56	81
7	32	57	82
8	33	58	83
9	34	59	84
10	35	60	85
11	36	61	86
12	37	62	87
13	38	63	88
14	39	64	89
15	40	65	90
16	41	66	91
17	42	67	92
18	43	68	93
19	44	69	94
20	45	70	95
21	46	71	96
22	47	72	97
23	48	73	98
24	49	74	99
25	50	75	100

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Boring No. _____ Sample No. _____ Depth _____ Description of Soil _____

Tested by _____ Date _____

Hydrometer No. _____ Concentration of Dispersing Agent (X_d) _____ g/L Volume of Stock Solution in 1L (V_d) _____ ml

Weight of soil in suspension $W_0 =$ _____ g $G_s =$ _____ H_R = the depth from surface of suspension to center of hydrometer bulb (from calibration charts)

Percent passing #_____ sieve: _____

[illegible]

This data sheet is based on the symbols, equations, and procedures in *Experimental Soil Mechanics* by Jean-Pierre Bardet (1997), Prentice Hall, N.J. pp 42 -54 with the exception of performing a composite correction similar to that described in ASTM D422.

Dry Sieve Greater than #10

(Large Sieves)

Location: _____

Date: _____

Mass of Sample: _____

Sieve #	Opening (mm)	Sieve Mass (g)	Sieve + Soil Mass	Mass Retained (g)	% Retained	% Passing
1/2	12.5					
3/8	9.5					
4	4.75					
8	2.36					
Pan	0					

Dry Sieve from Wash 200

(Small Sieves)

Location: _____

Date: _____

Mass of Sample: _____

Sieve #	Opening (mm)	Sieve Mass (g)	Sieve + Soil Mass	Mass Retained (g)	% Retained	% Passing
40	0.425					
60	0.25					
100	0.15					
Pan	0					

Particle Size Distribution		
Location Name		
Date Collected		
Procedure Dates		

Air Dry Material	
Total Mass Data	
Container Mass:	
Mass of Container + Material:	
Mass of Material:	0
# 10 Sieve	
Passing:	MIX
Retained:	Wash on #10
Wash #10	
Passing:	Goes into MIX
Retained:	Oven Dry
Tare Wt.:	
Total Mass:	
Material Mass:	0
Oven Dry	
Tare Wt.:	
Total Dry Mass:	
Mass of Material:	0
Percent Retained #10:	
Percent Passing #10:	
Sieve Analysis on >#10	
Location	0
Date	
Mass Tested:	

Sieve	Sieve Opening	Sieve Mass	Sieve and Soil Mass	Mass Retained	Mass Passing	% Retained	% Passing
#10	2	NA	NA	0	0		
#8	2.36			0	0		
#4	4.75			0	0		
3/8	9.5			0	0		
1/2	12.5			0	0		
SUM and CHECK:				0	0	TRUE	

MIX	
Sieve Analysis on #40	
Location	0
Date	
Total Mass Tested:	
Mass Tested:	

From Hydrometer Sheet

Sieve	Sieve Opening	Sieve Mass	Sieve and Soil Mass	Mass Retained	Total Mass Retained	Mass Passing	Total Mass Passing	% Retained	% Passing
#200	0.075			0		0			
#100	0.15			0		0			
#60	0.25			0		0			
#40	0.425			0		0			
SUM and CHECK:				0		0		TRUE	

Hydrometer Test						
Location		0				
Date Performed						
Hygroscopic Correction Factor	Weight of Soil in Suspension	% Passing #10 Sieve	W			
Elapsed Time (min)	Temperature (°C)	Hydrometer Reading With Correction (g/L)	Distance of Fall (cm)	Viscosity of Water (g/cm-s)	Grain Size (mm)	Percent Finer
2					0	
5					0	
10					0	
15					0	
30					0	
60					0	
250					0	
1725					0	
2625					0	

Particle Size Distribution			
Sieve	Grain Size	% Retained	% Finer
1	25.4	0.00	100.00
1/2	12.5		
3/8	9.5		
4	4.75		
8	2.36		
10	2		
40	0.425		
60	0.25		
100	0.15		
200	0.075		
NA	0.0000	NA	
NA	0.0000	NA	
NA	0.0000	NA	
NA	0.0000	NA	
NA	0.0000	NA	
NA	0.0000	NA	
NA	0.0000	NA	
NA	0.0000	NA	
NA	0.0000	NA	

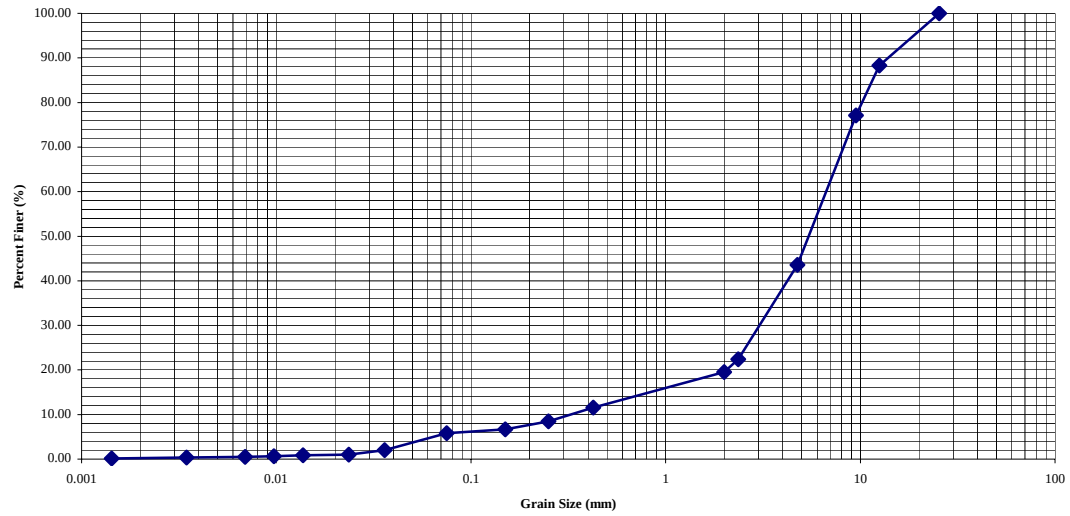
Appendix B

Site Locations	Latitude	Longitude
ALEXA000.2HS	36.517933	-82.717117
BARM000.5SU	36.420500	-82.246300
BLIME004.0WN	36.245000	-82.615000
BOONE001.7WN	36.388600	-82.406900
BOONE003.7WN	36.372500	-82.429200
BRUSH000.7WN	36.369200	-82.305000
BSPRI000.2CT	36.360800	-82.150000
BUFFA000.2CT	36.327200	-82.271900
CANEY004.3RO	35.896900	-84.607300
CARSO000.1WN	36.248830	-82.639400
CAWOO000.2CL	36.455900	-83.880500
CROOK001.1BT	35.770740	-83.879440
DAVIS011.6CL	36.443100	-83.916600
DAVIS014.6CL	36.456000	-83.885360
DAVIS016.2CL	36.446280	-83.865080
DAVIS018.1CL	36.460940	-83.851690
DAVIS020.5CL	36.473500	83.813580
DAVIS022.6CL	36.503390	-83.798310
DAVIS024.1CL	36.520900	-83.794700
DRY001.3SU	36.452500	-82.213300
ECO6701	36.477800	-82.938700
ECO6702	36.490000	-82.940300
ECO6707	36.480000	-82.199440
ECO67F06	36.213610	-84.059720
ECO67F13	36.343610	-83.891660
ECO67F16	36.650800	-83.247200
ECO67F17	36.426810	-83.347400
ECO67F23	36.591110	-83.335000
ECO67G01	36.124180	-83.051850
ECO67G05	36.209700	-83.133300
ECO67G08	35.126660	-84.963880
ECO67G09	35.172400	-84.975100
ECO67H04	35.224720	-84.970550
ECO67H06	35.448290	-84.288330
ECO67I12	35.988330	-84.288880
ELLEJ000.1BT	35.773250	-83.849090
FALL000.6WN	36.424166	-82.630277
FLAT001.0HA	36.160360	-83.209920
FOURM000.1HK	36.584020	-83.372910
INDIA001.0SU	36.460600	-82.255000
JOCKE000.1WN	36.225780	-82.635570
LICK052.3GE	36.322600	-82.787000
LICK061.0GE	36.366200	-82.710500

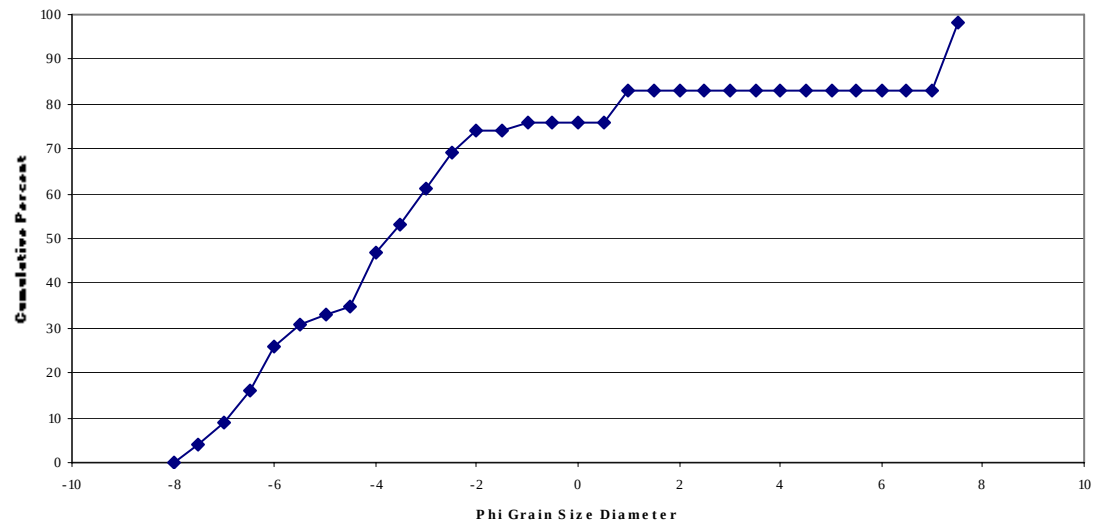
Site Locations	Latitude	Longitude
MADD001.2SU	36.539030	-82.546390
MEADO000.4GE	36.057990	-82.911310
PIGEO001.0GE	36.084430	-82.918770
PISTO000.2BT	35.817500	-83.943400
RICHL001.5GE	36.099150	-82.851940
RICHL003.5GE	36.141380	-82.826290
RICHL004.2GE	36.153190	-82.826480
RUSSE000.3CL	36.496330	-83.811500
RUSSE000.9BT	35.830440	-83.953300
RUSSE003.0CL	36.485900	-83.544200
SFLSE001.7MM	35.580300	-84.669700
SINKI003.2GE	36.198400	-82.741770
STEEK000.7LO	35.733000	-84.340400
STONY000.3CT	36.370600	-82.155600
SWEET009.3LO	35.683100	-84.402200
SWEET017.3MO	35.625500	-84.448700
SWEET019.4MO	35.609600	-84.459800
SWEET023.3MO	35.575400	-84.487100
THOMP000.6MM	35.364700	-84.450300
TOWN000.5LO	35.790500	-84.262900
TOWN002.1LO	35.805600	-84.275500
TURKE000.5HK	36.549700	-83.068600
WFPAN000.1HK	36.555000	-83.158600
Beaver Creek at Halls Park*		
Beaver Ck @Beeler Rd		
Beaver Ck @Brown Gap Rd		
Willow Fork@Willow Fork Ln		
Hines Branch@Cunningham Rd		
Knob Fork		
Cox Creek @at Brown Gap Rd		
Breaver Creek@ Stormer Rd		
Beaver Creek@ Clinton Hwy		
Meadow Creek@Cross Lane		

*Last ten sites were used in conjunction with another study and coordinates were not available

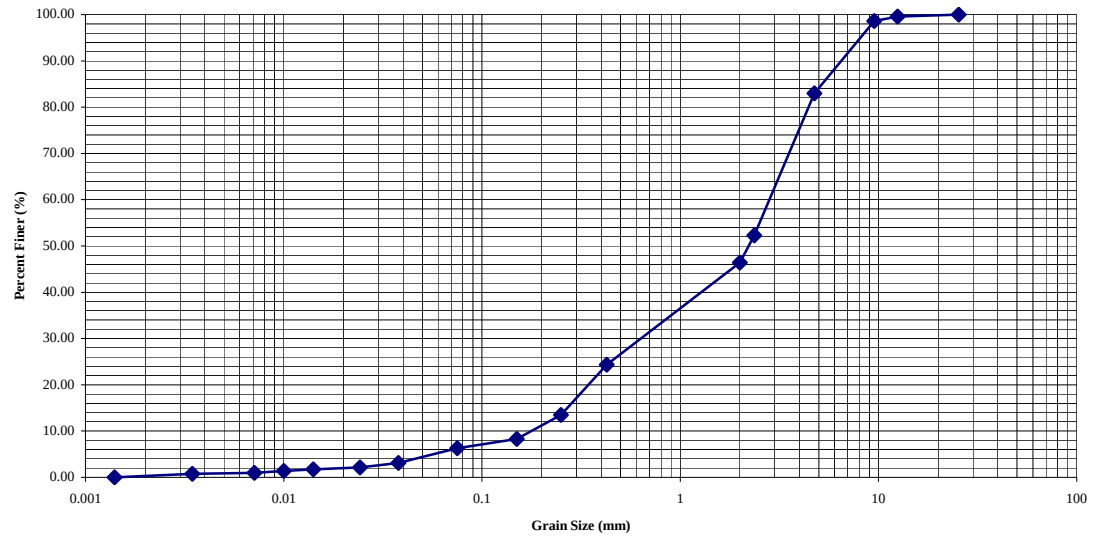
Particle Size Distribution for ALEXA000.2HS



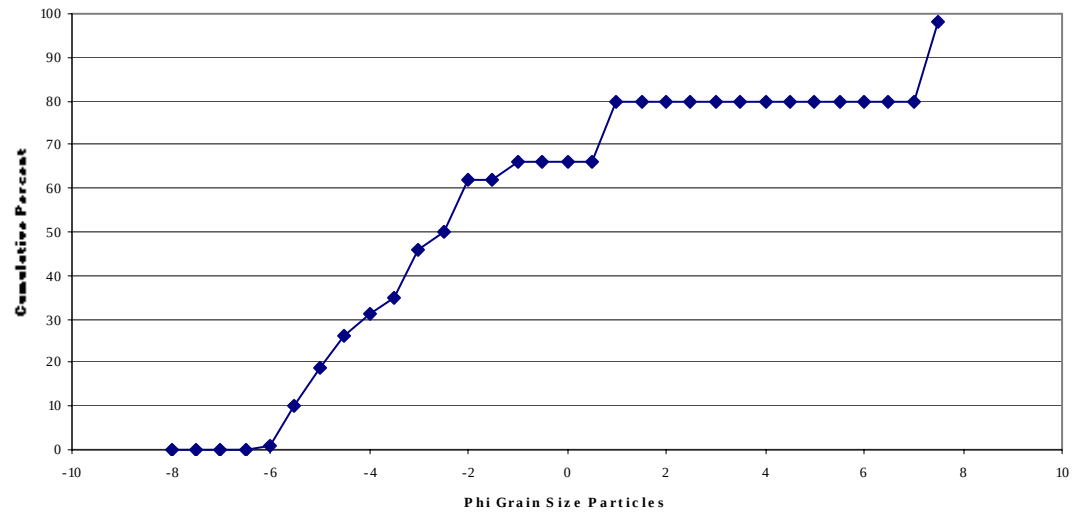
ALEXA000.2HS Cumulative Frequency Plot



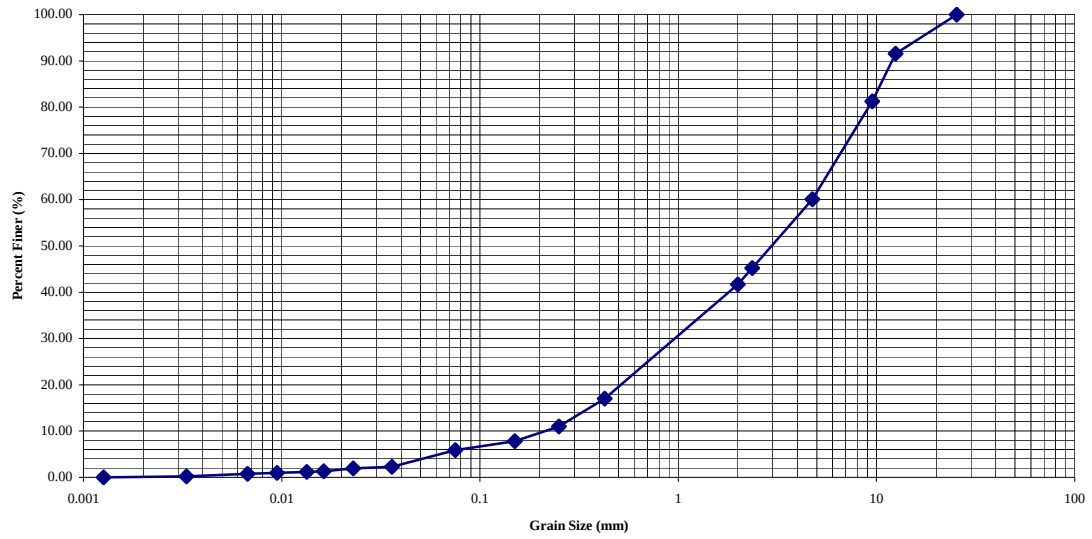
Particle Size Distribution for BARM000.5SU



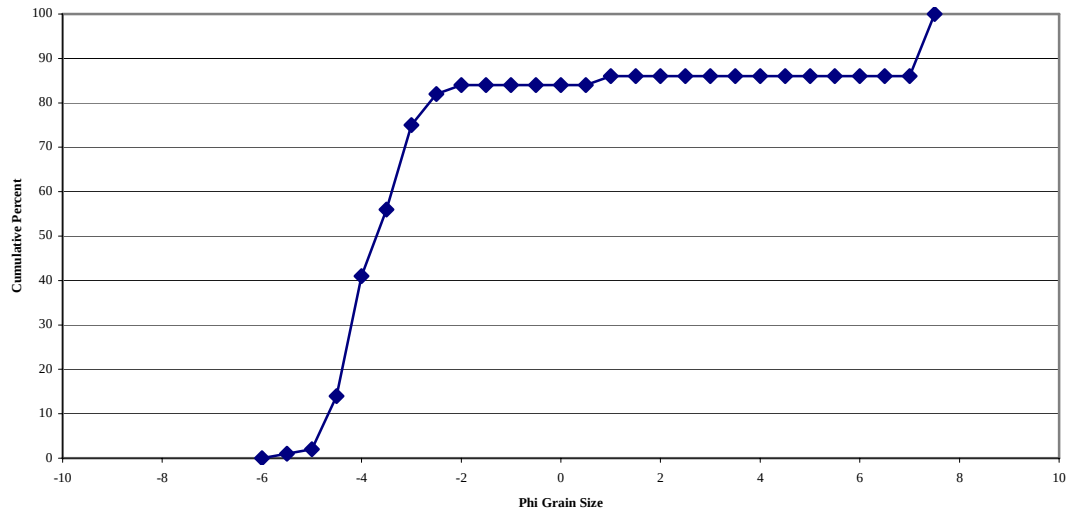
BARM000.5SU Cumulative Frequency



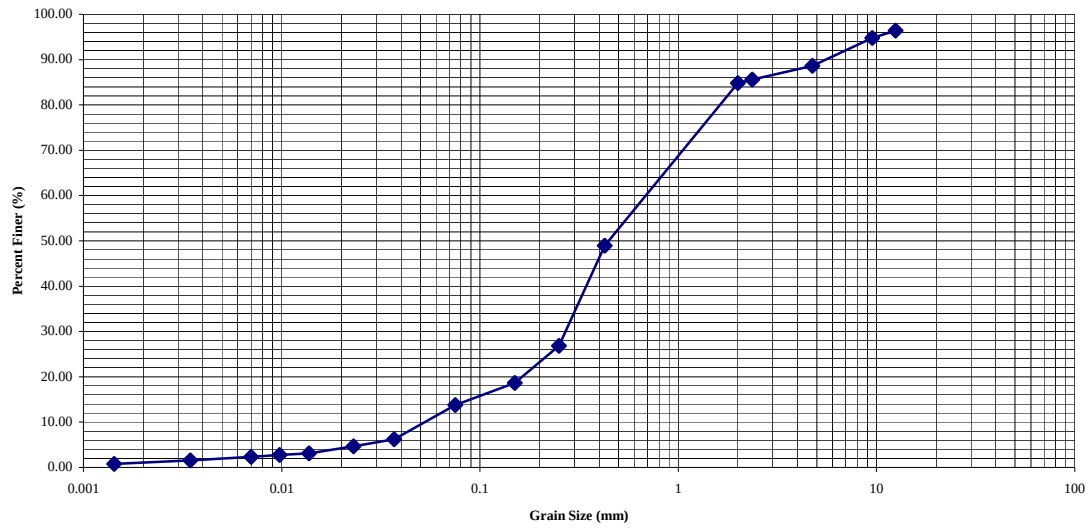
Particle Size Distribution for BLIME004.0



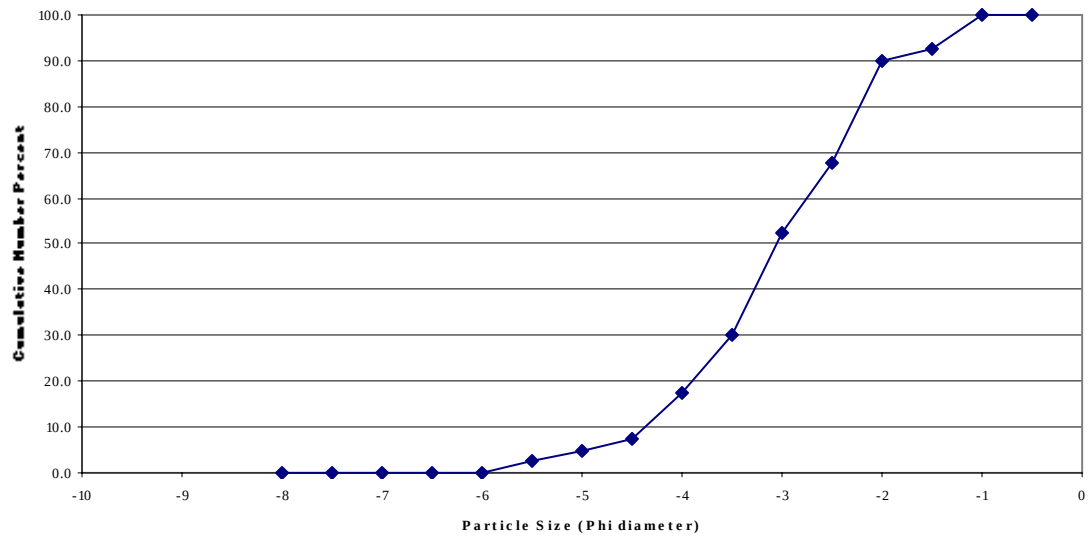
BLIME4.0WN Cumulative Frequency Plot



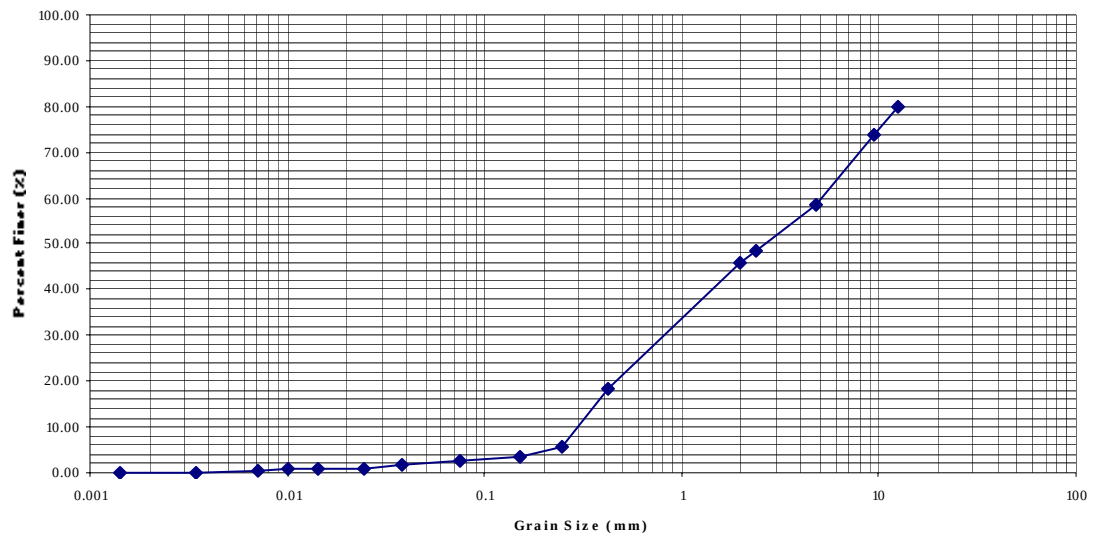
Particle Size Distribution for BOON001.7WN



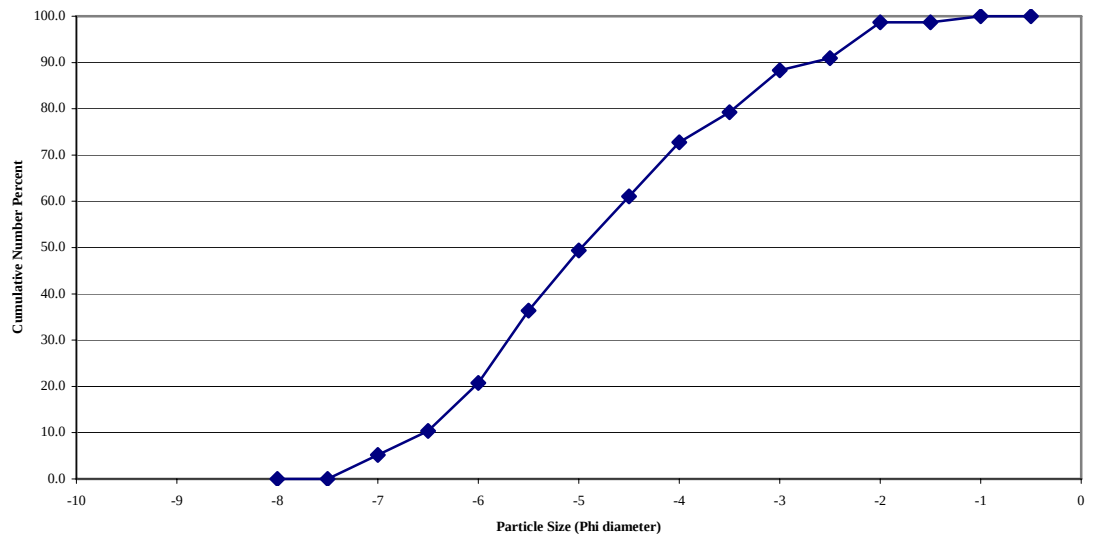
BOONE001.7WN Cumulative Frequency Plot



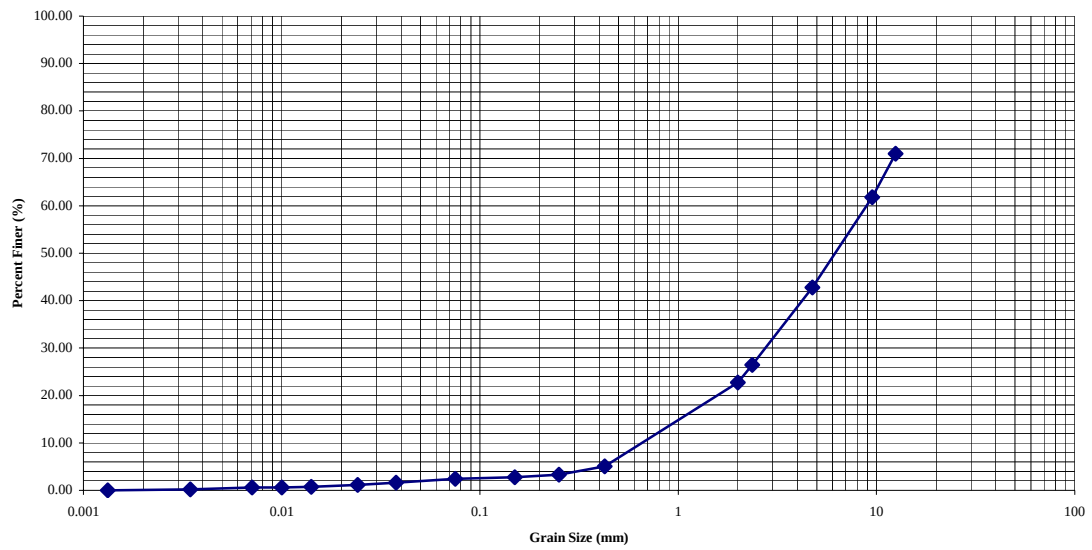
Particle Size Distribution for BOONE003.7WN



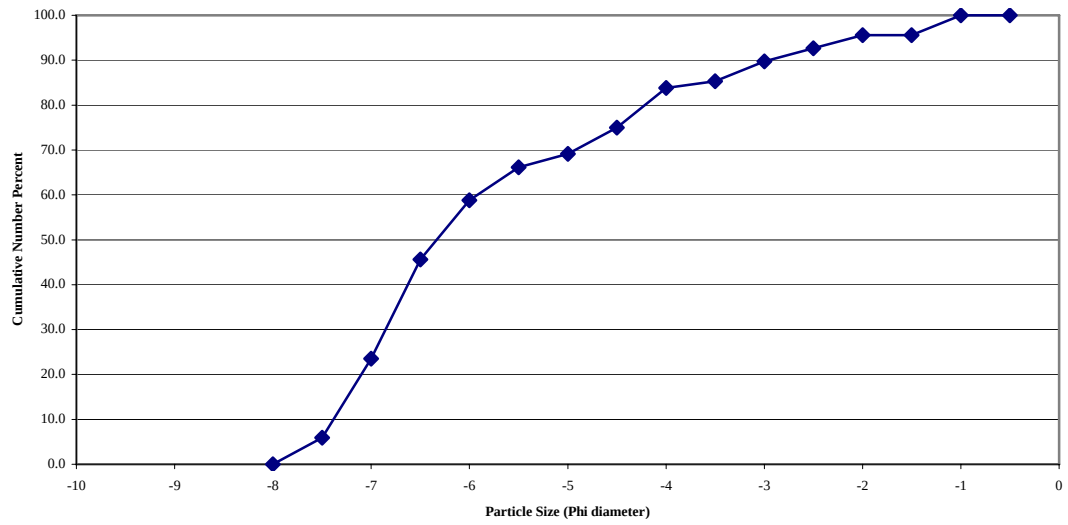
BOONE003.7WN Cumulative Frequency Plot



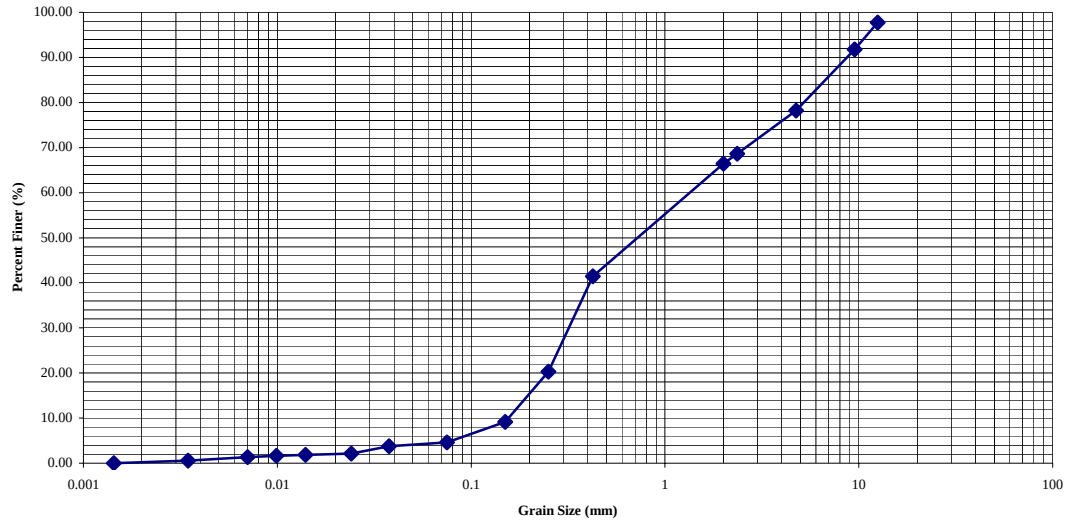
Particle Size Distribution for BRUSH000.7WN



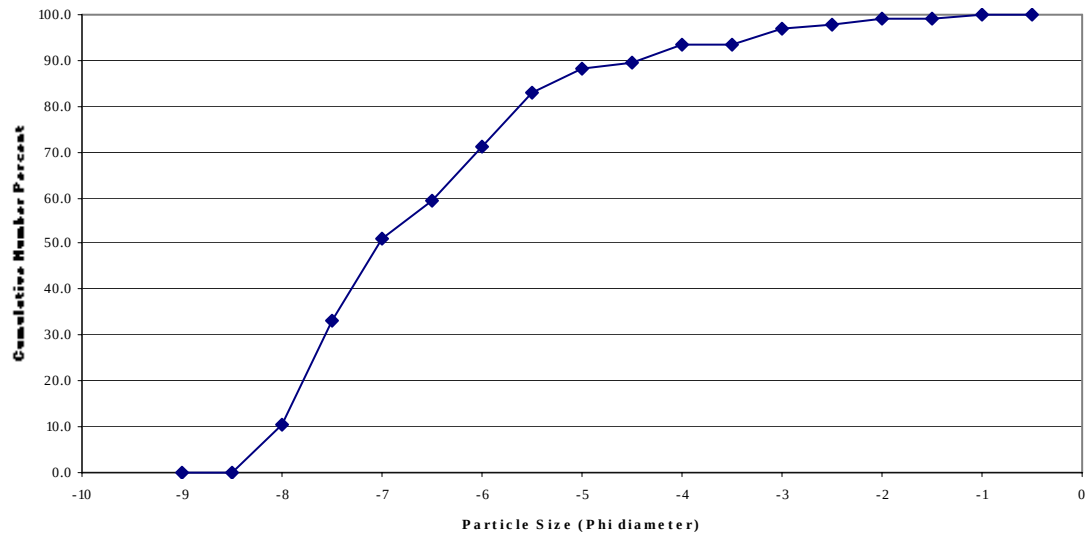
BRUSH000.7WN Cumulative Frequency Plot



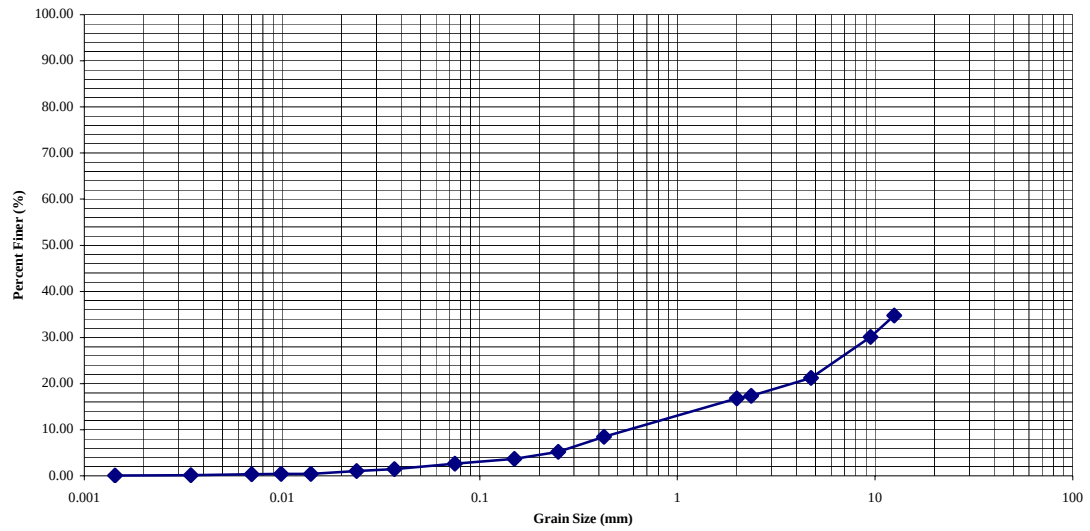
Particle Size Distribution for BSPRI000.2CT



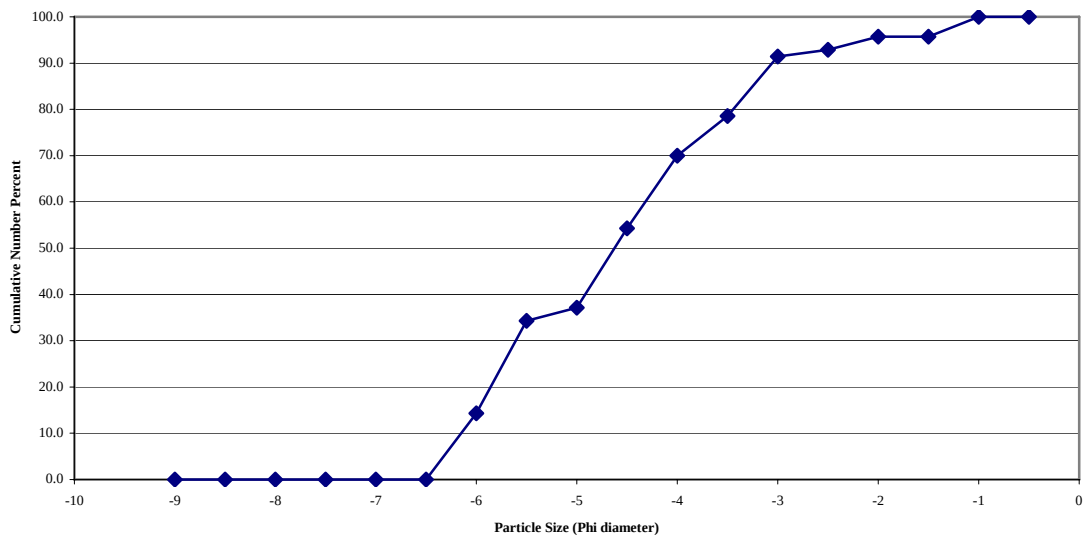
BSPRI000.2CT Cumulative Frequency Plot



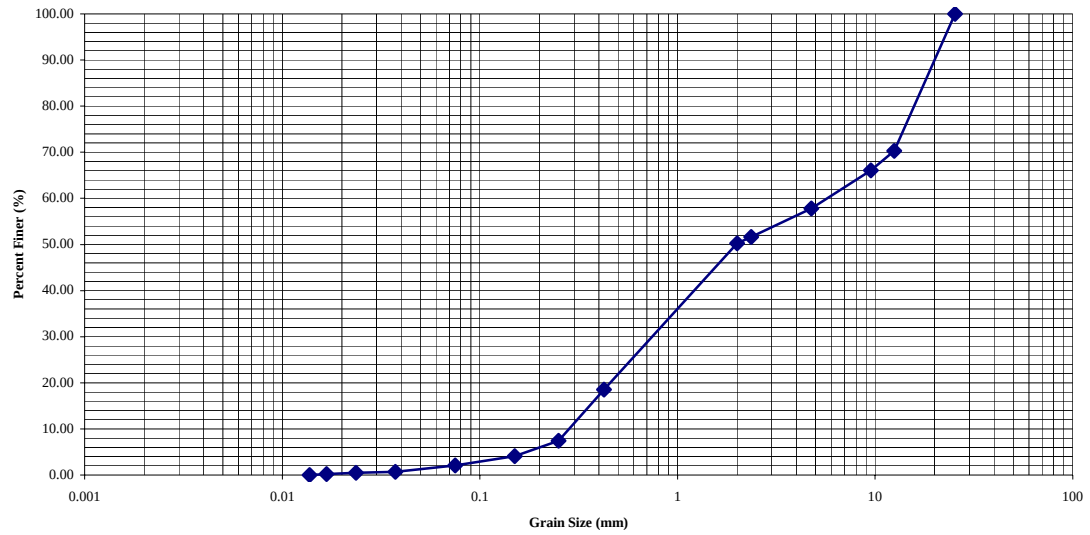
Particle Size Distribution for BUFFA000.2CT



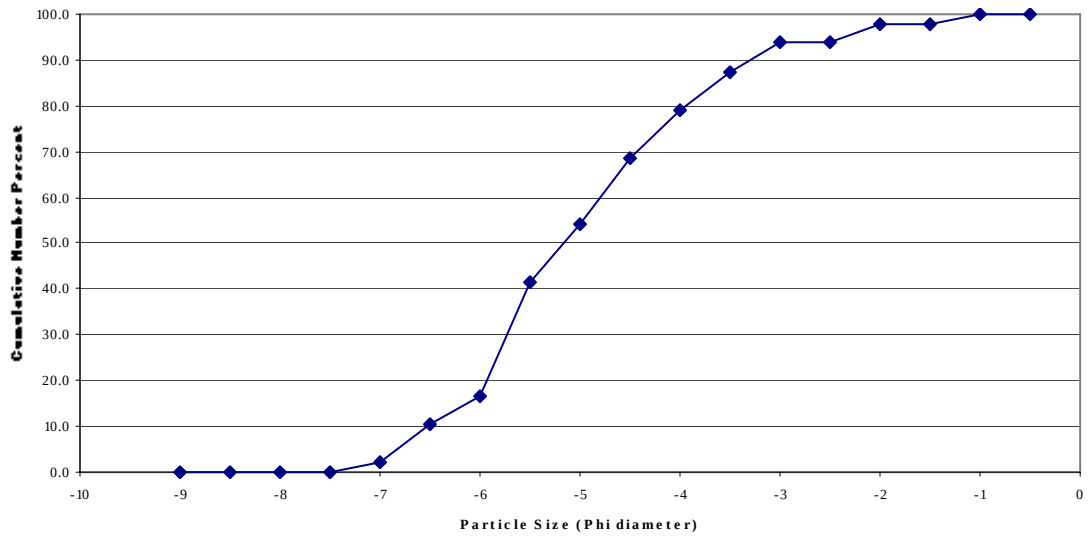
BUFFA000.2CT Cumulative Frequency Plot



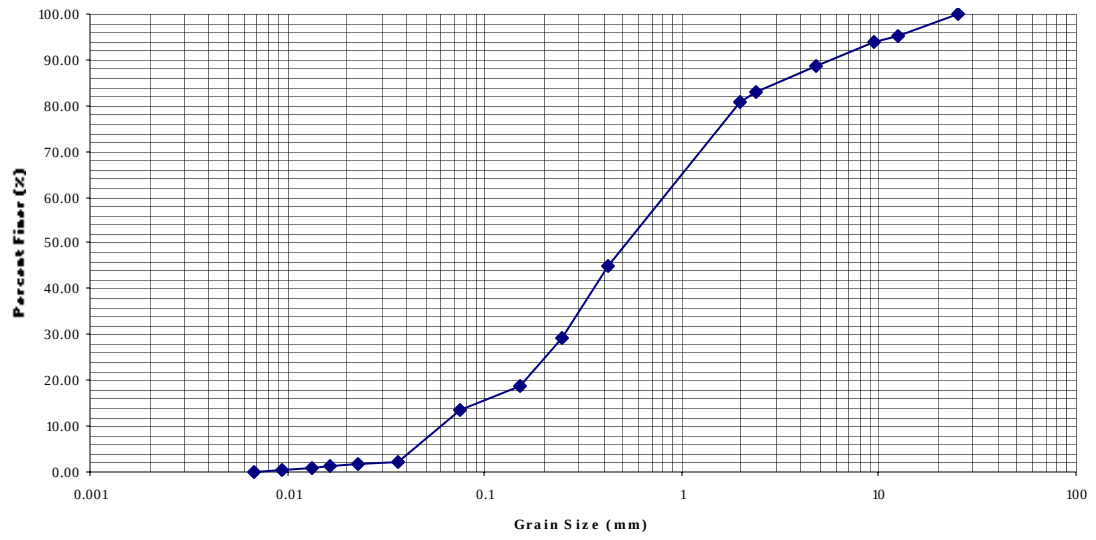
Particle Size Distribution for CANEY004.3RO



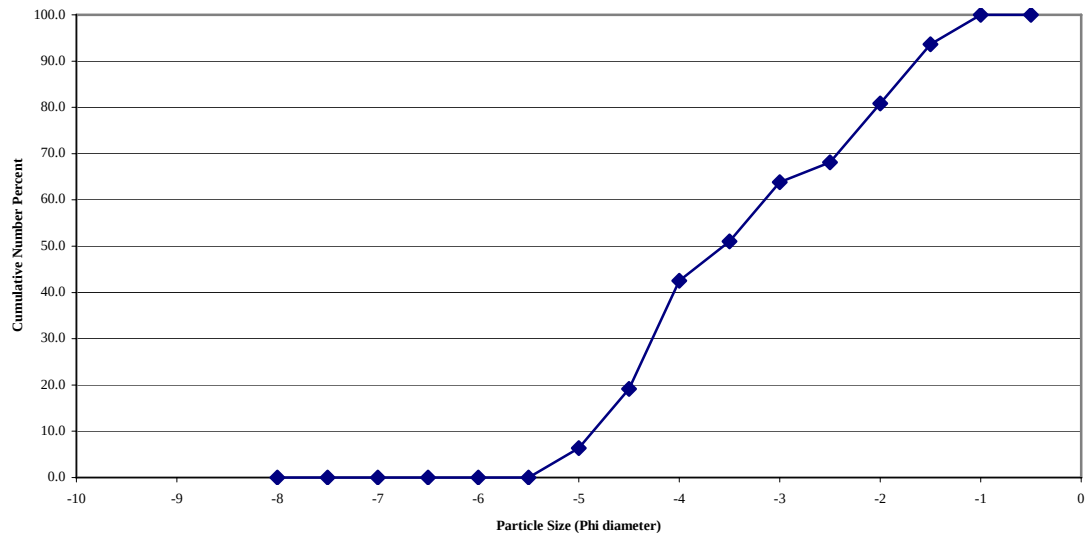
CANEY004.3RO Cumulative Frequency Plot



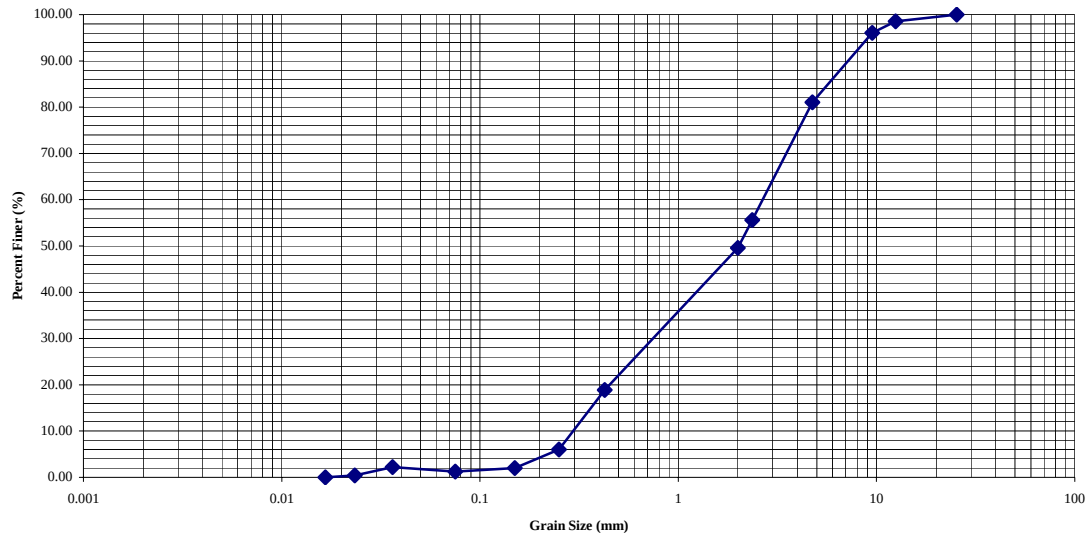
Particle Size Distribution for CARSO 000.1WN



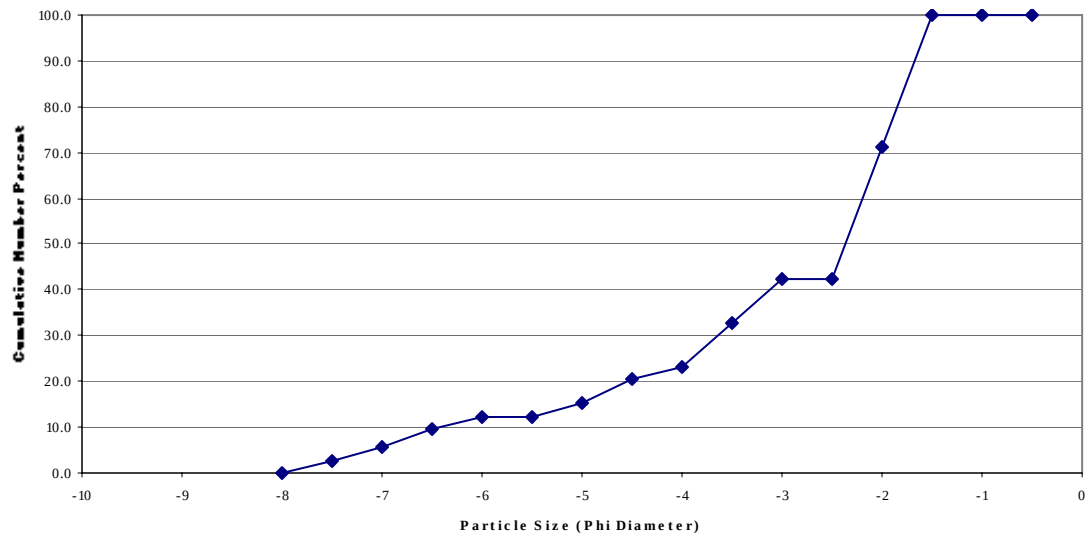
CARSO000.1WN Cumulative Frequency Plot



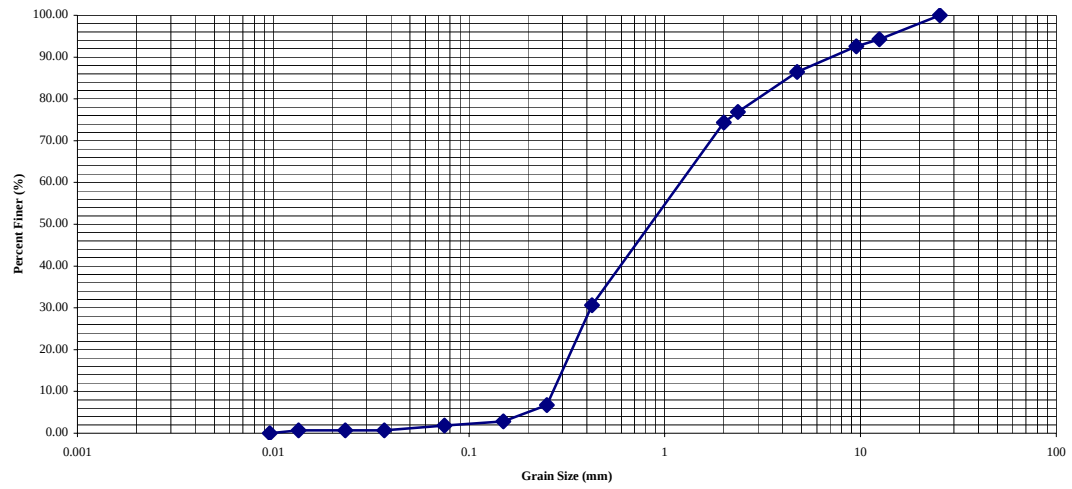
Particle Size Distribution for CAWOO000.2



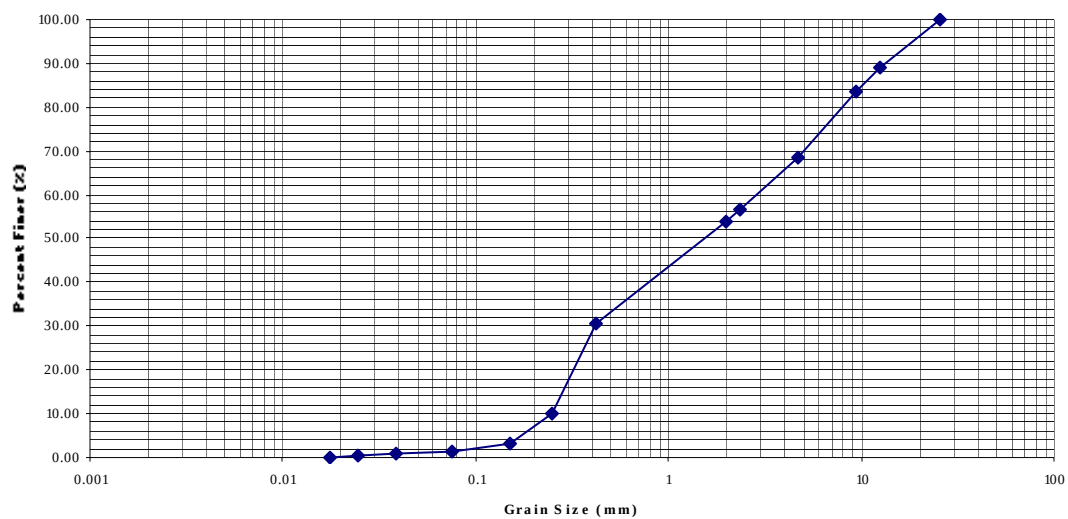
CAWOO000.2CL Cumulative Frequency Plot



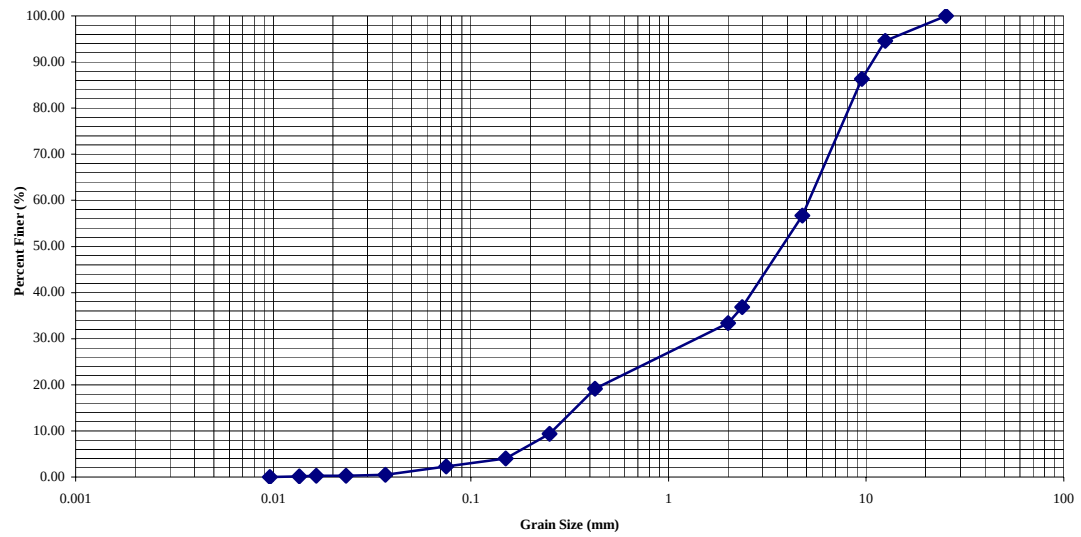
Particle Size Distribution for CROOK001.BT



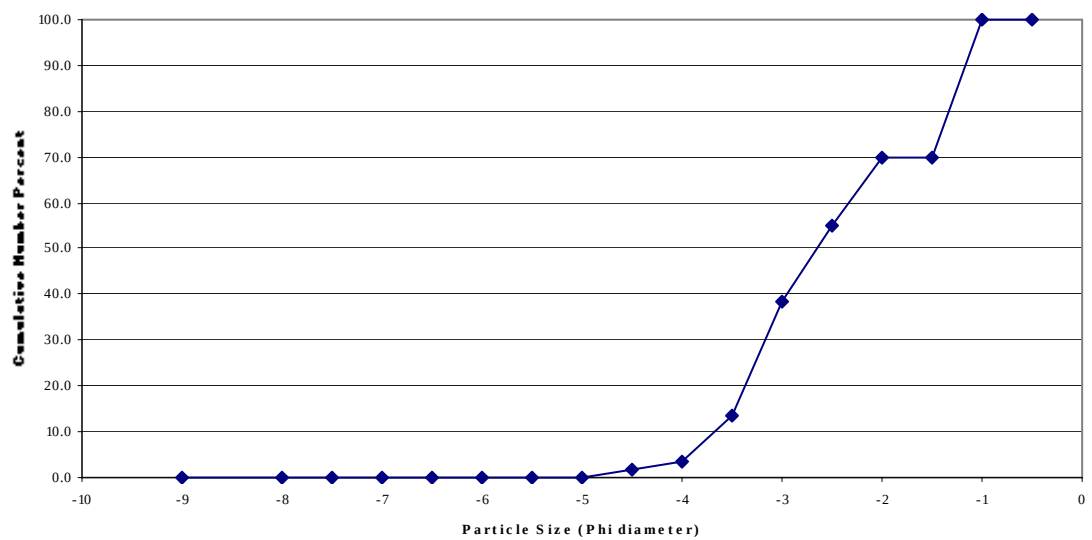
Particle Size Distribution for DAVIS011.6CL



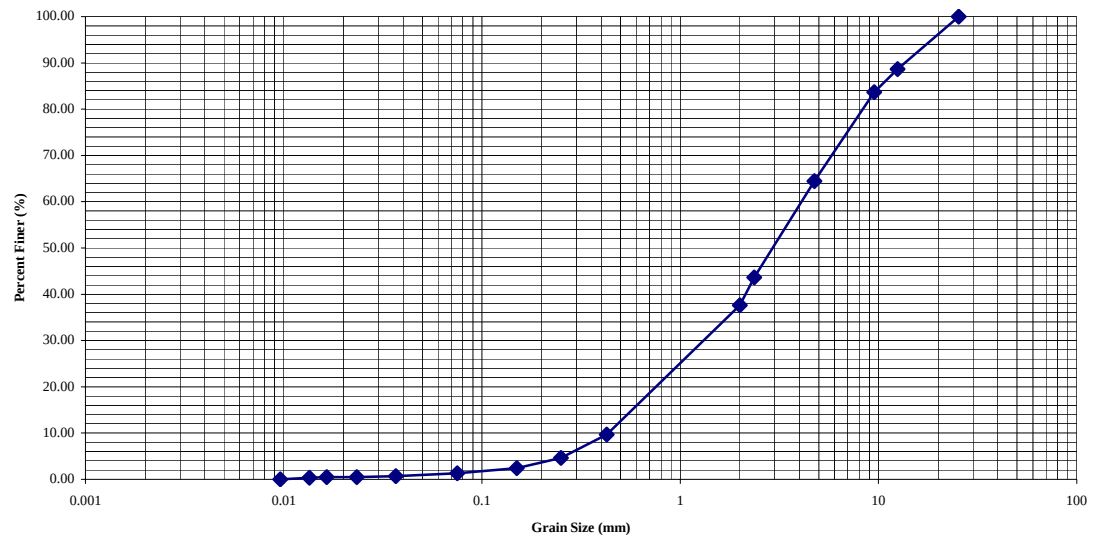
Particle Size Distribution for DAVIS014.6CL



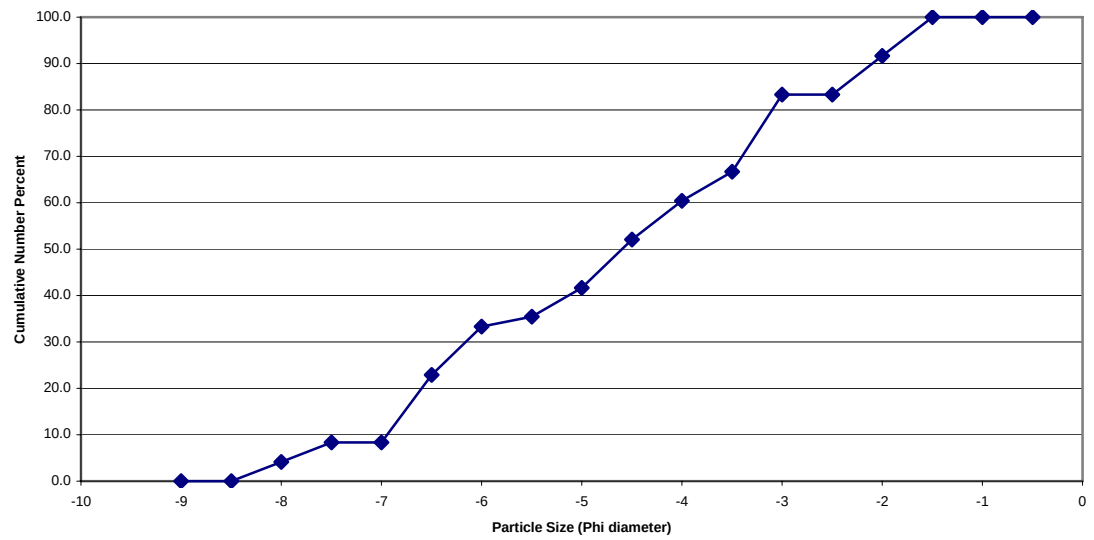
DAVIS014.6CL Cumulative Frequency Plot



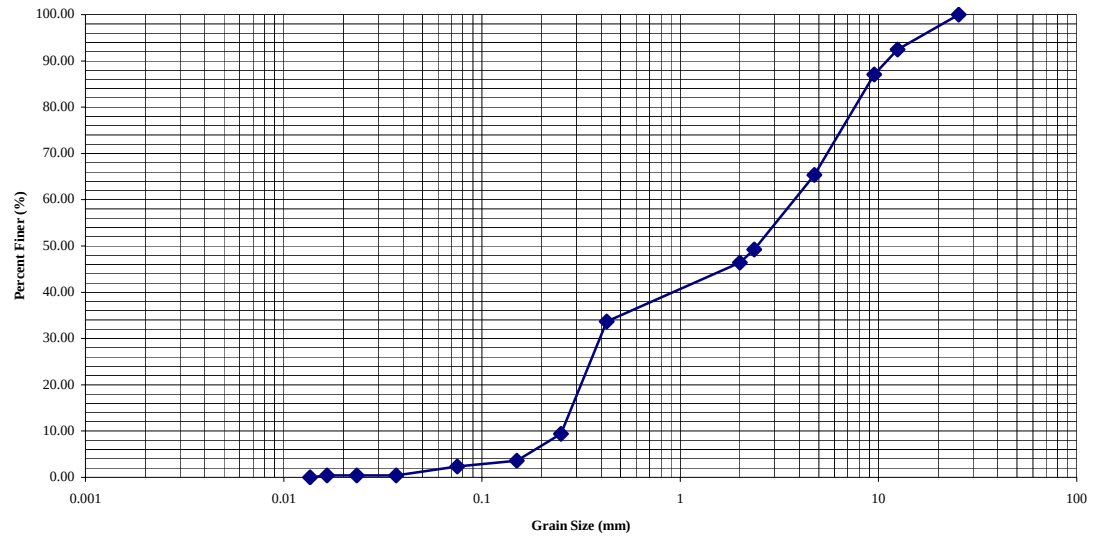
Particle Size Distribution for DAVIS016.2CL



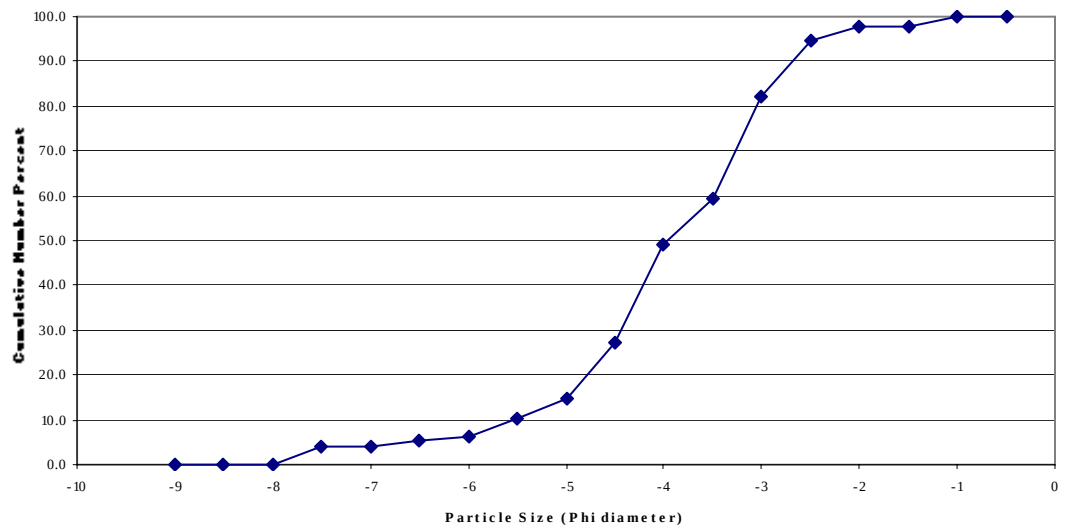
DAVIS016.2CL Cumulative Frequency Plot



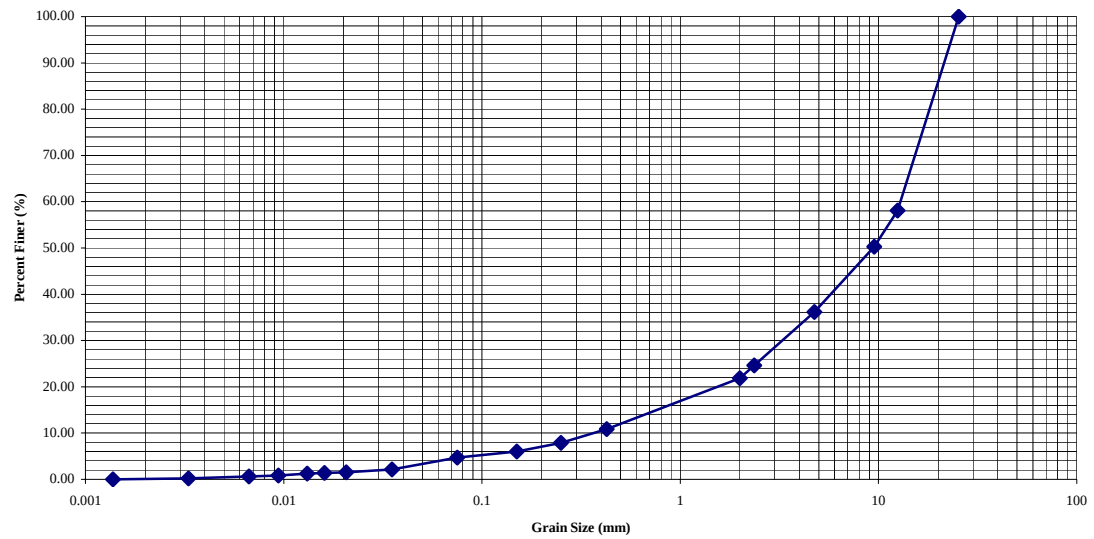
Particle Size Distribution for DAVIS018.1CL



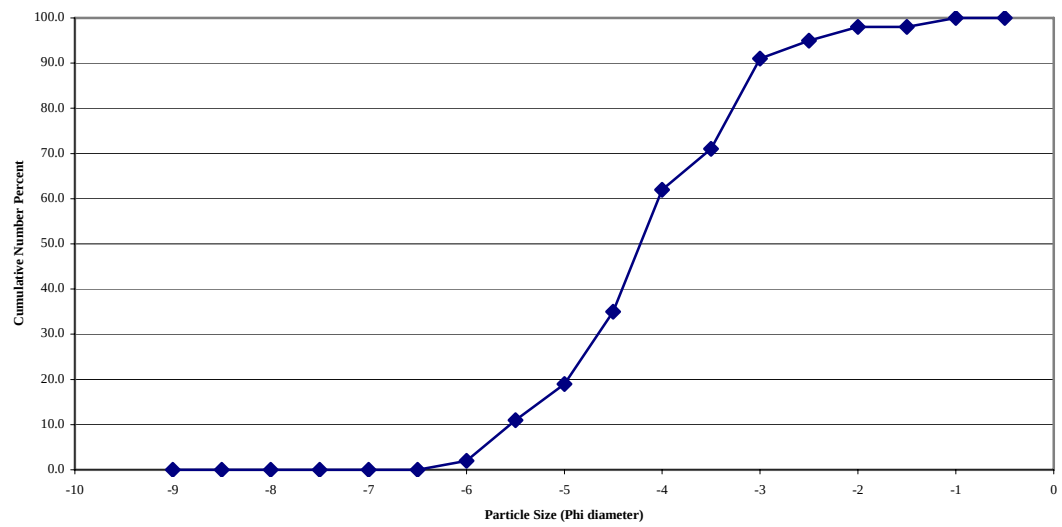
DAVIS018.1CL Cumulative Frequency Plot



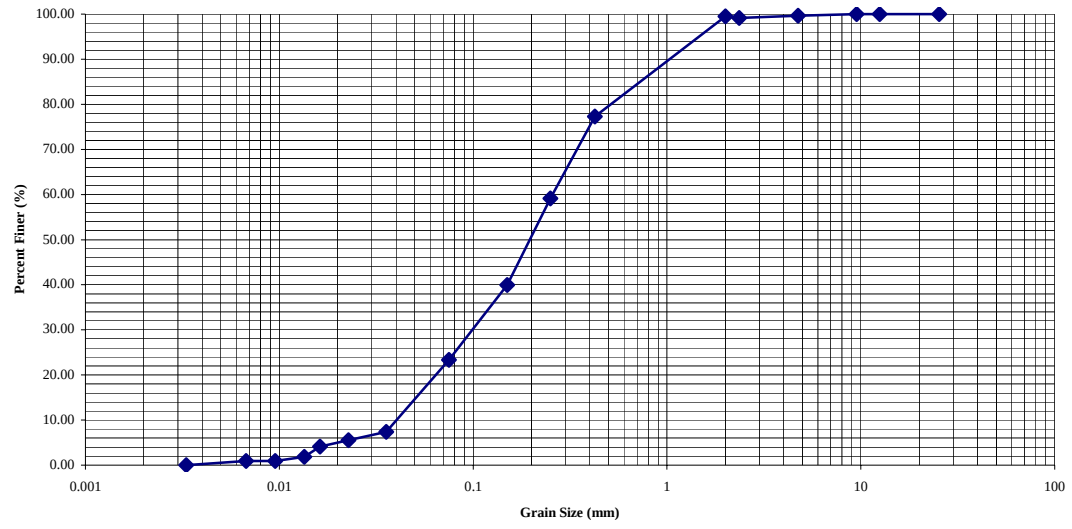
Particle Size Distribution for DAVIS020.5CL



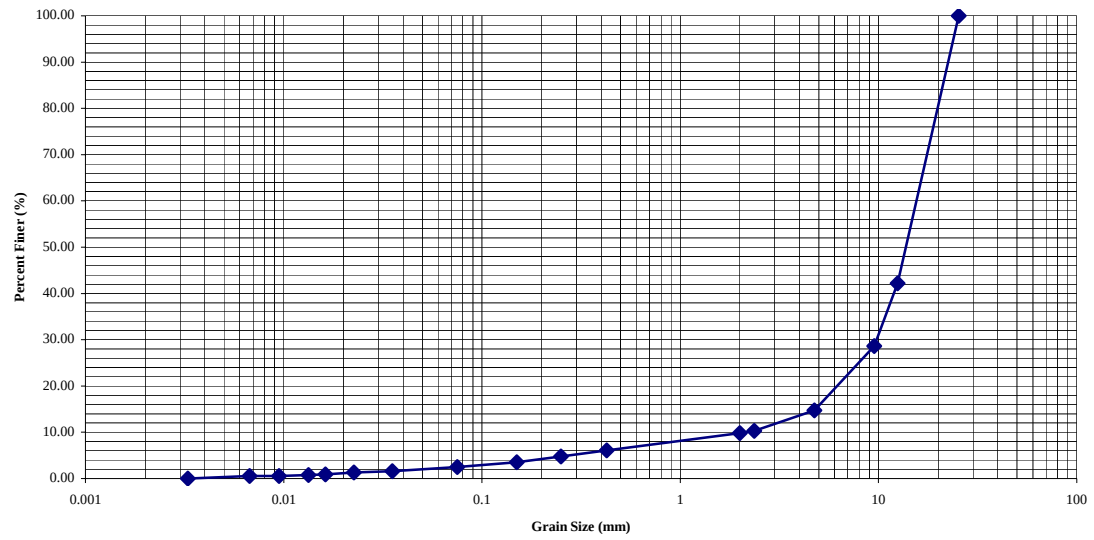
DAVIS020.5CL Cumulative Frequency Plot



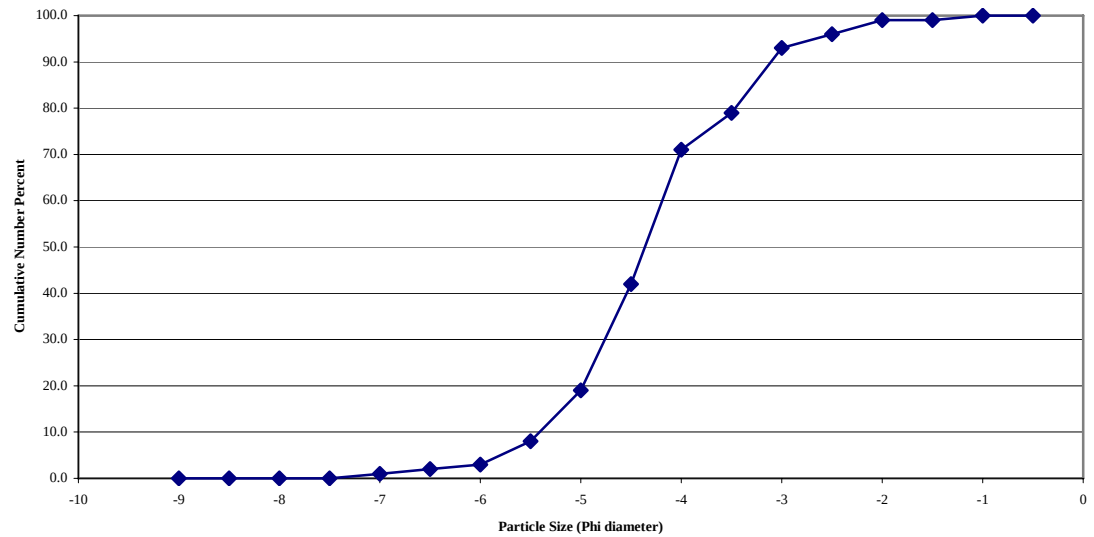
Particle Size Distribution for DAVIS22.6CL



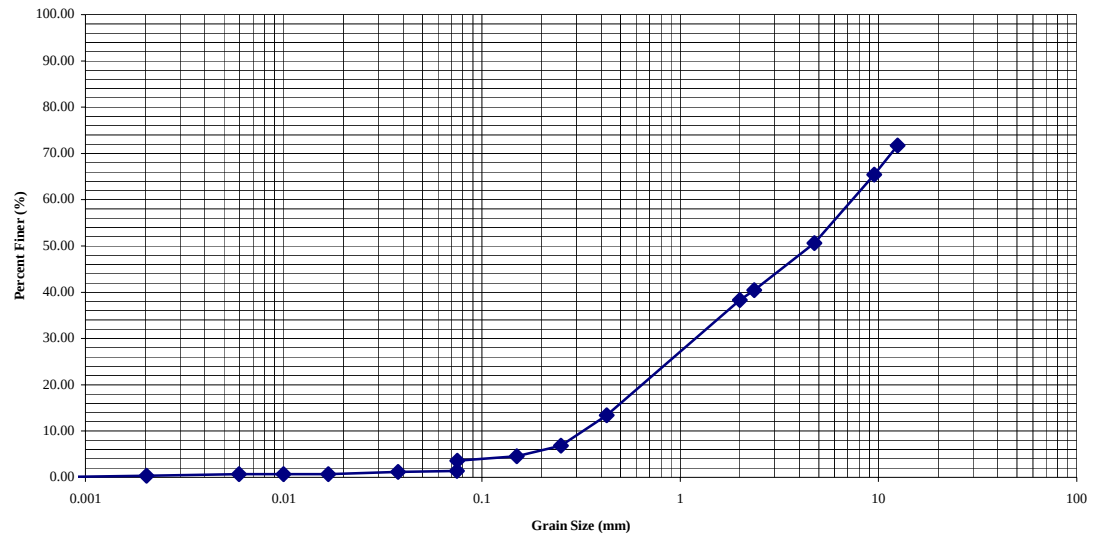
Particle Size Distribution for DAVIS024.1CL



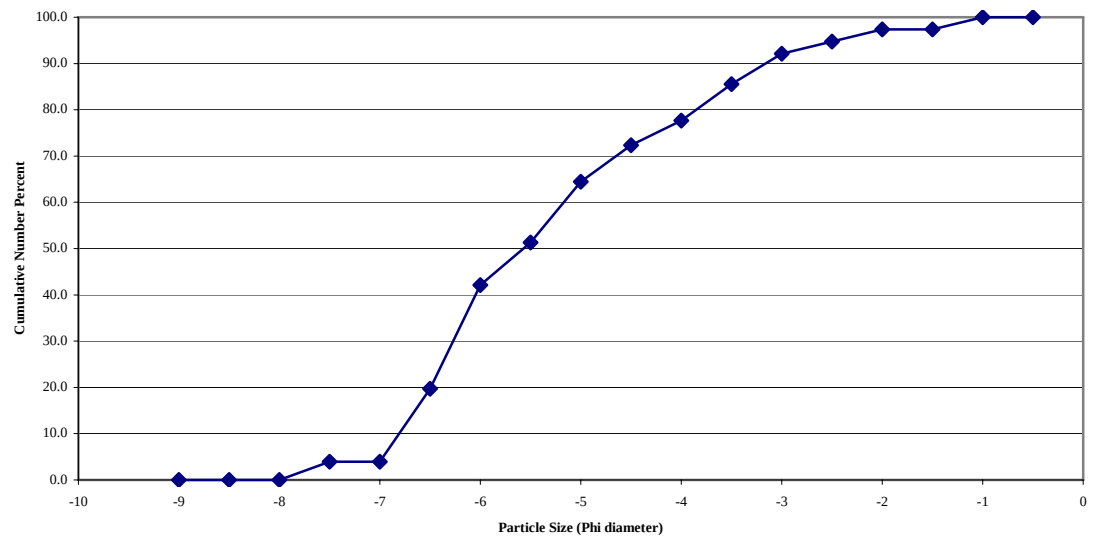
DAVIS024.1CL Cumulative Frequency Plot



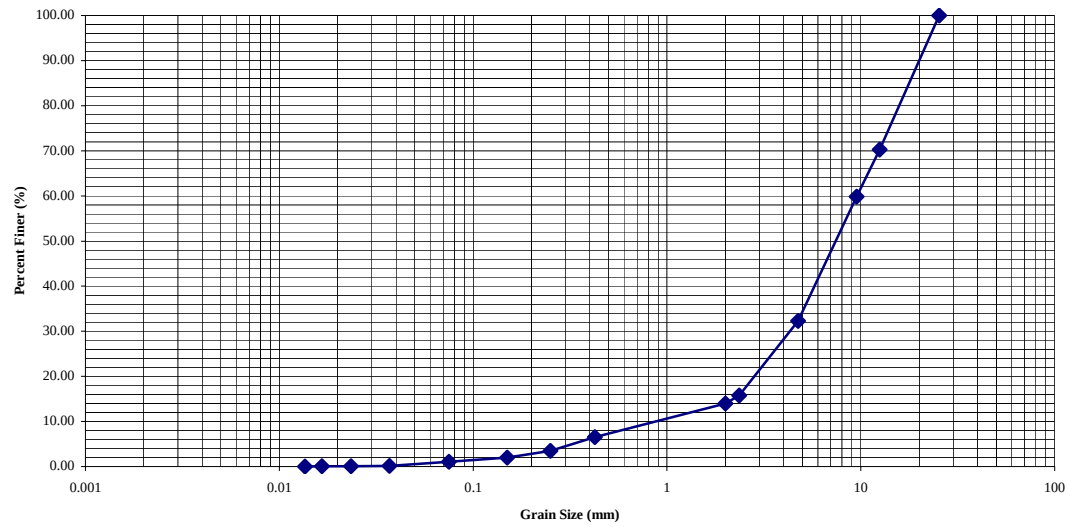
Particle Size Distribution for DRY001.3SU



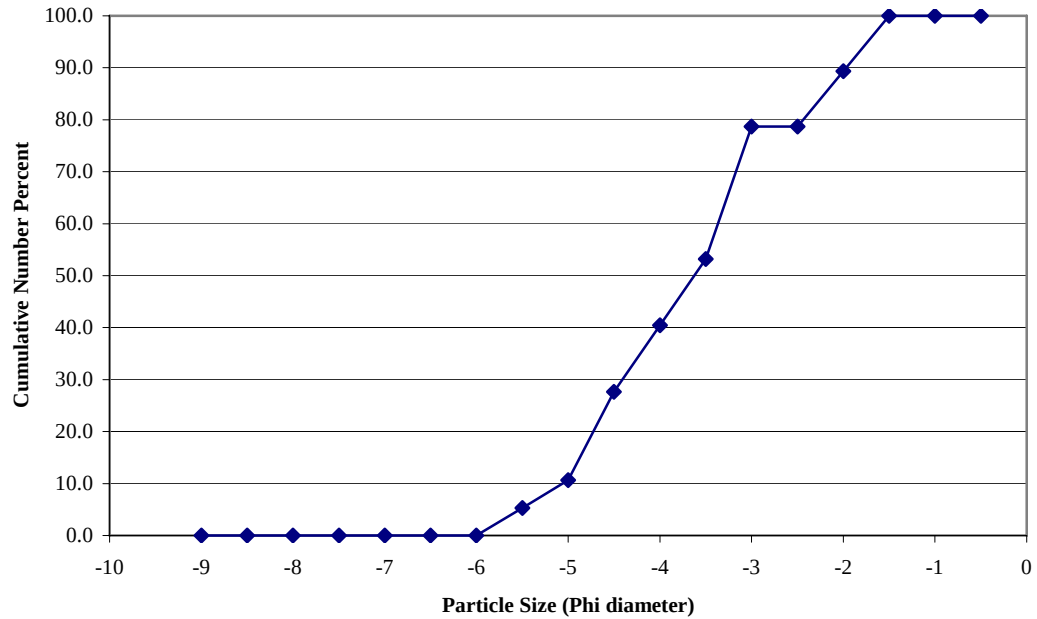
DRY001.3SU Cumulative Frequency Plot



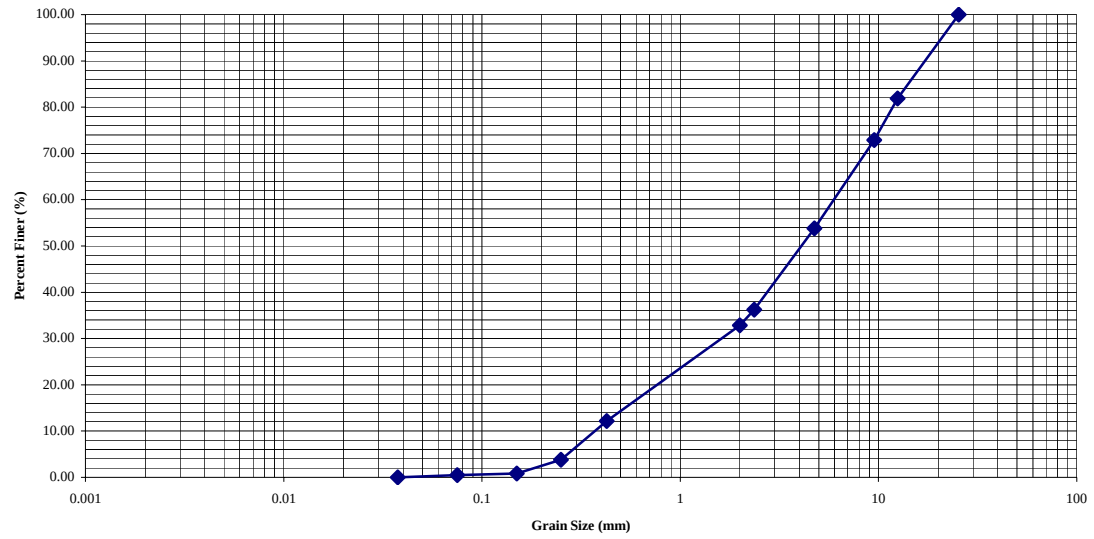
Particle Size Distribution for ECO67F06



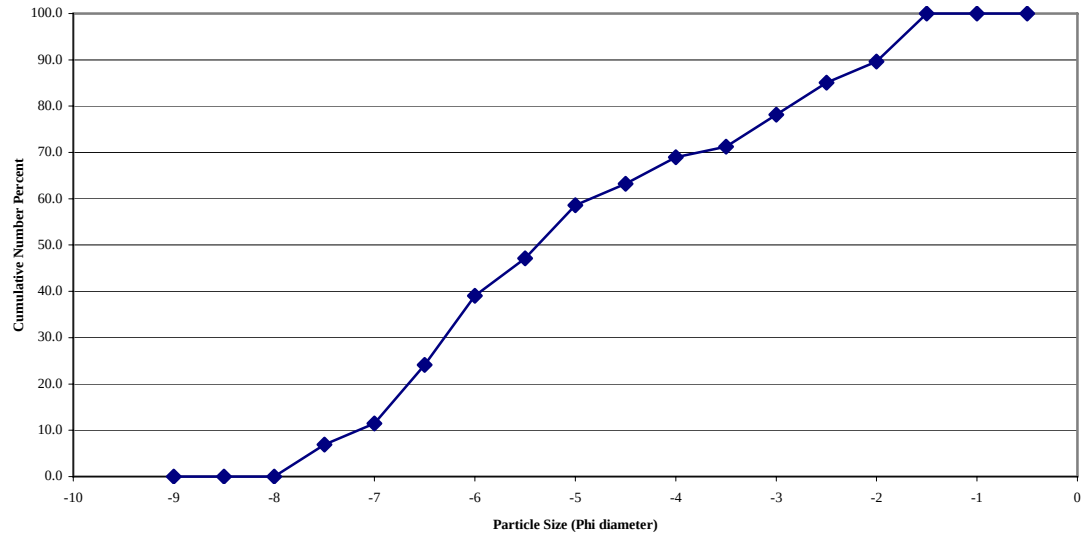
ECO67F06 Cumulative Frequency Plot



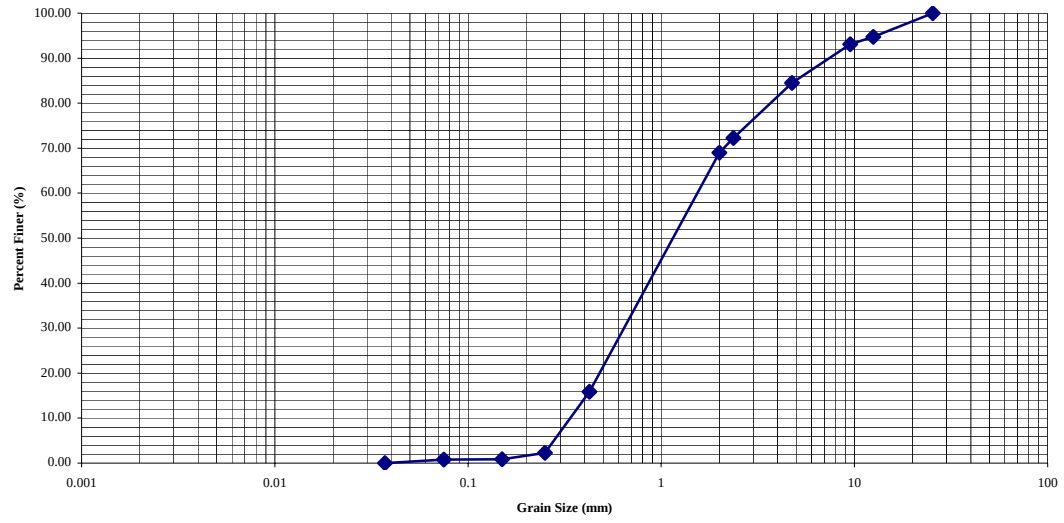
Particle Size Distribution for ECO67F13



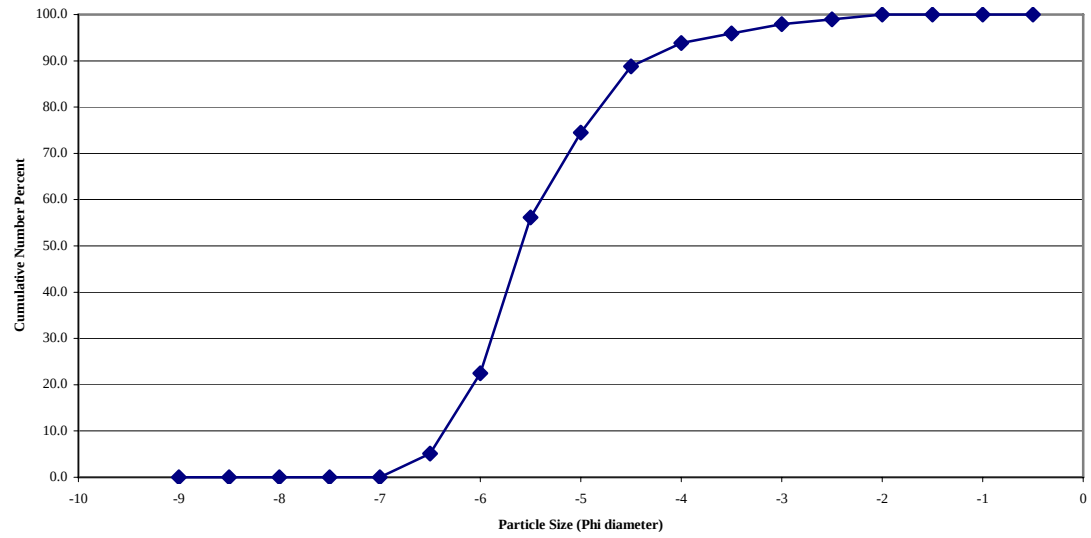
ECO67F13 Cumulative Frequency Plot



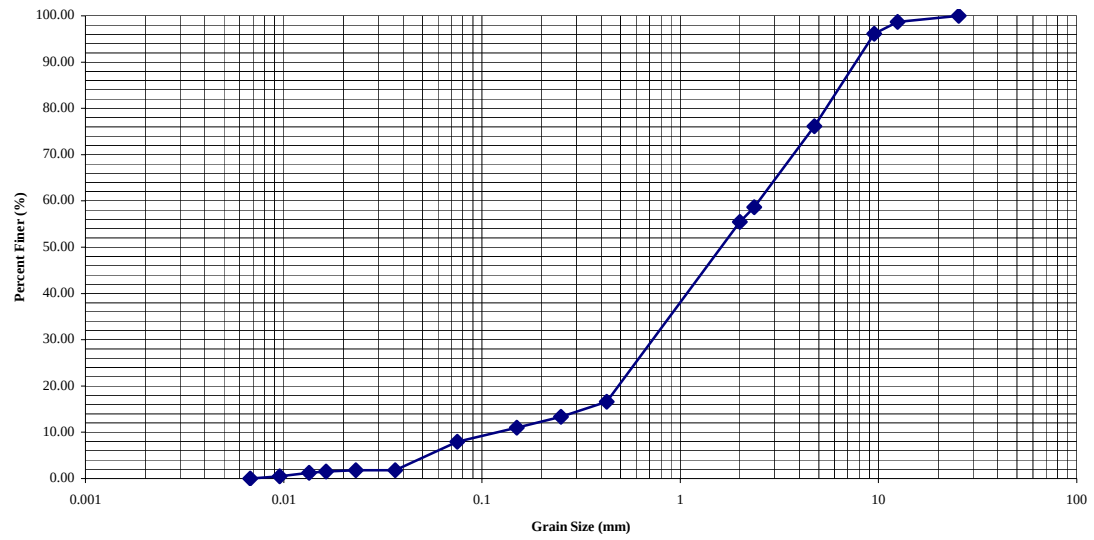
Particle Size Distribution for ECO67F16



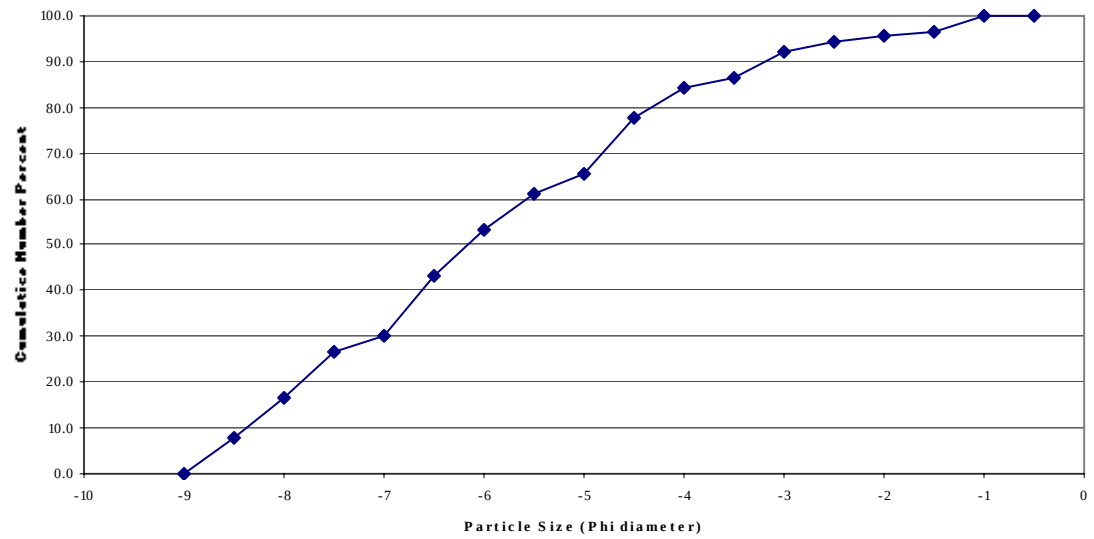
ECO67F16 Cumulative Frequency Plot



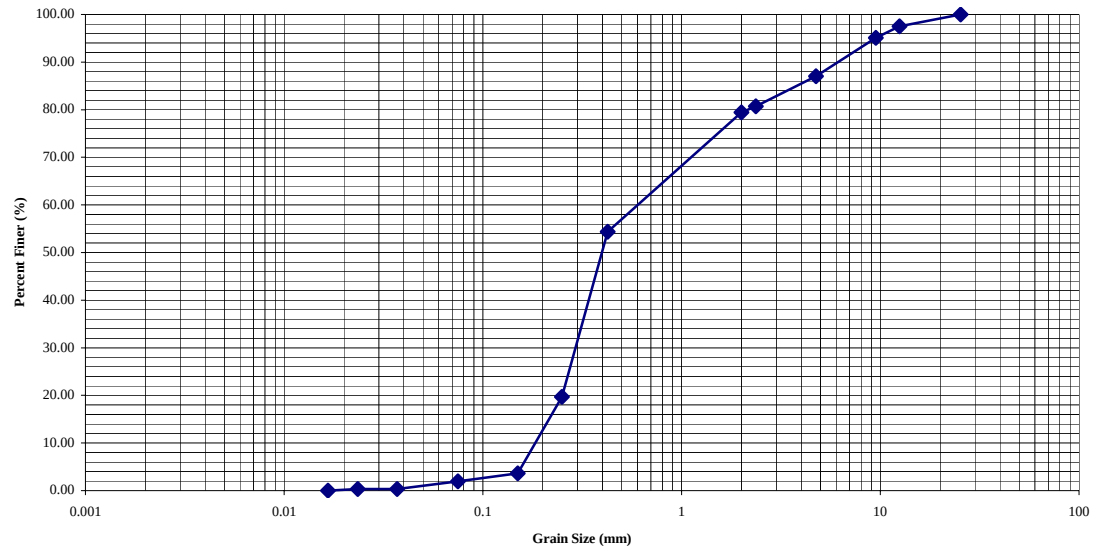
Particle Size Distribution for ECO67F17



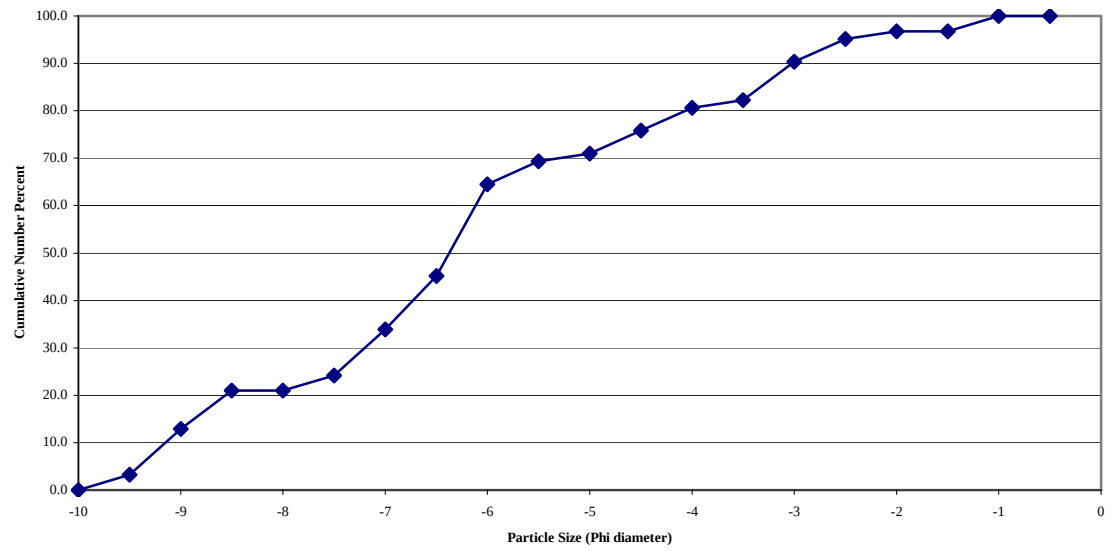
ECO67F17 Cumulative Frequency Plot



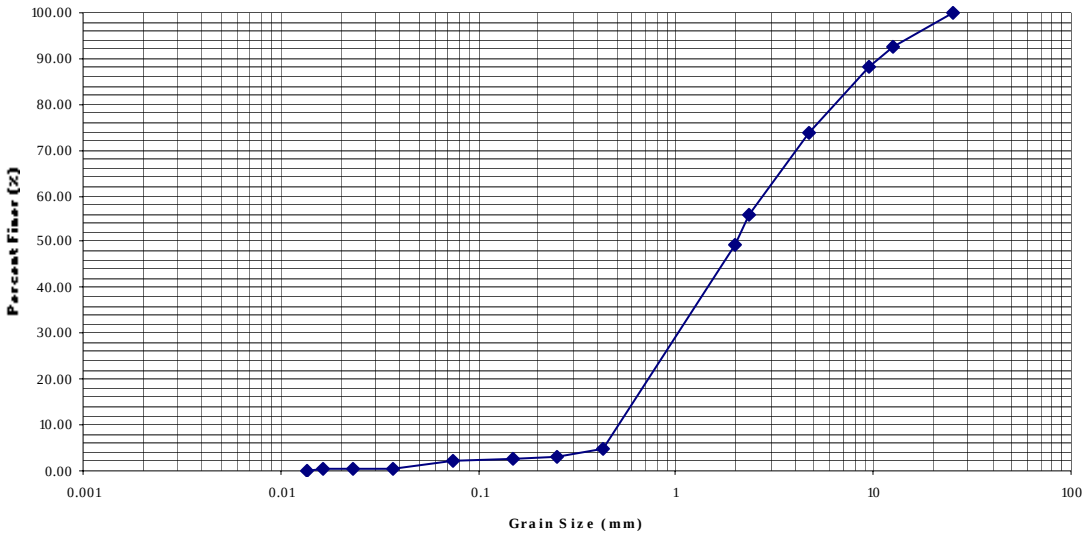
Particle Size Distribution for ECO67F23



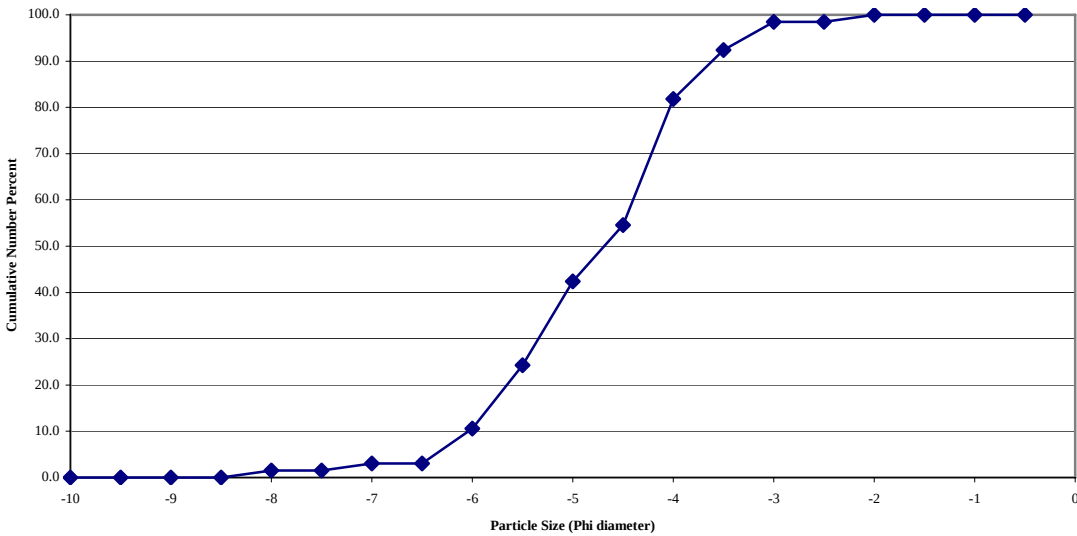
ECO67F23 Cumulative Frequency Plot



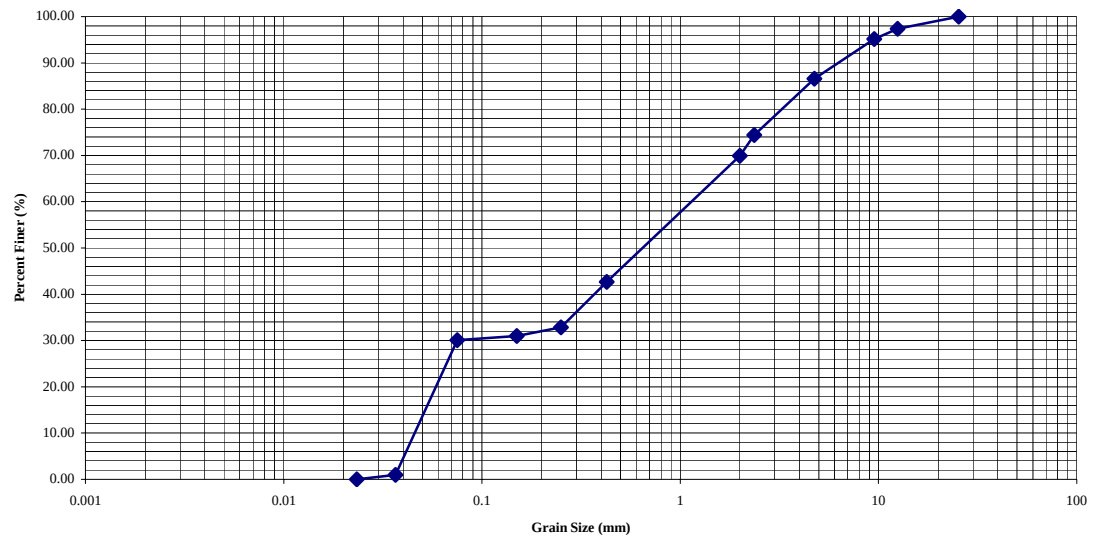
Particle Size Distribution for EC O67G01



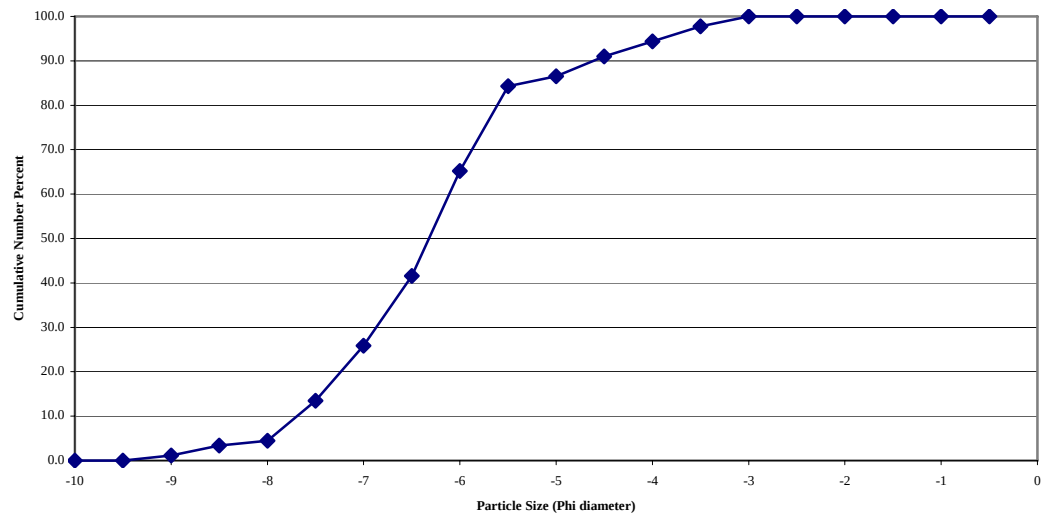
ECO67G01 Cumulative Frequency Plot



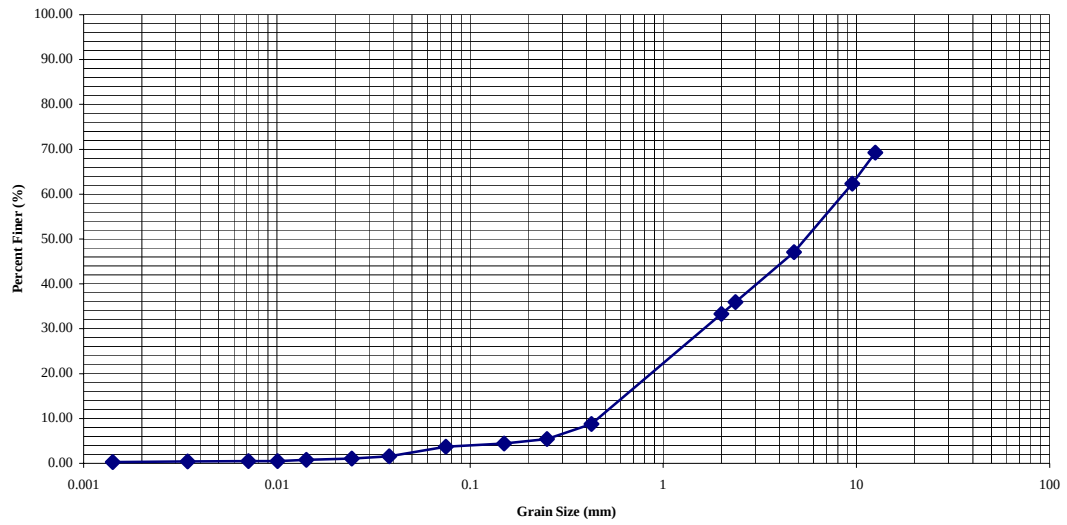
Particle Size Distribution for ECO67G05



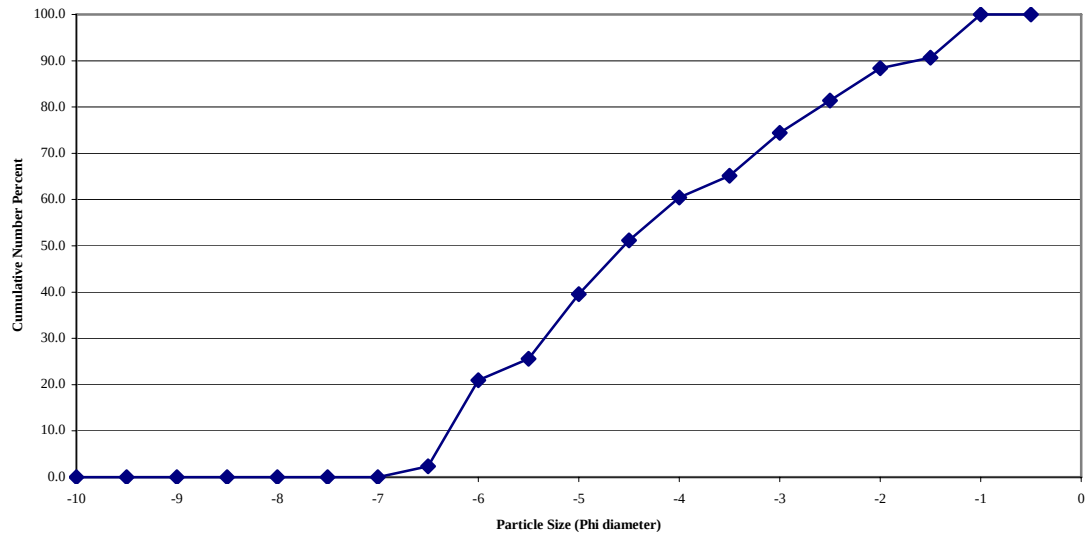
ECO67G05 Cumulative Frequency Plot



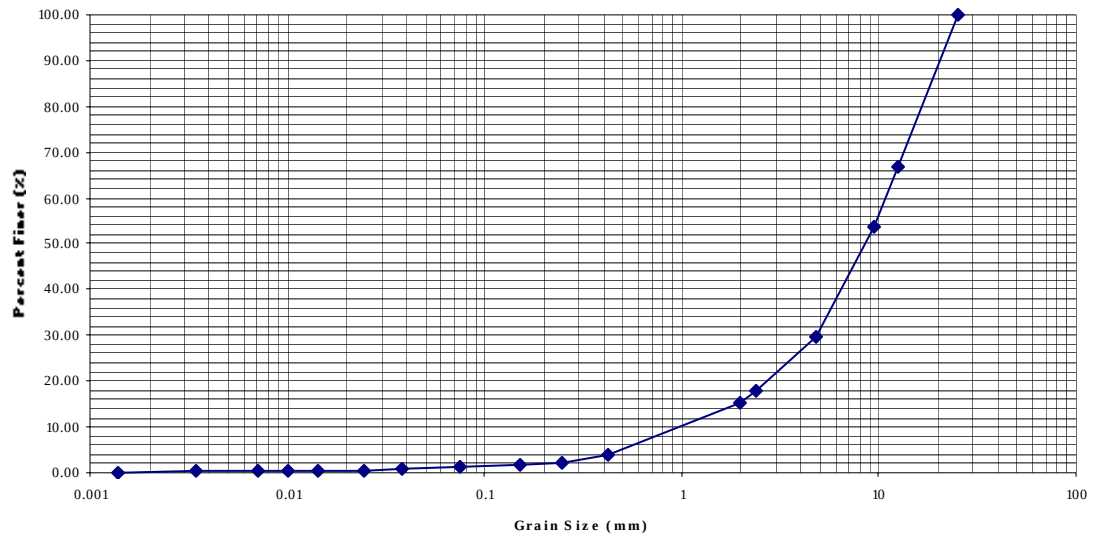
Particle Size Distribution for ECO67G08



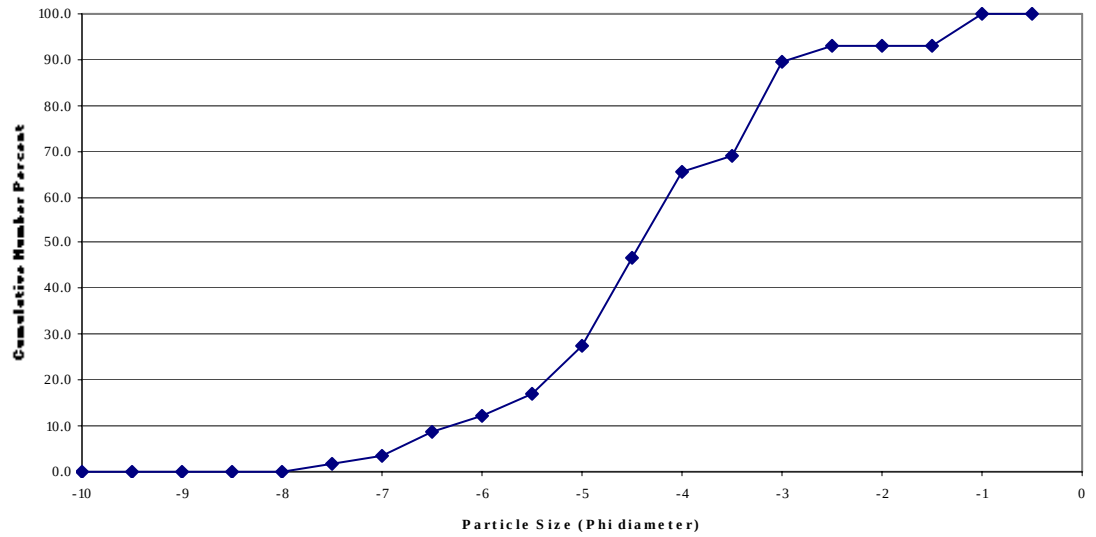
ECO67G08 Cumulative Frequency Plot



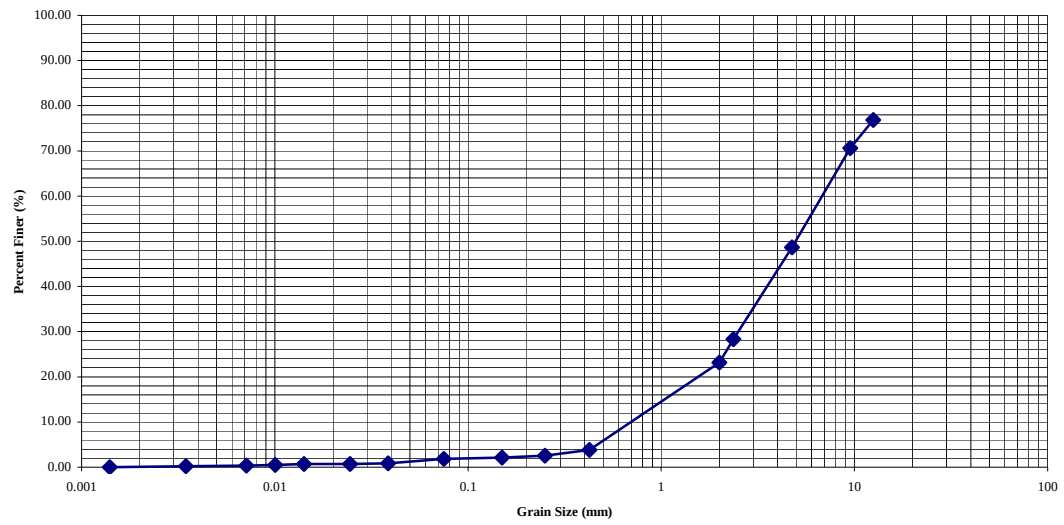
Particle Size Distribution for EC O67G09



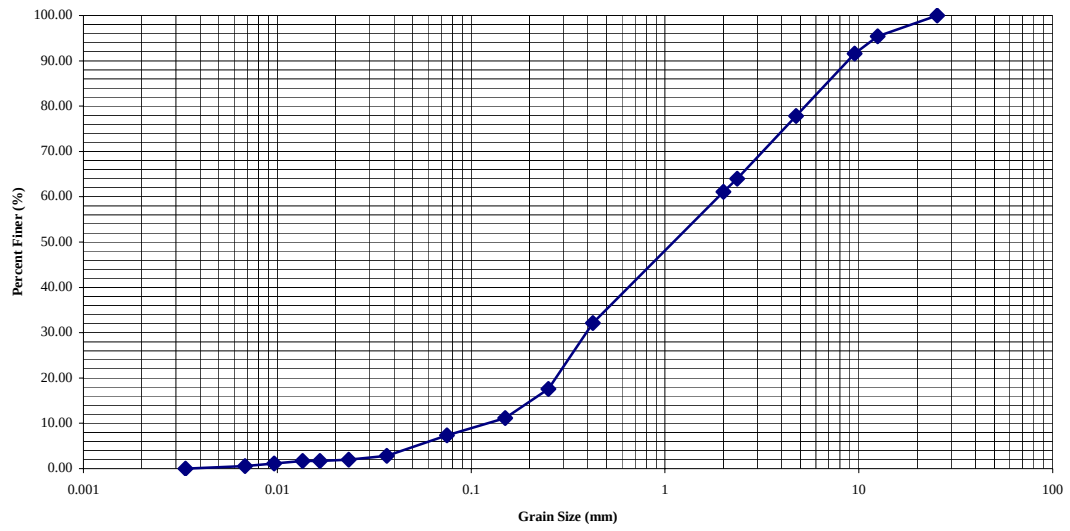
ECO67G09 Cumulative Frequency Plot



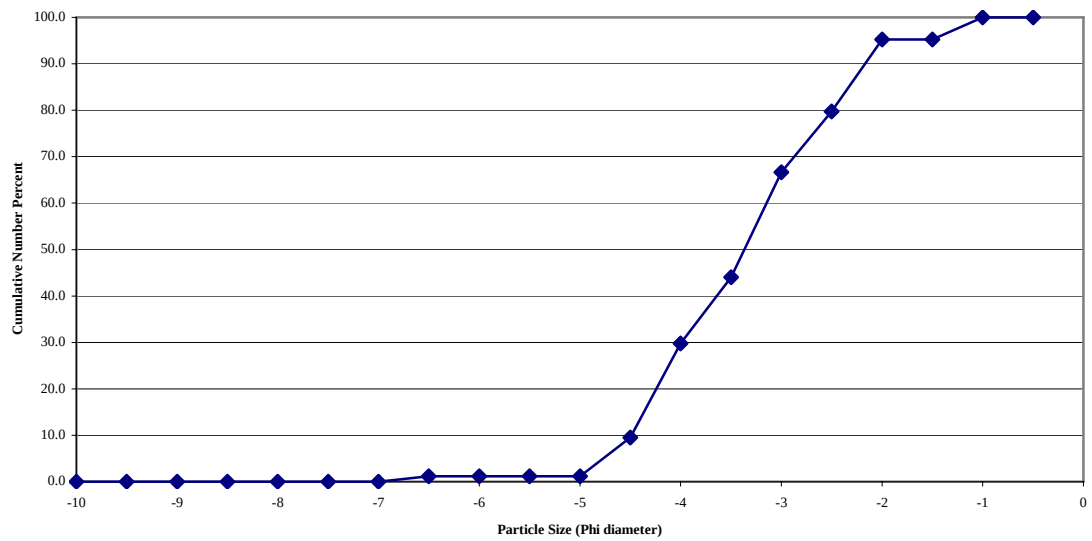
Particle Size Distribution for ECO67H04



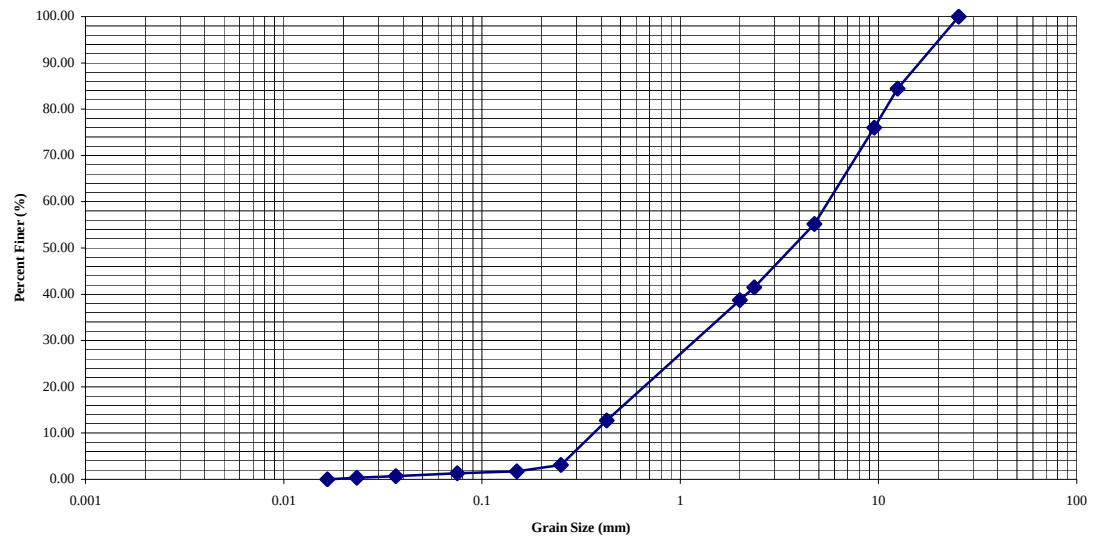
Particle Size Distribution for ECO67I12



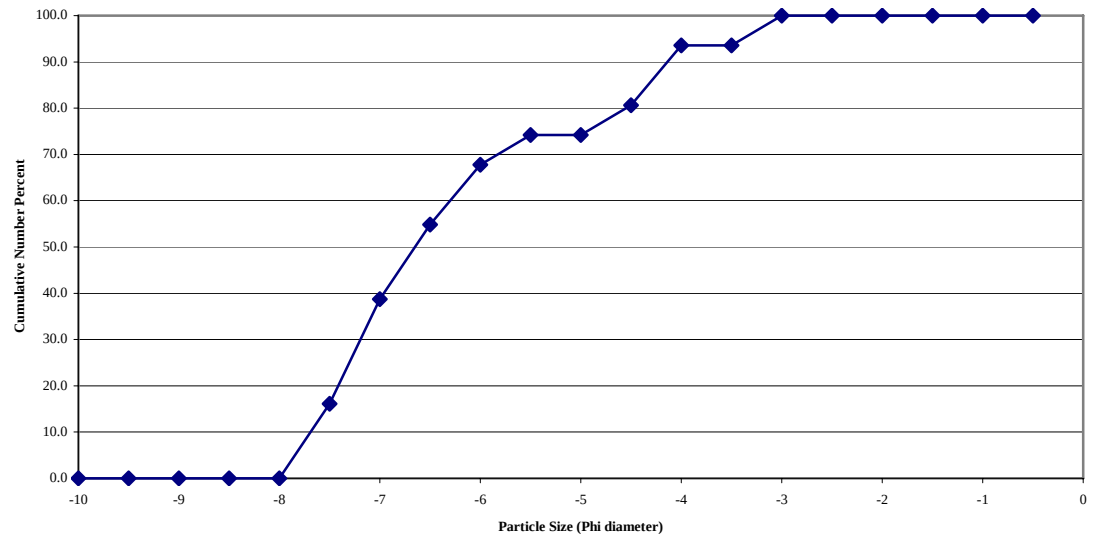
ECO67I12 Cumulative Frequency Plot



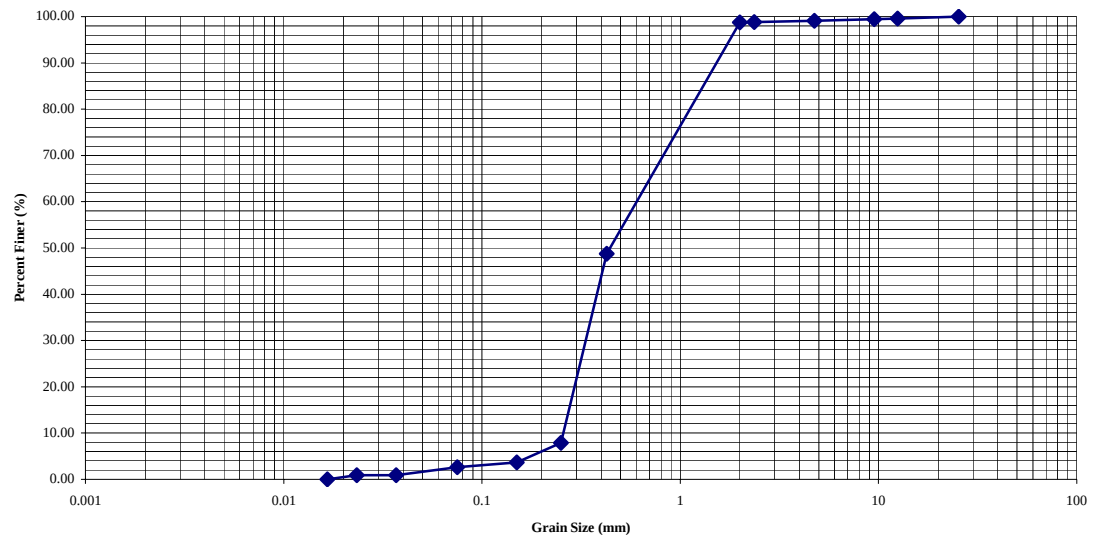
Particle Size Distribution for ECO6701



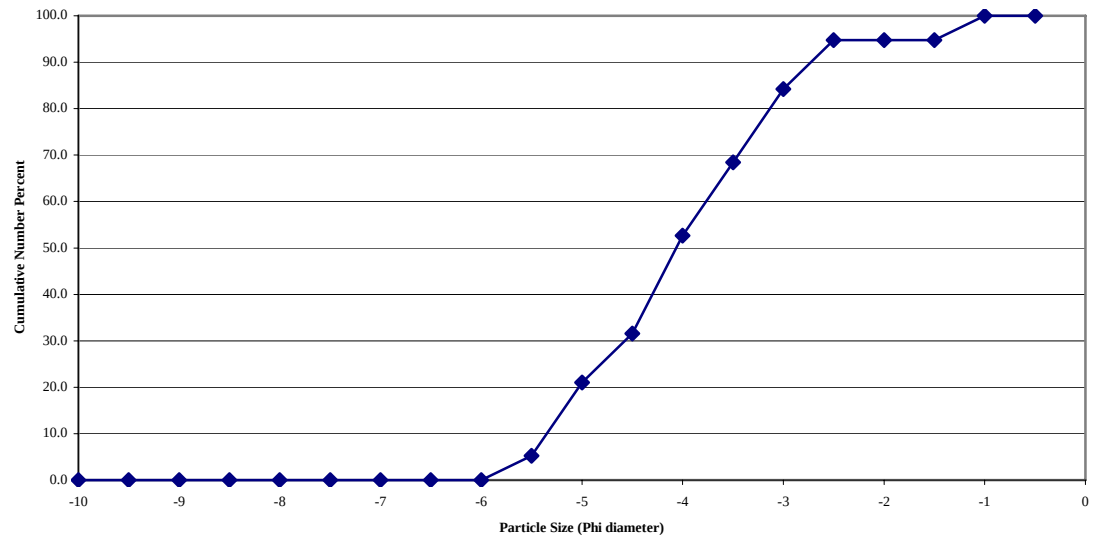
ECO6701 Cumulative Frequency Plot



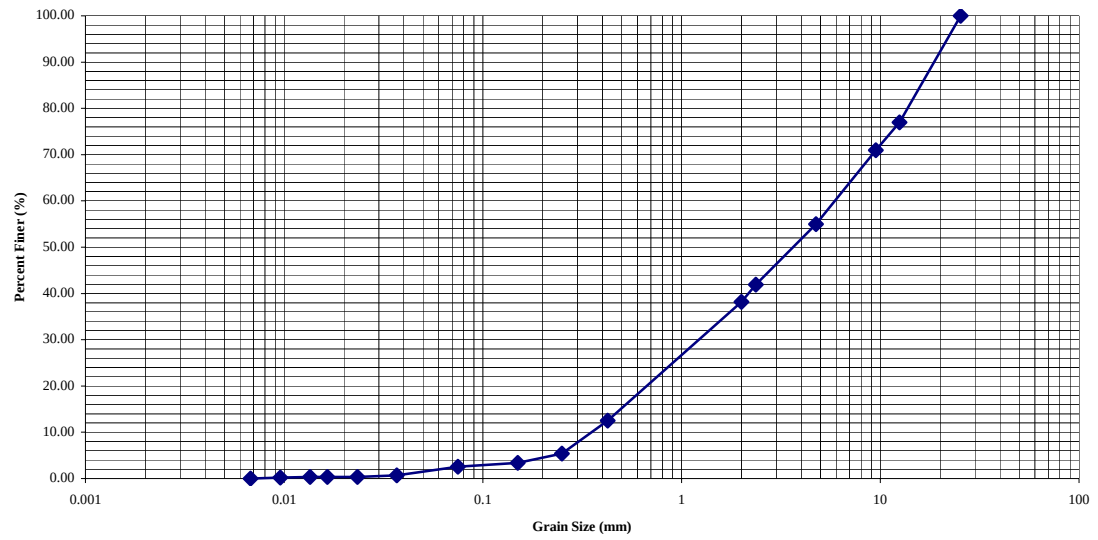
Particle Size Distribution for ECO6702



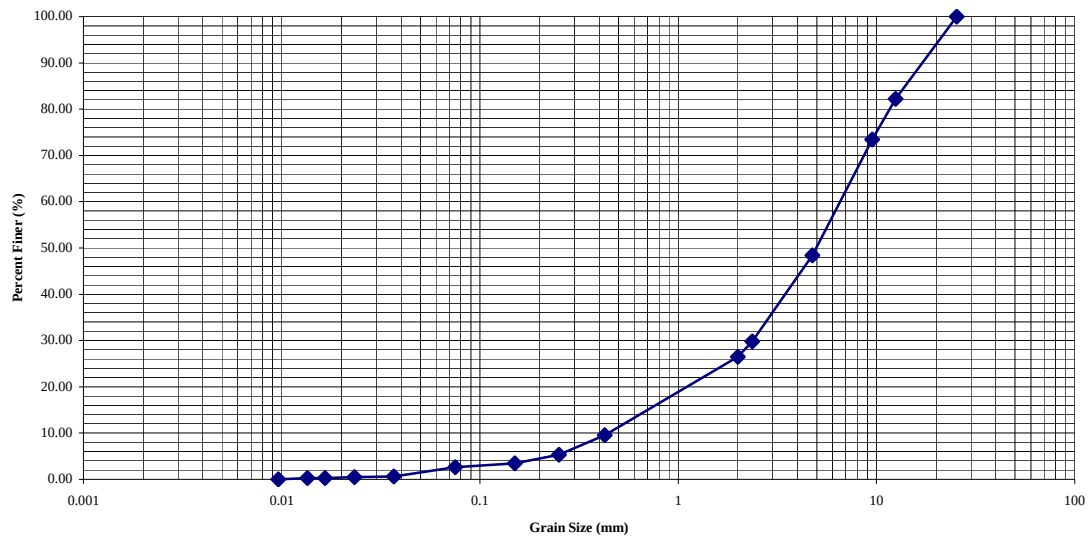
ECO6702 Cumulative Frequency Plot



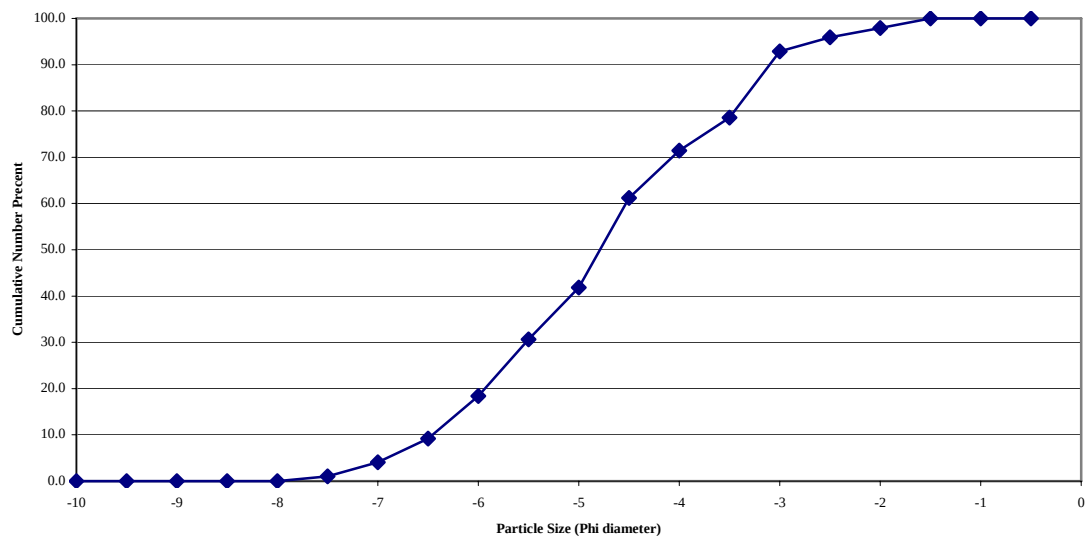
Particle Size Distribution for FALL000.6WN



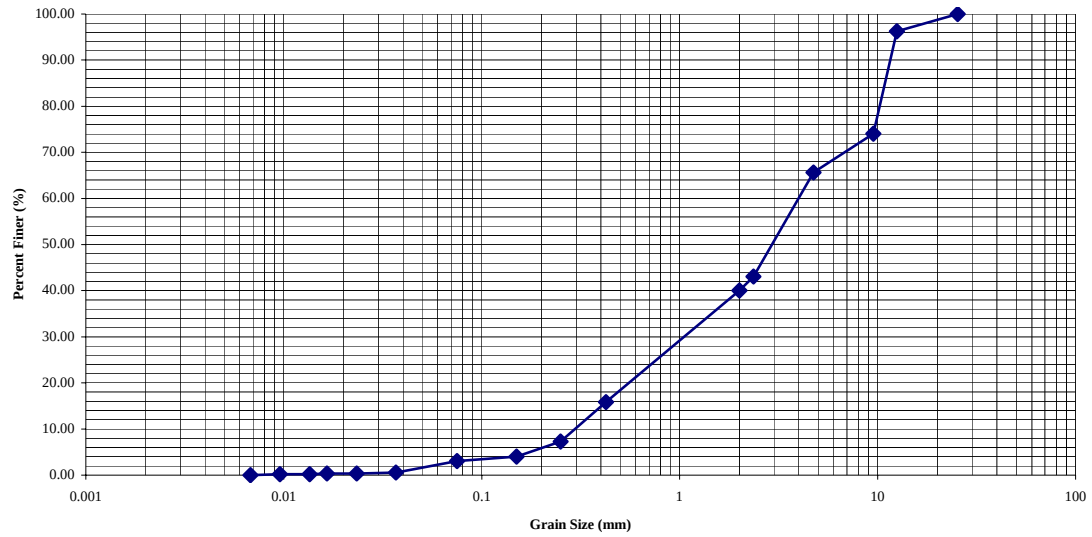
Particle Size Distribution for FLAT001.0HA



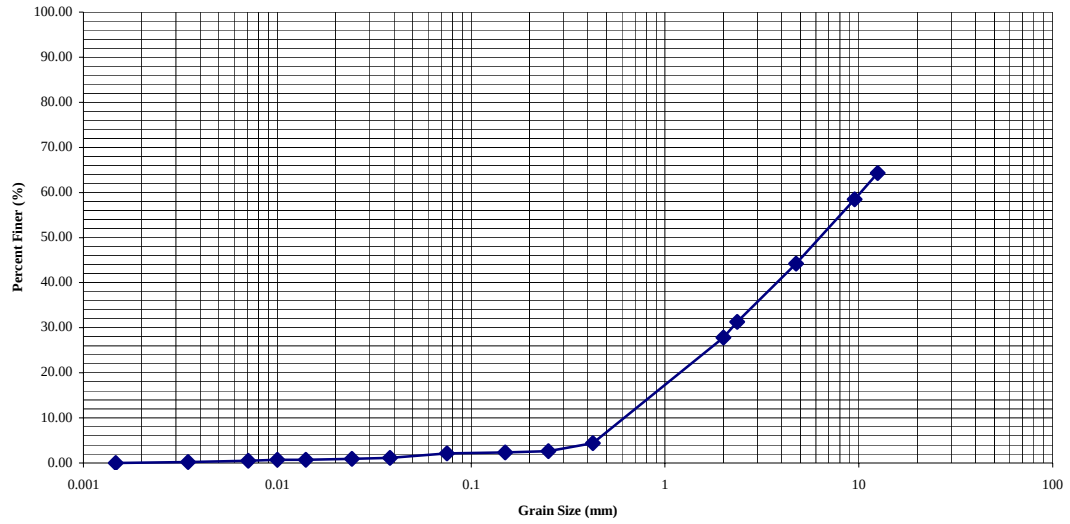
FLAT001.0HA Cumulative Frequency Plot



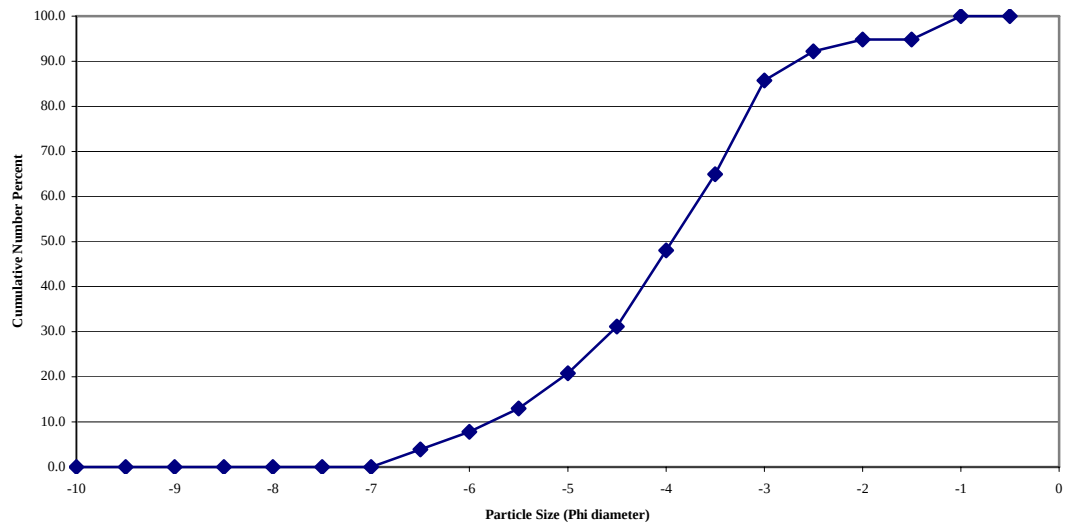
Particle Size Distribution for FOURM000.1HK



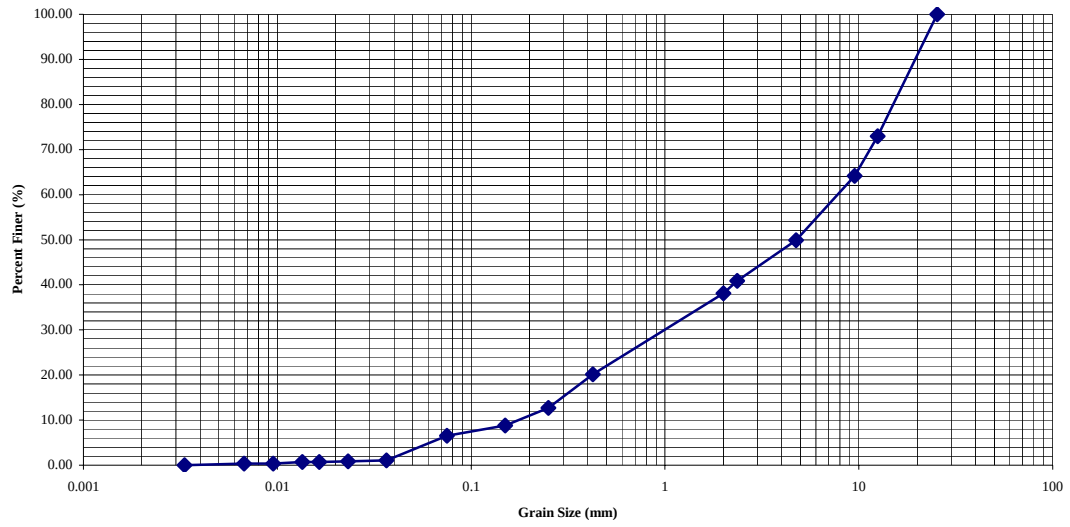
Particle Size Distribution for INDIA001.0SU



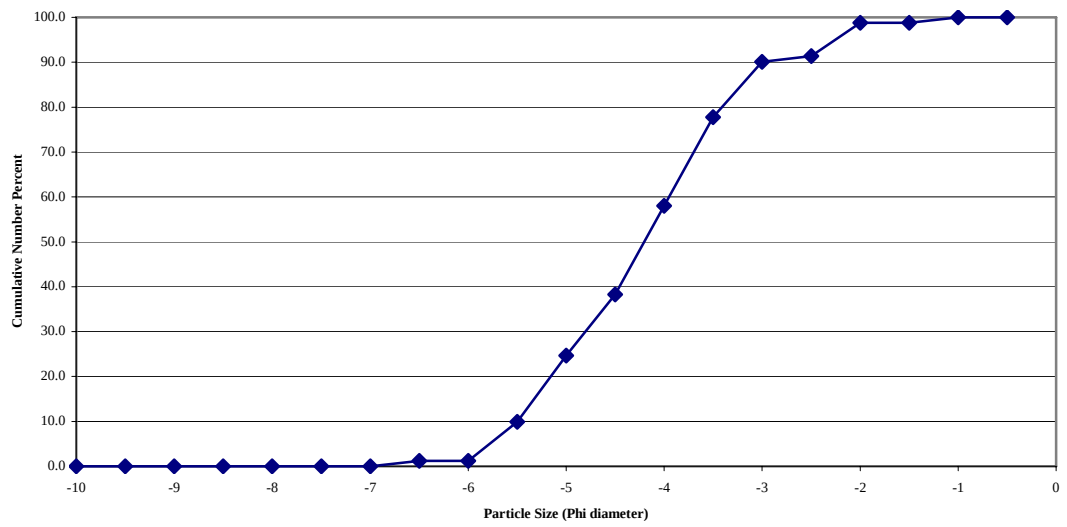
INDIA001.0SU Cumulative Frequency Plot



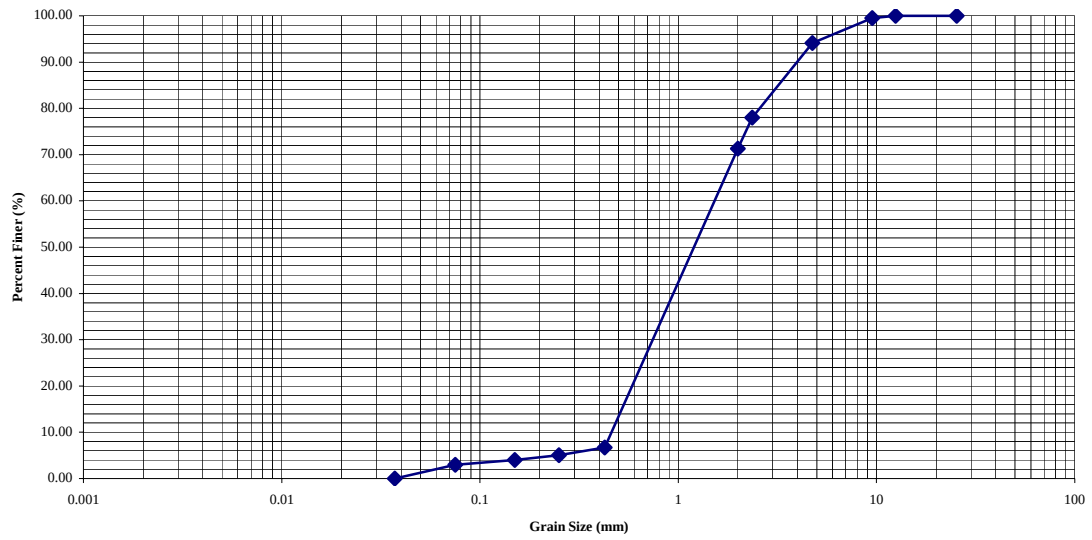
Particle Size Distribution for JOCKE000.1WN



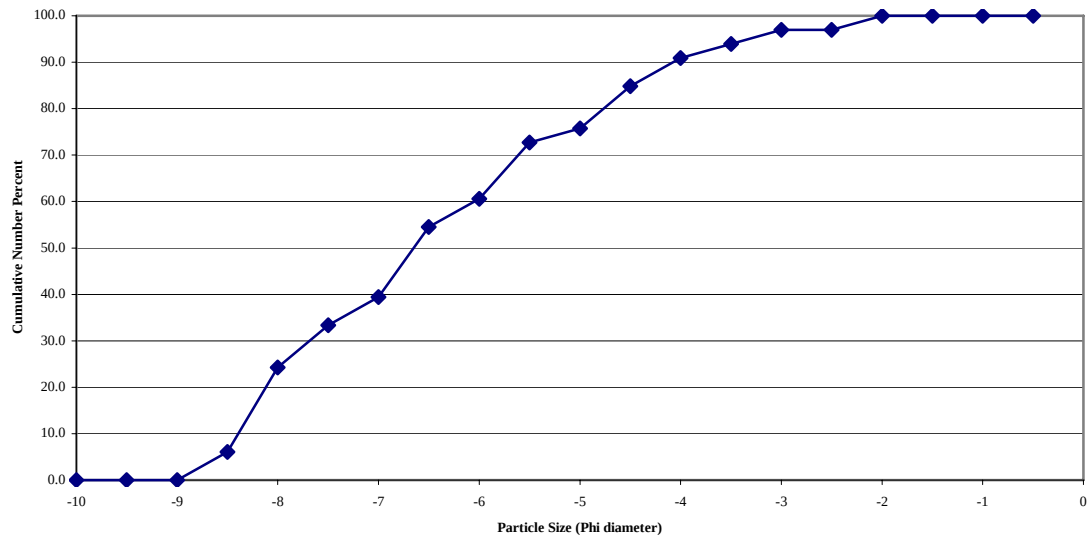
JOCKE000.1WN Cumulative Frequency Plot



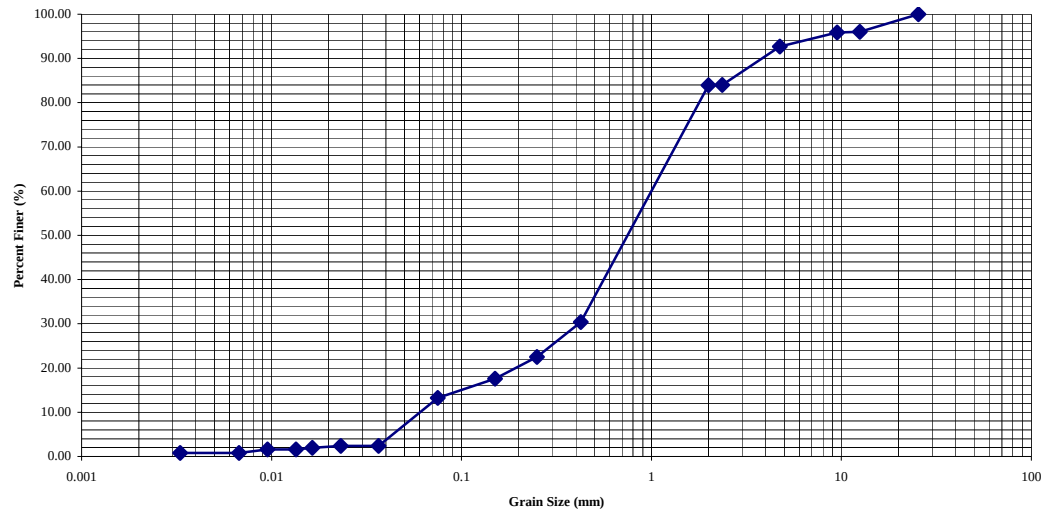
Particle Size Distribution for LICK052.3GE



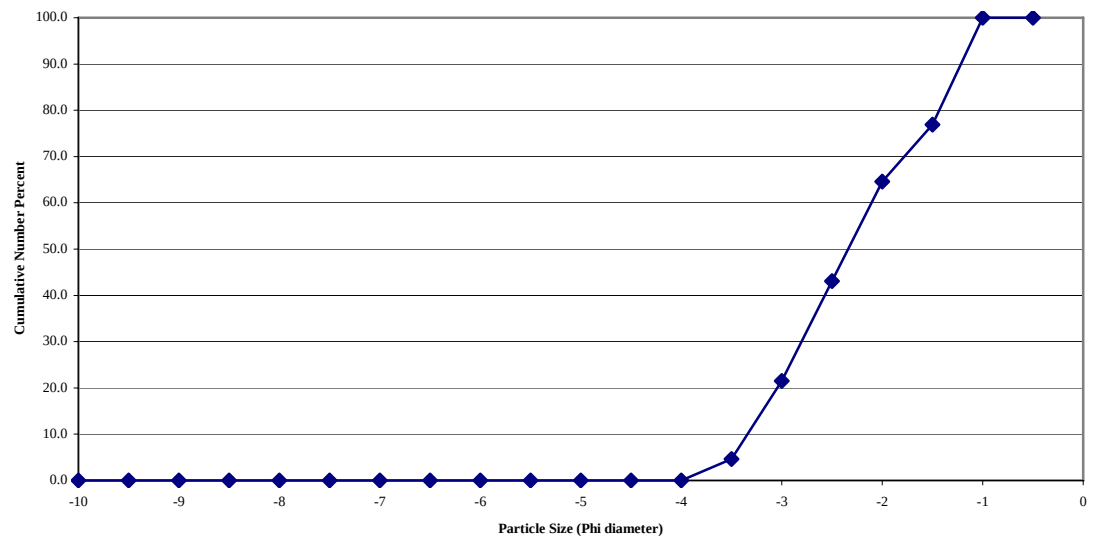
LICK052.3GE Cumulative Frequency Plot



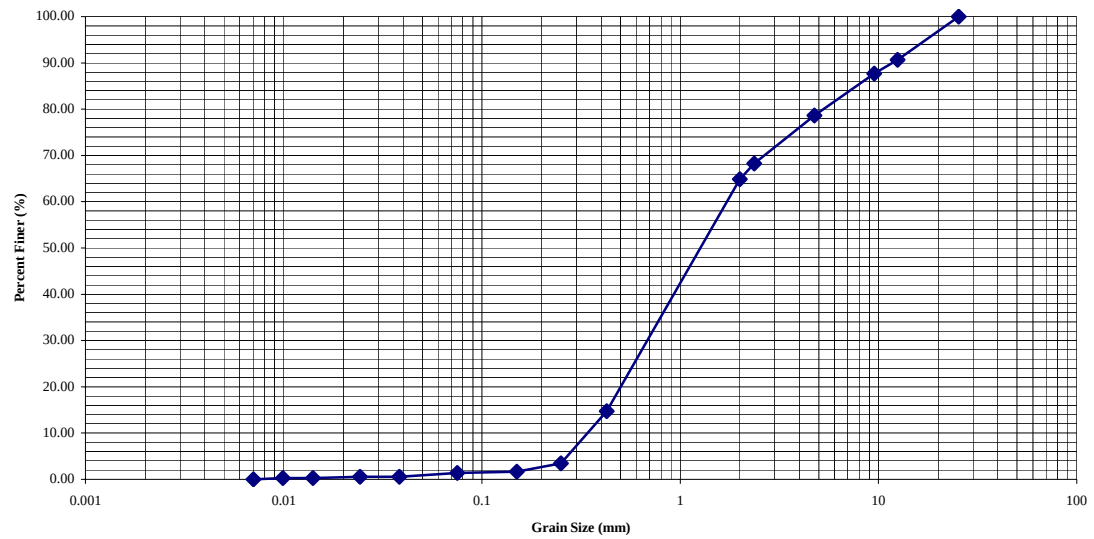
Particle Size Distribution for LICK061.0GE



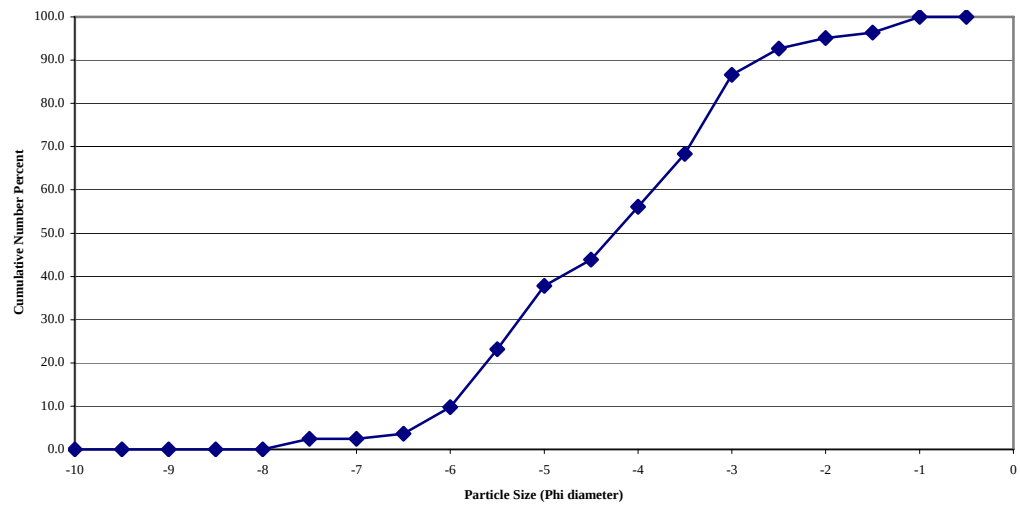
LICK061.1GE Cumulative Frequency Plot



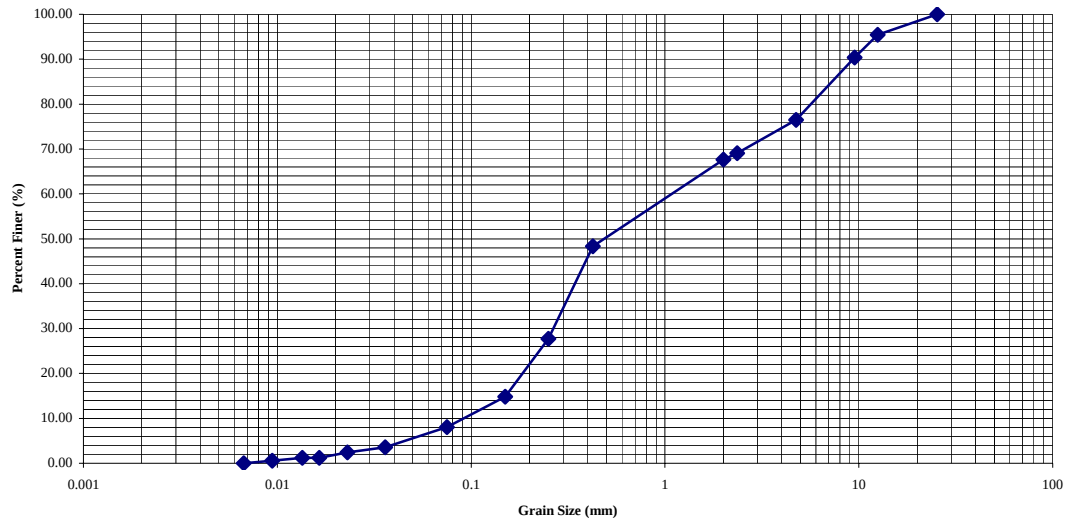
Particle Size Distribution for MADD001.2SU



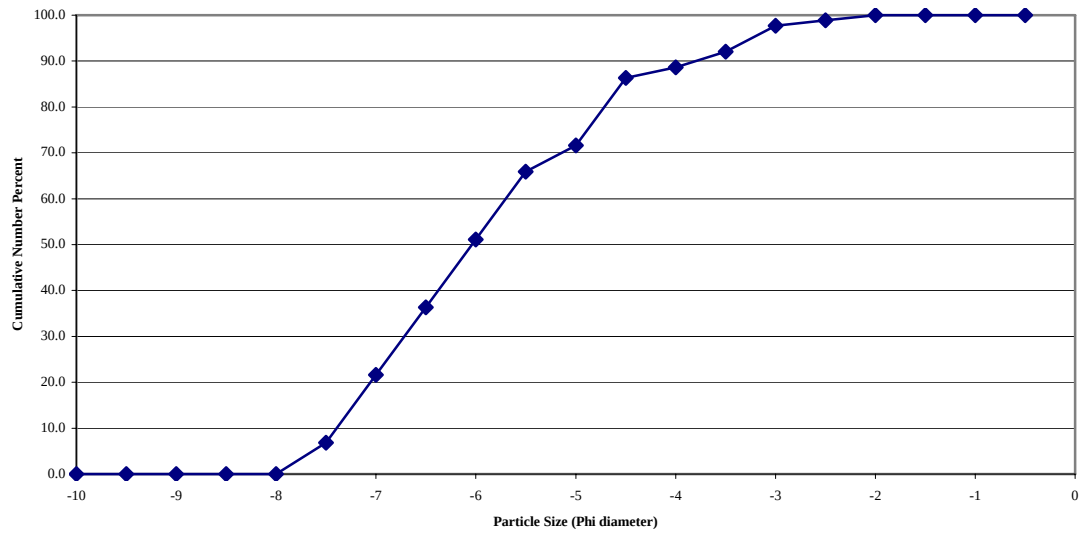
MADD1.2SU Cumulative Frequency Plot



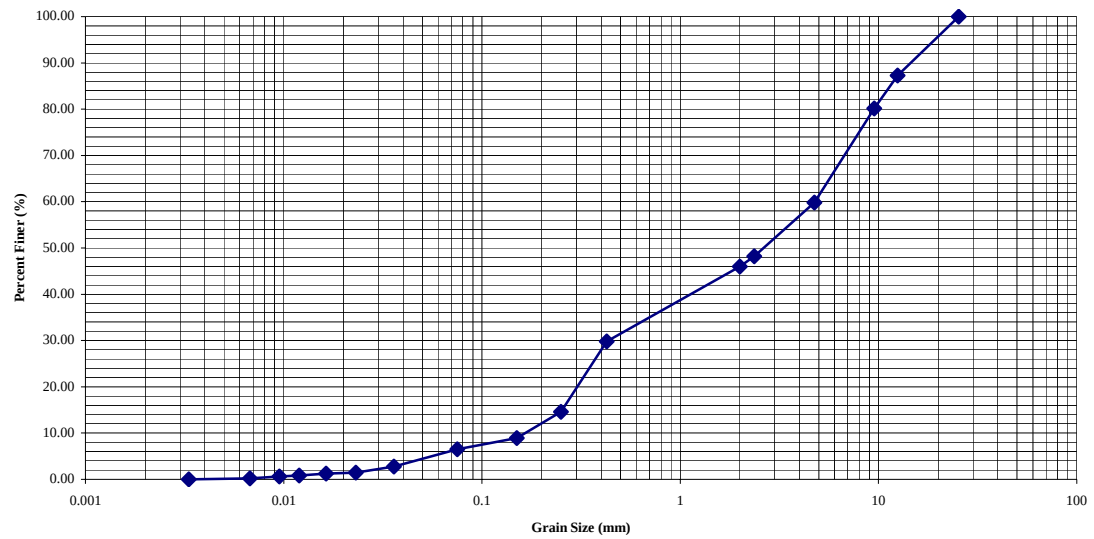
Particle Size Distribution for MEADO000.4GE



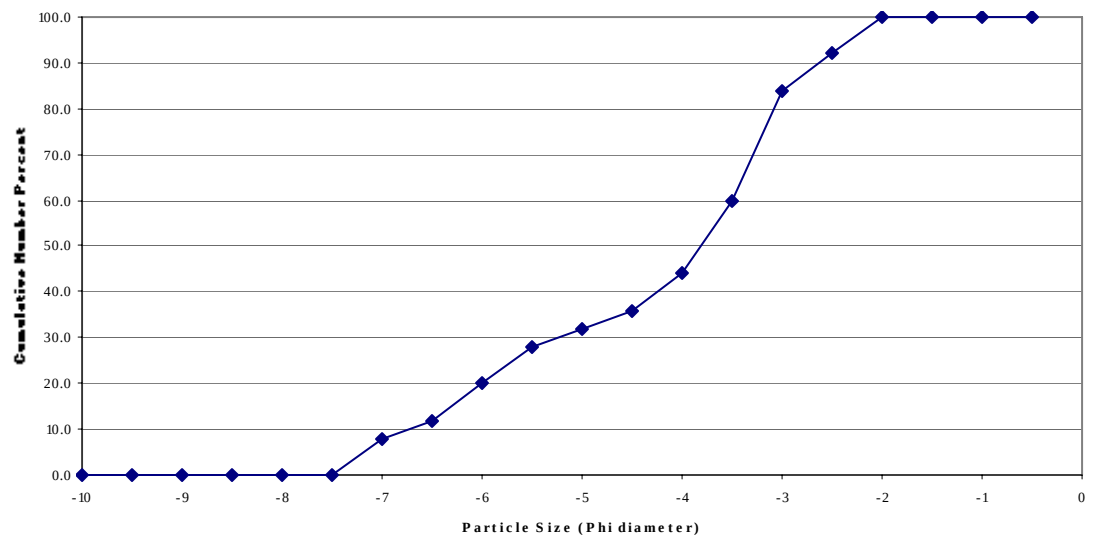
MEADO000.4GE Cumulative Frequency Plot



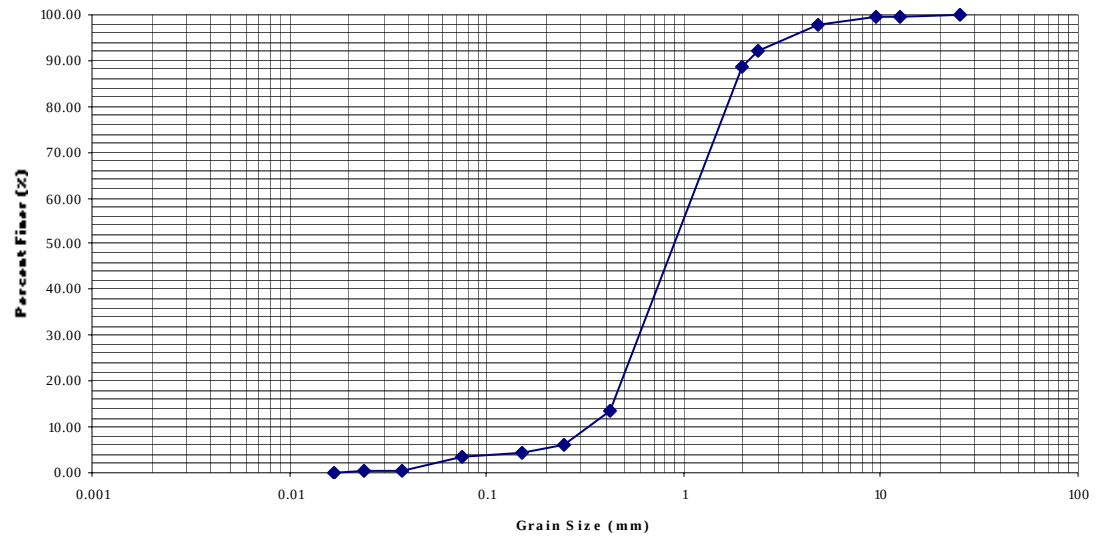
Particle Size Distribution for PIGO000.1GE



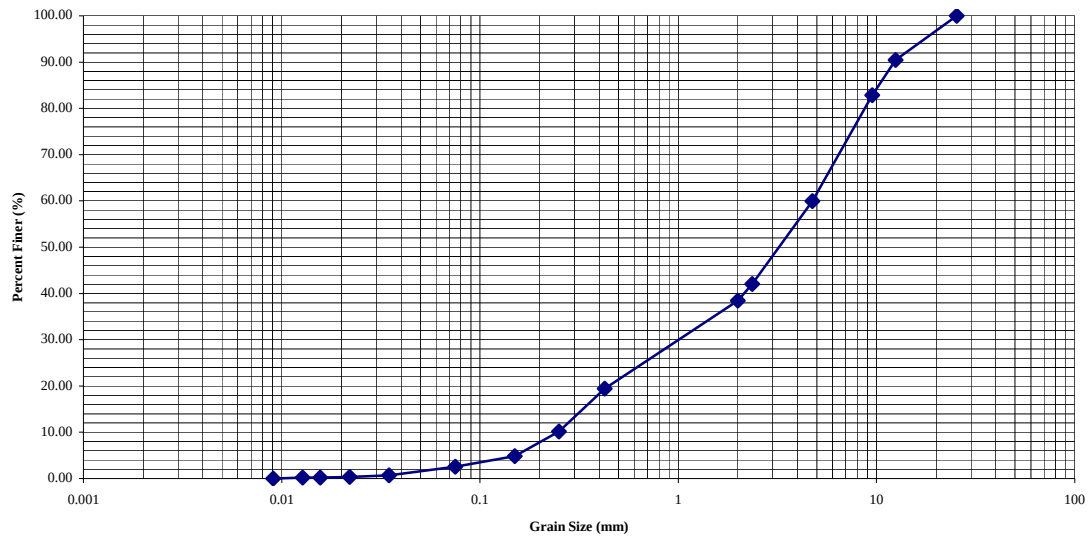
PIG000.1GE Cumulative Frequency Plot



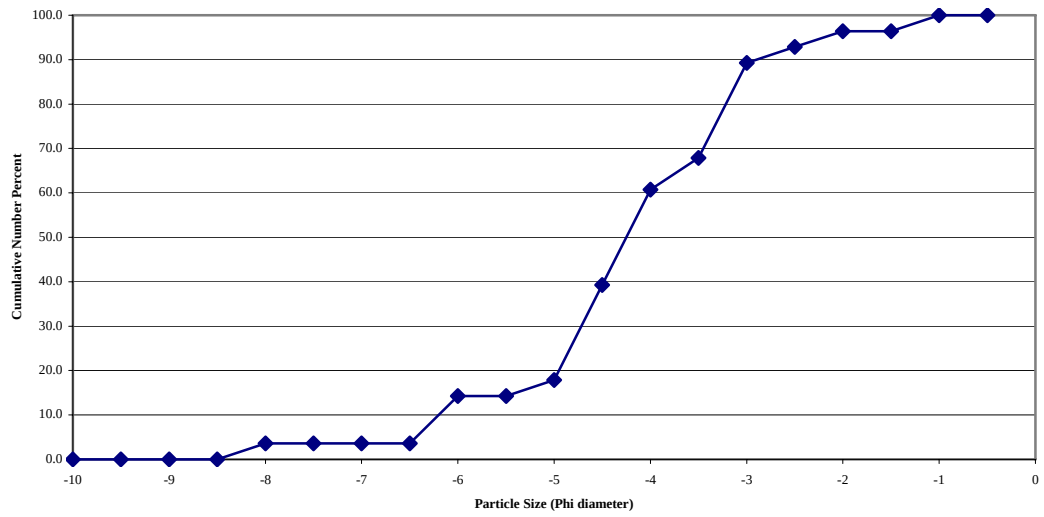
Particle Size Distribution for PISTO000.2BT



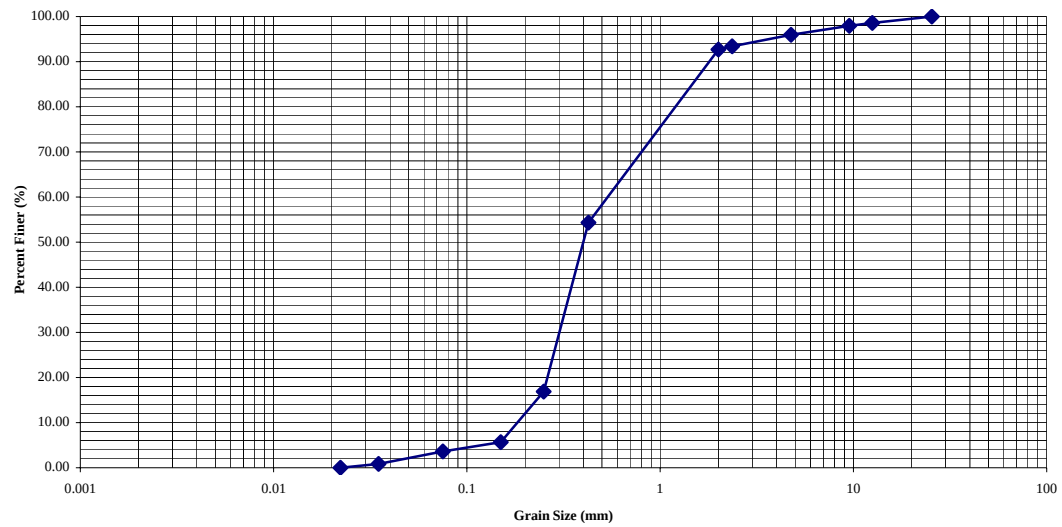
Particle Size Distribution for RICHL001.5GE



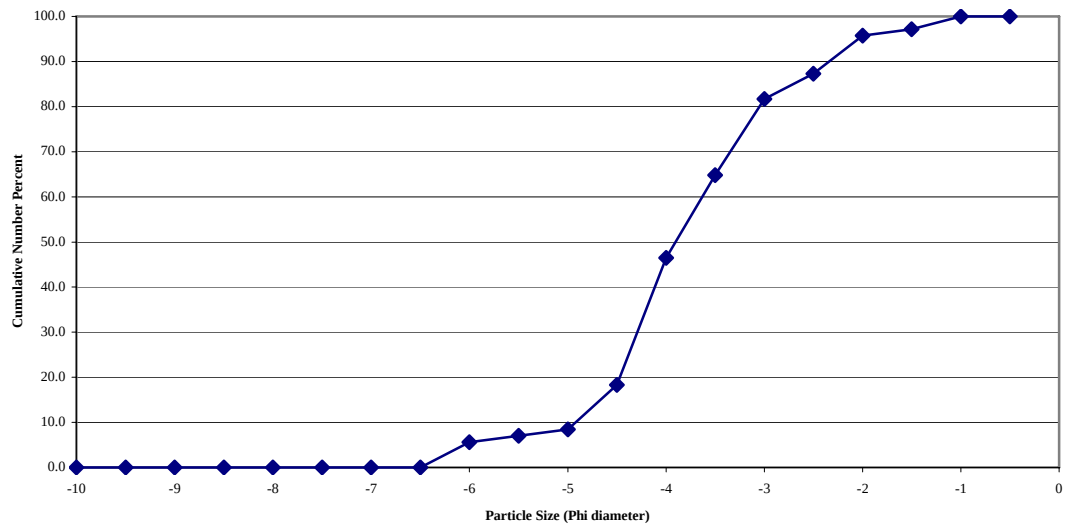
RICH001.5GE Cumulative Frequency Plot



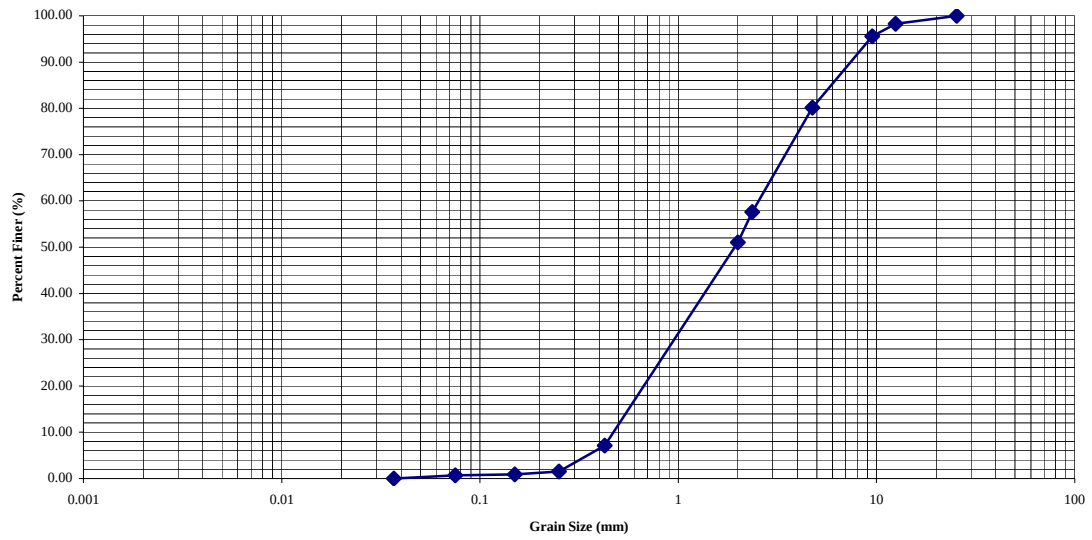
Particle Size Distribution for RICHL003.5GE



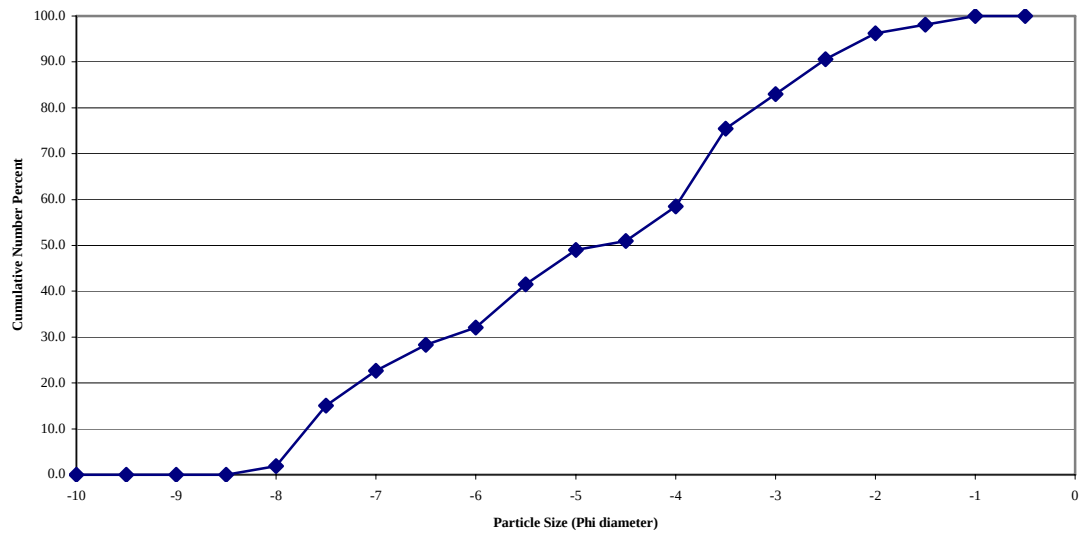
RICHL003.5GE Cumulative Frequency Plot



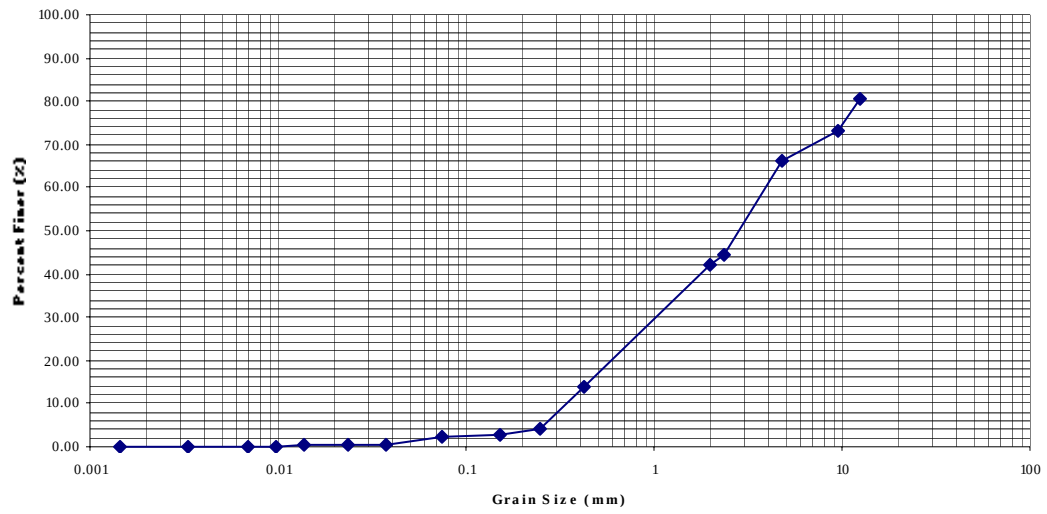
Particle Size Distribution for RICHL004.2GE



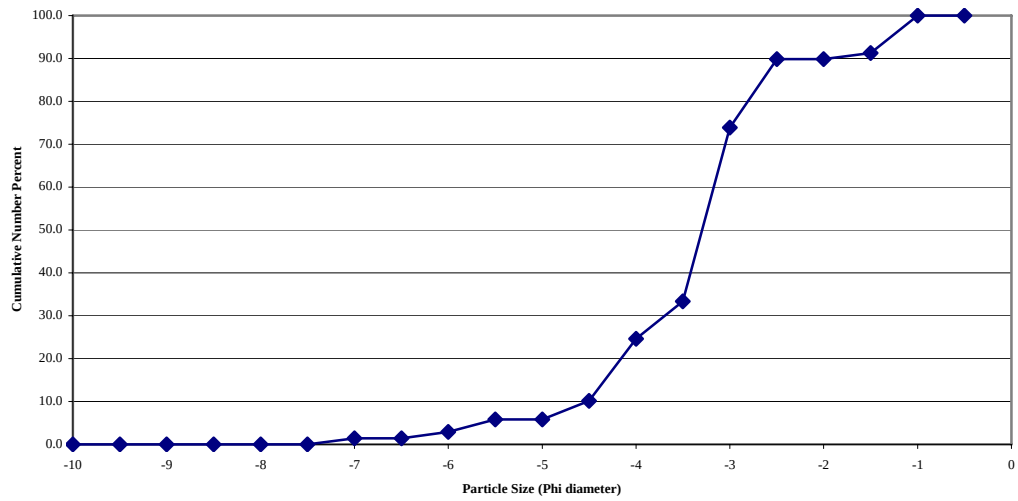
RICHL004.2GE Cumulative Frequency Plot



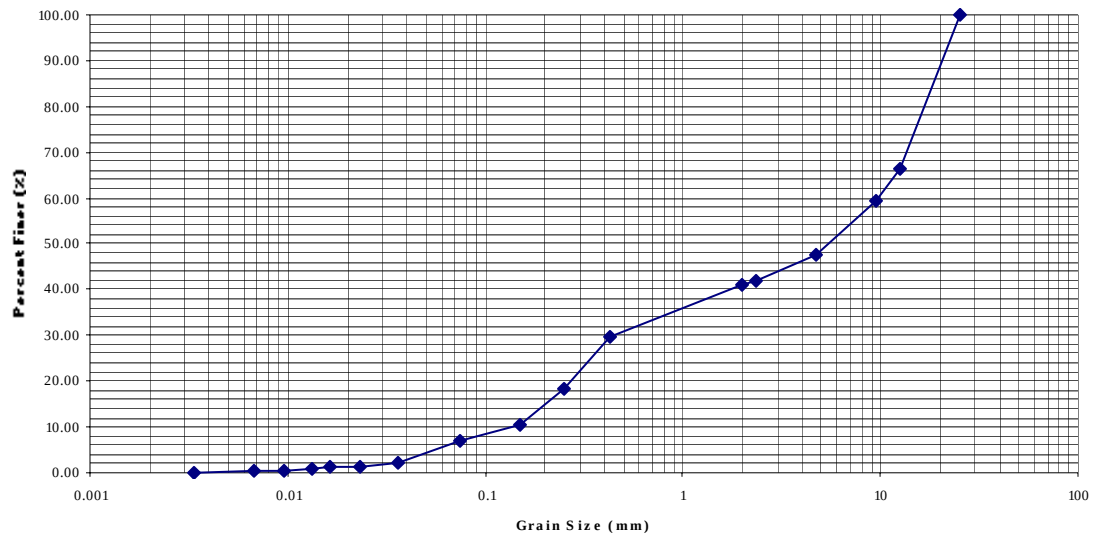
Particle Size Distribution for RUSSE000.9BT



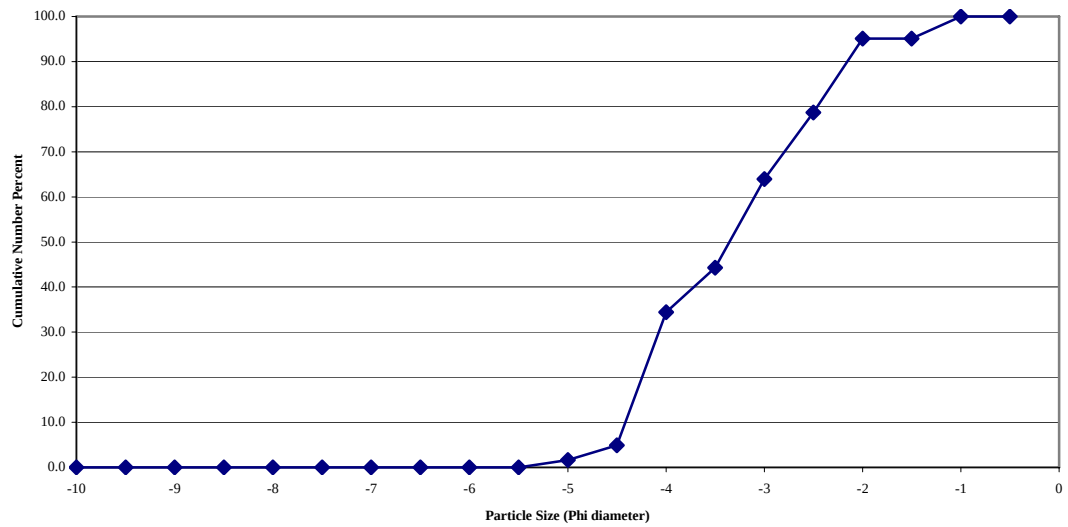
RUSSE000.9BT Cumulative Frequency Plot



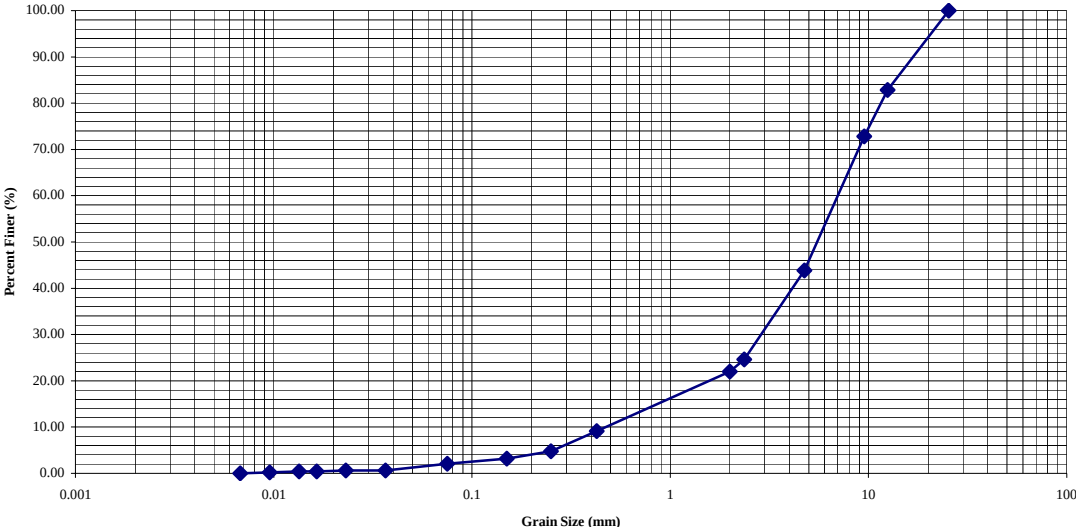
Particle Size Distribution for RUSSEL000.3CL



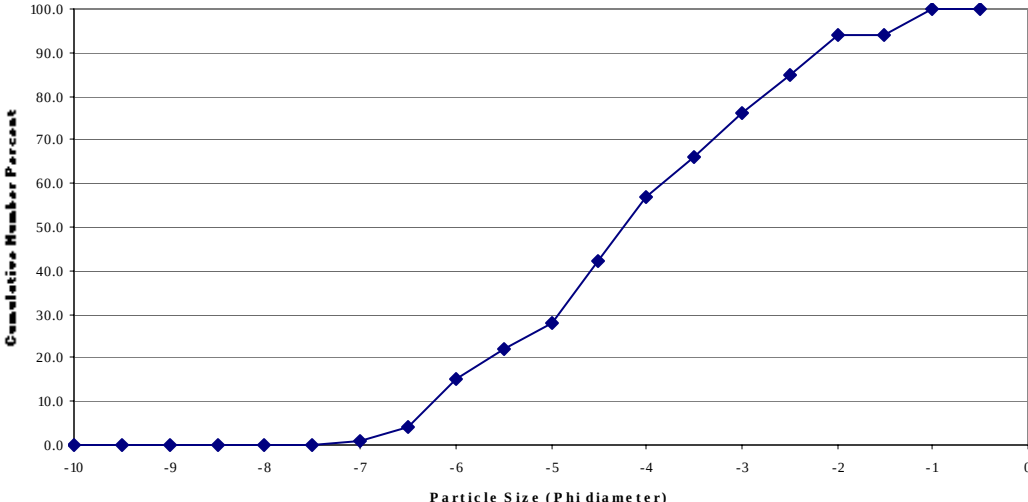
RUSSEL000.3CL Cumulative Frequency Plot



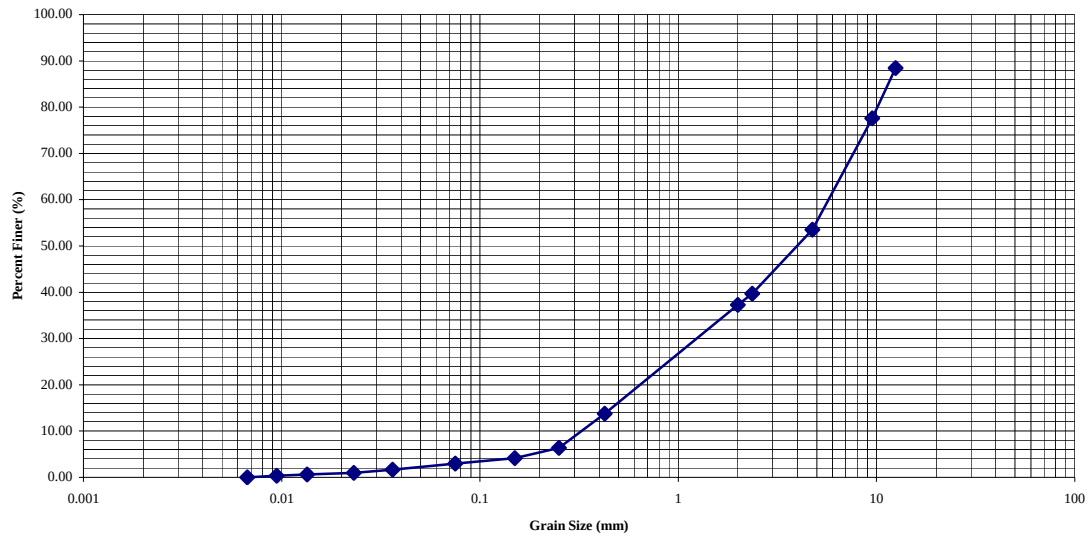
Particle Size Distribution for RUSSEL003.0CL



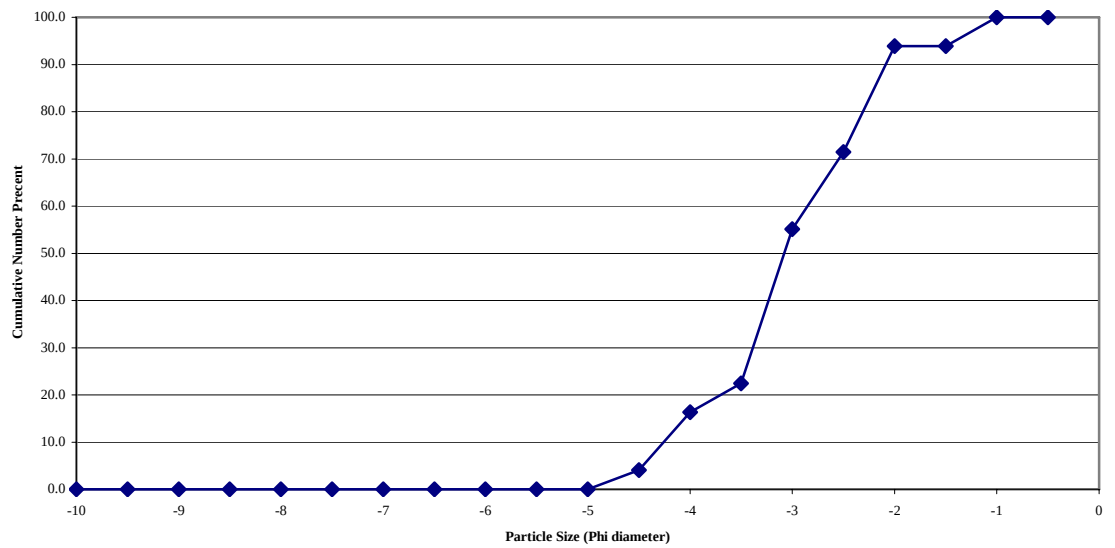
RUSSEL0003.0CL Cumulative Frequency Plot



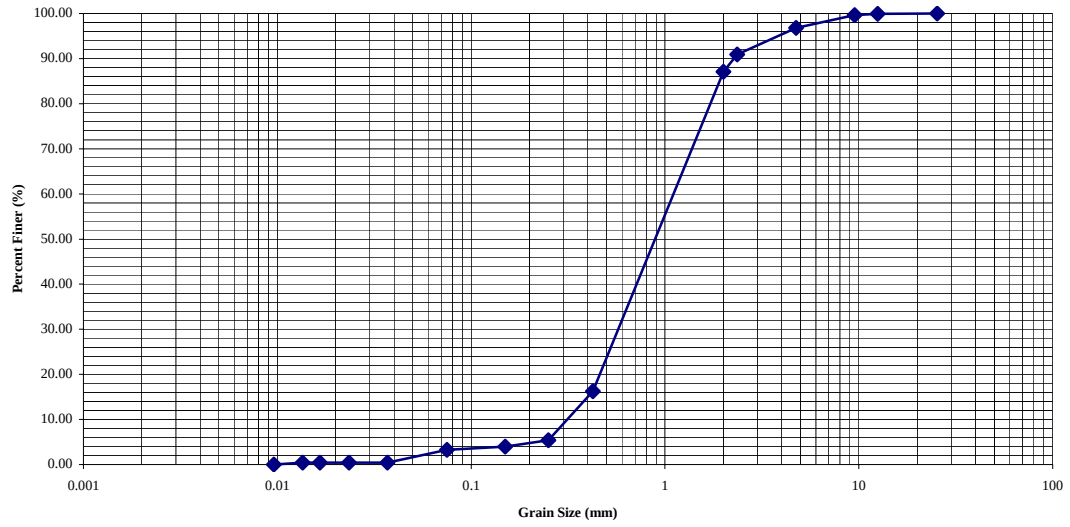
Particle Size Distribution for SFLSE001.7MM



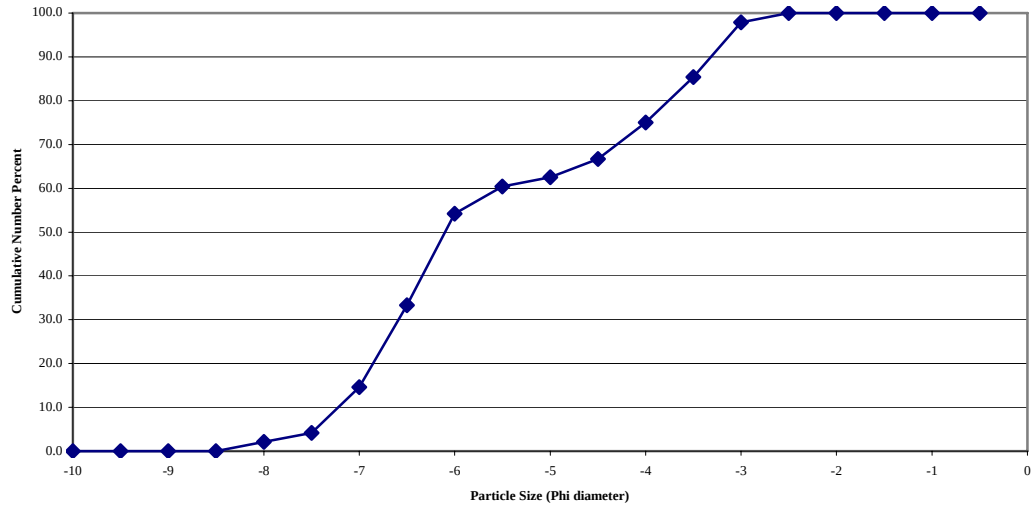
SFLSE001.7MM Cumulative Frequency Plot



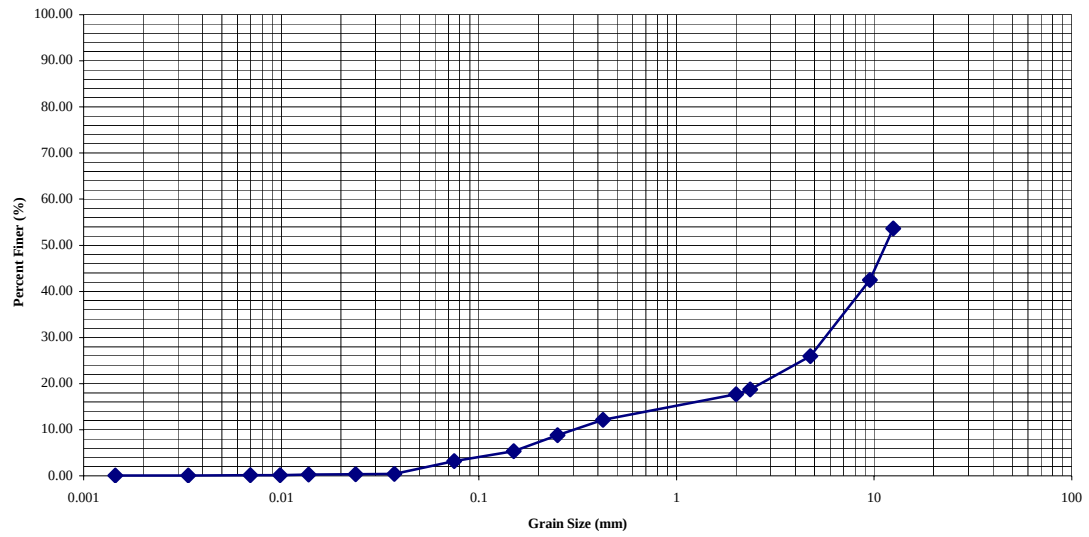
Particle Size Distribution for SINKI003.2GE



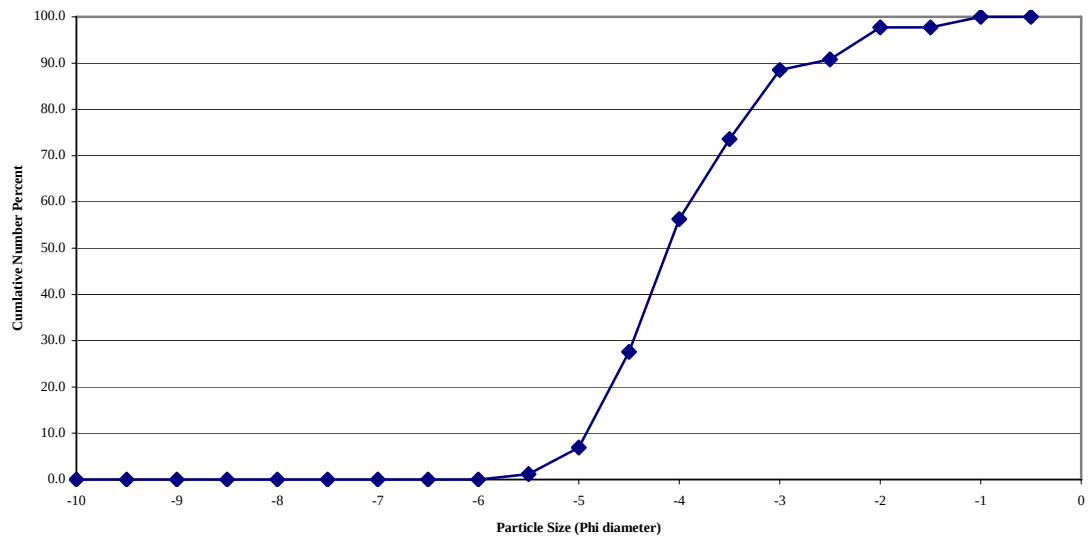
SINKI003.2GE Cumulative Frequency Plot



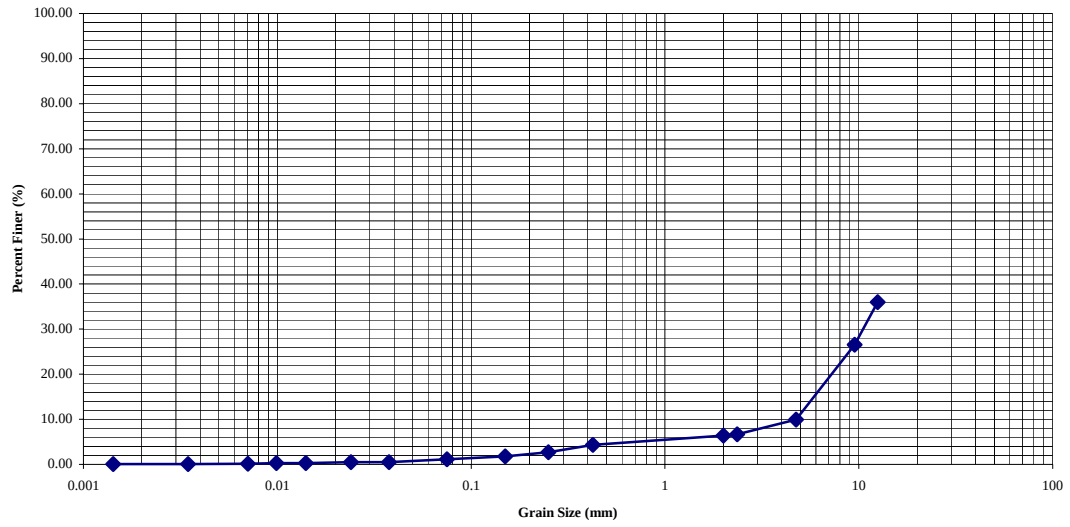
Particle Size Distribution for STEEK000.7LO



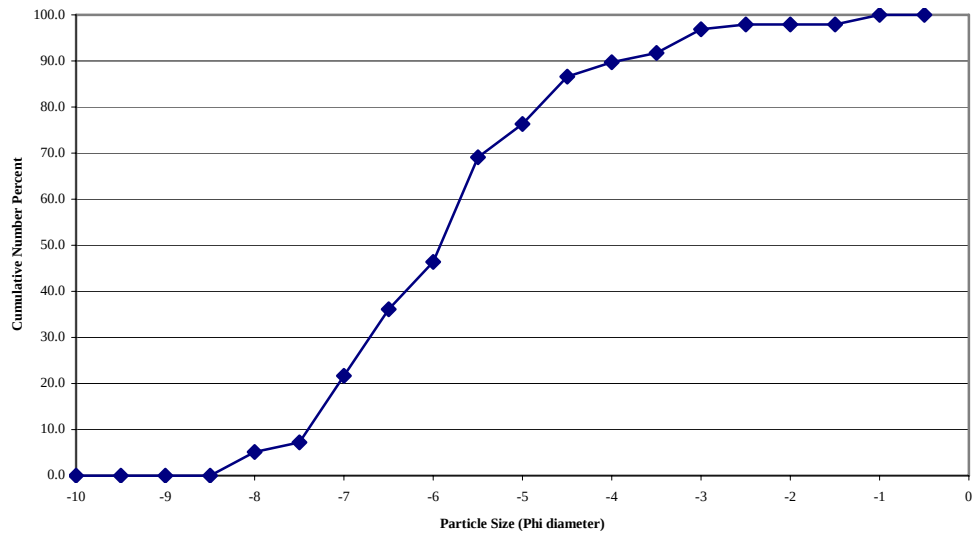
STEEK000.7LO Cumulative Frequency Plot



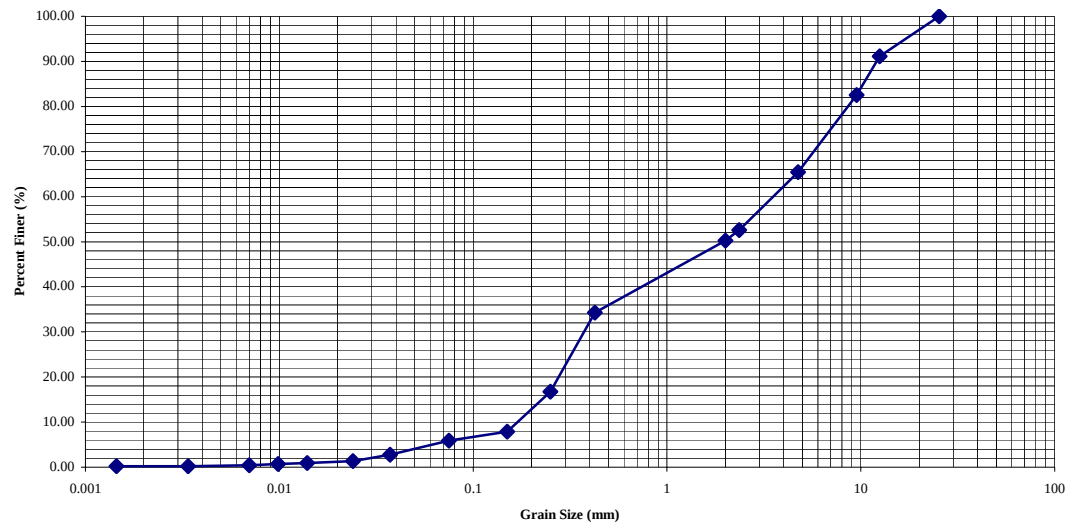
Particle Size Distribution for STONY000.3CT



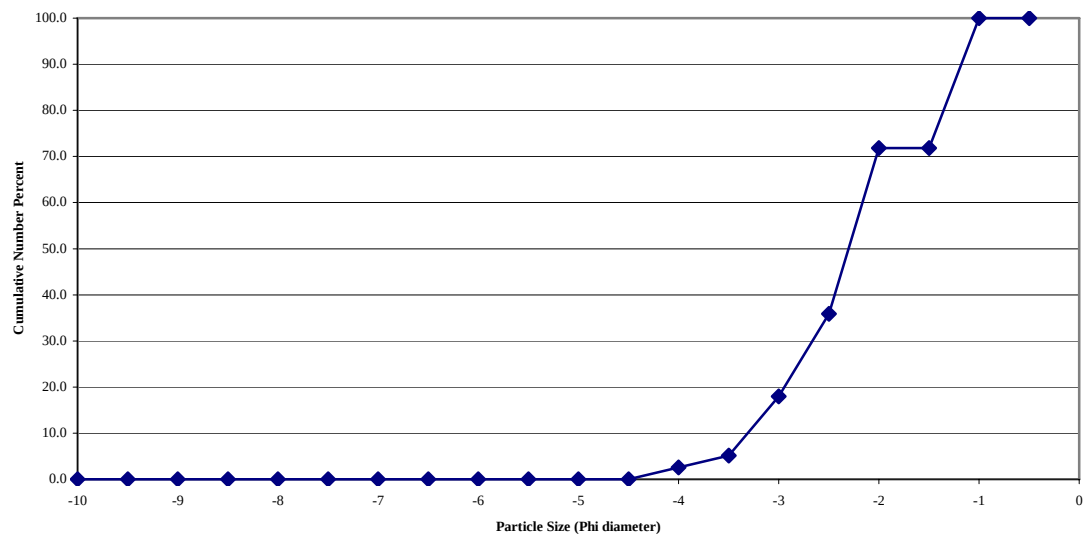
STONY000.3CT Cumulative Frequency Plot



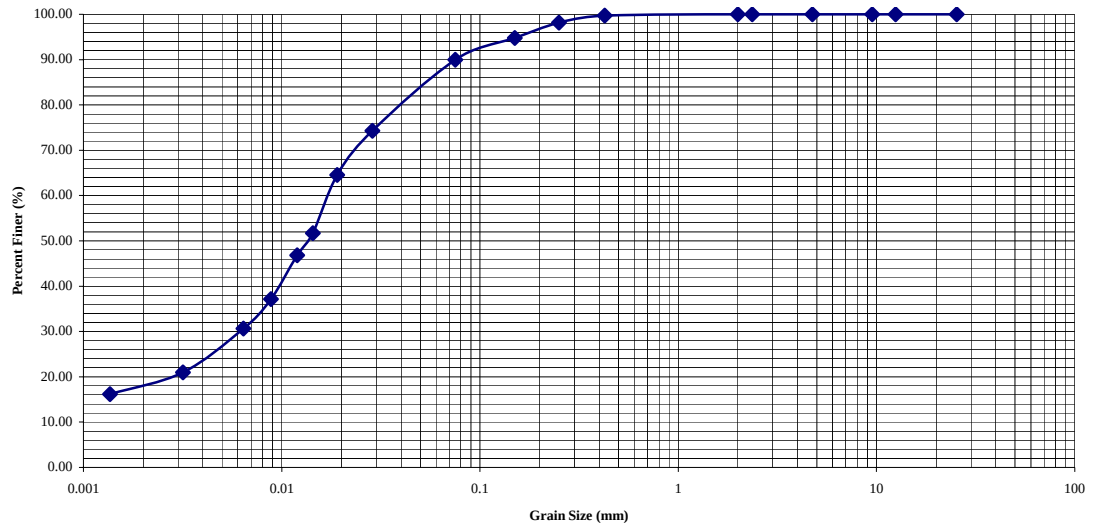
Particle Size Distribution for SWEET009.3LO



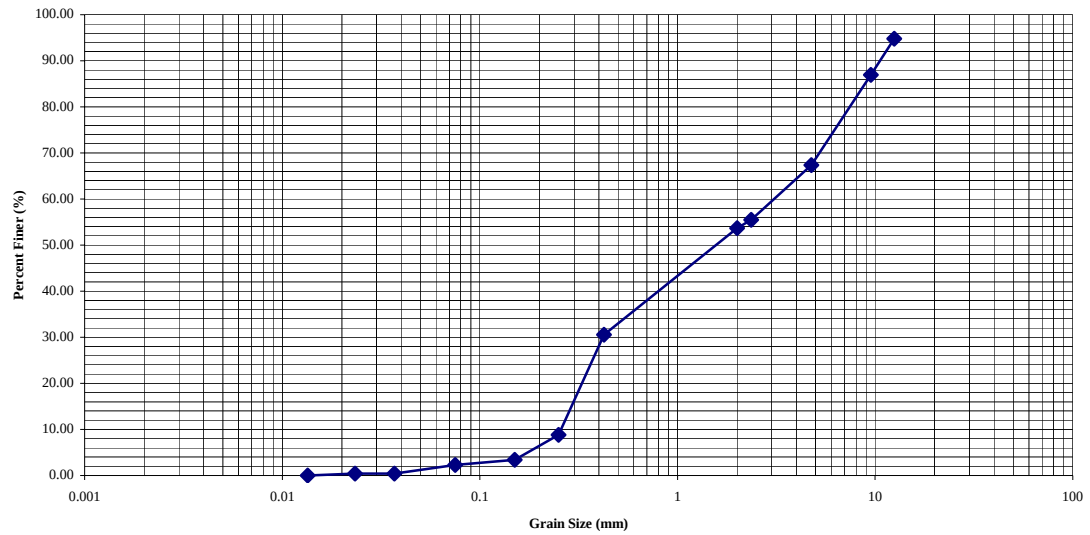
SWEET009.3LO Cumulative Frequency Plot



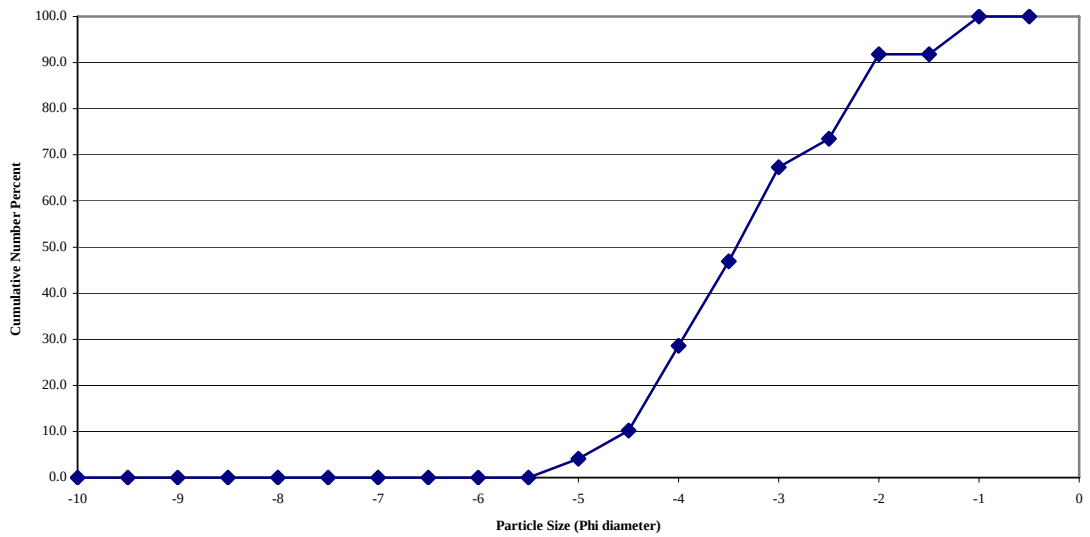
Particle Size Distribution for SWEET017.3MO



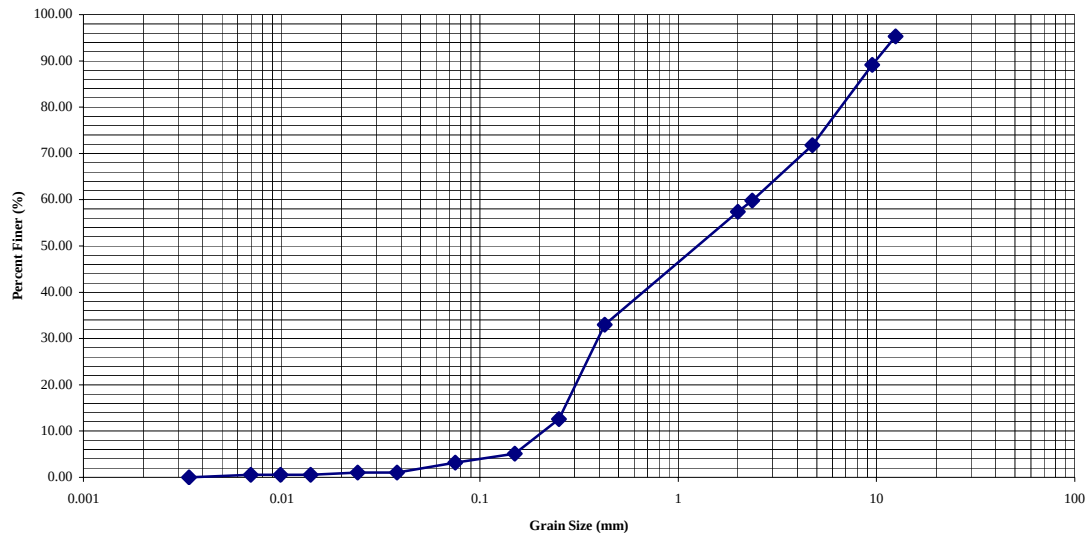
Particle Size Distribution for SWEET019.4MO



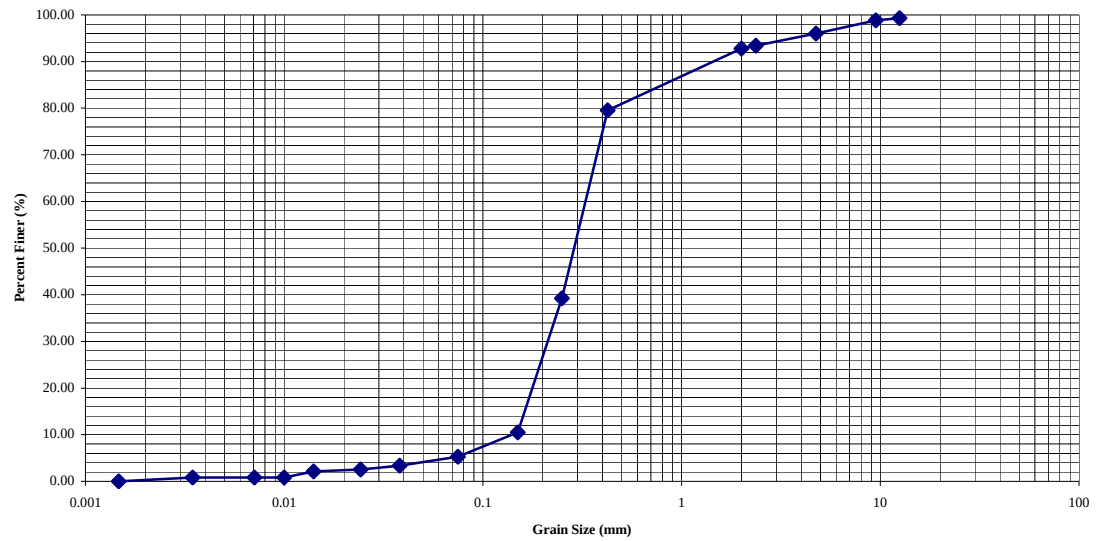
SWEET019.4MO Cumulative Frequency Plot



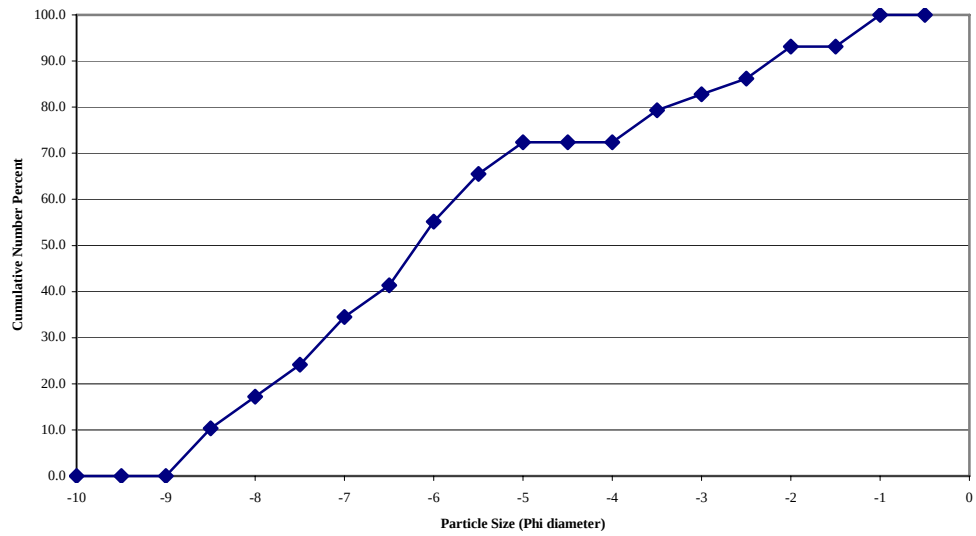
Particle Size Distribution for SWEET023.3MO



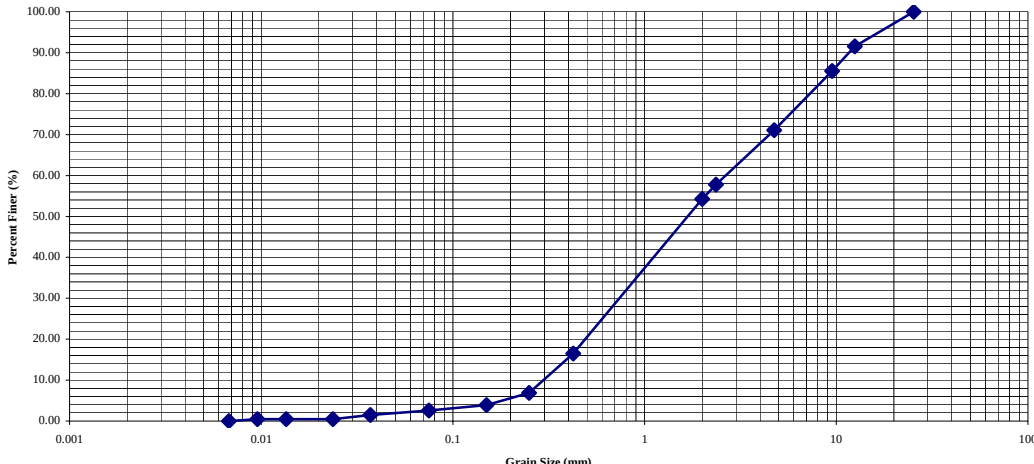
Particle Size Distribution for THOMP000.6MM



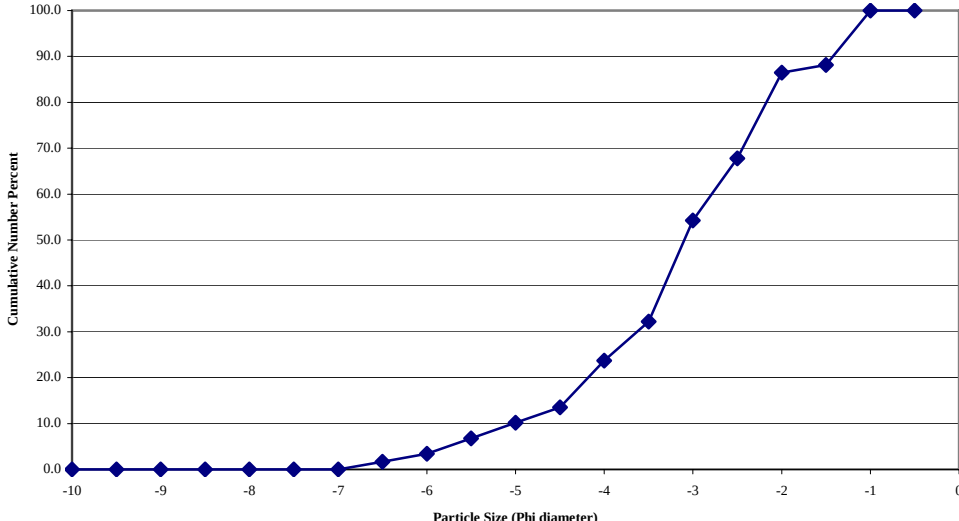
THOMP000.6MM Cumulative Frequency Plot



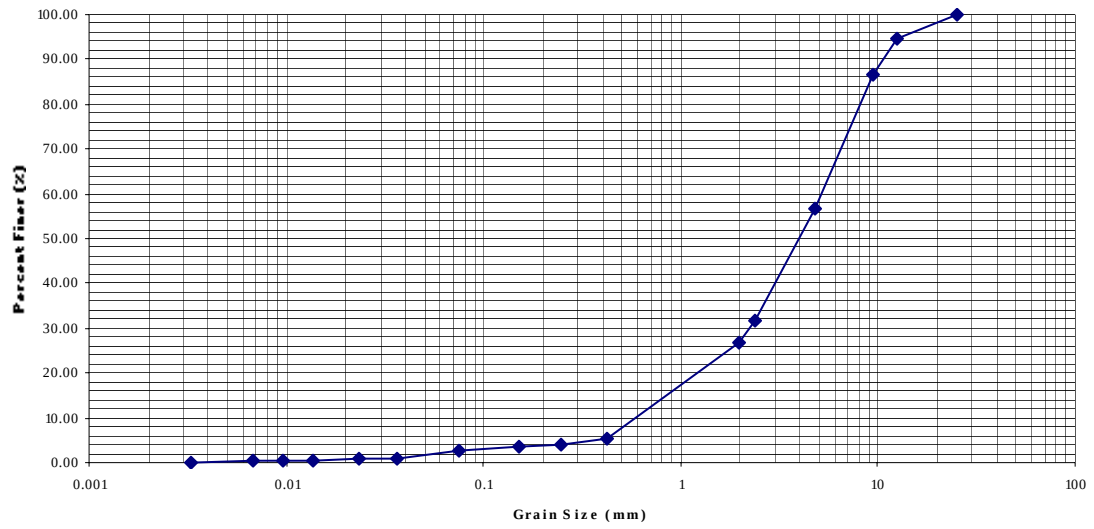
Particle Size Distribution for TOWN000.5LO



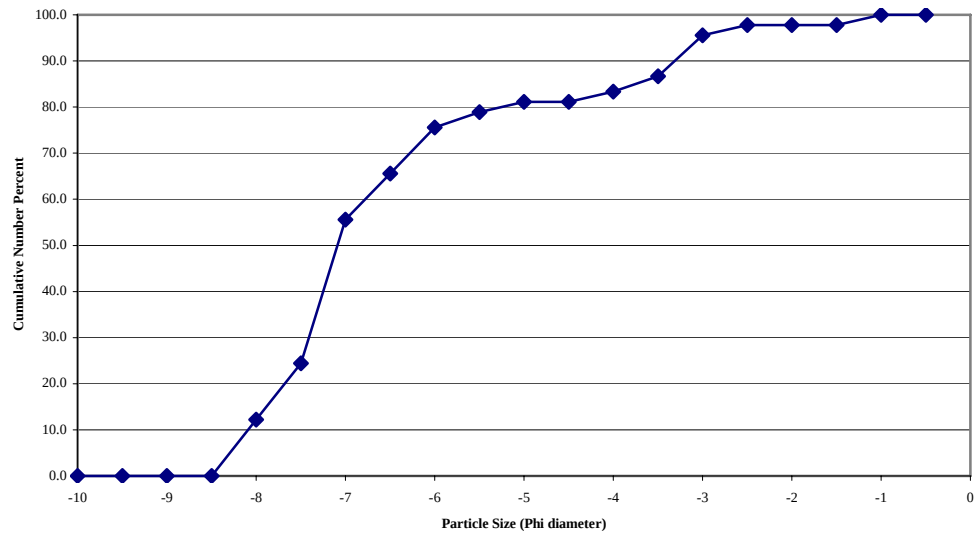
TOWN000.5LO Cumulative Frequency Plot



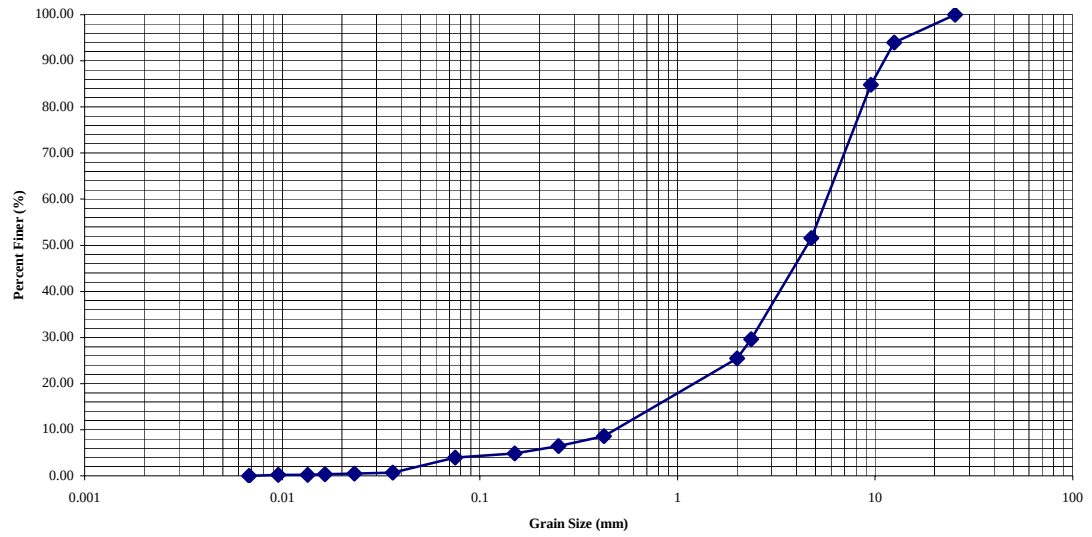
Particle Size Distribution for TOWN002.1LO



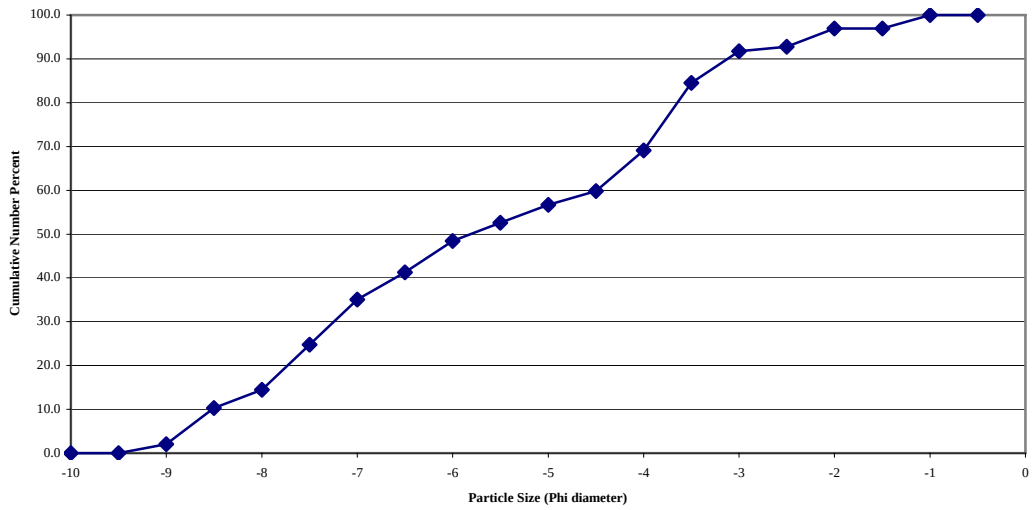
TOWN002.1LO Cumulative Frequency Plot



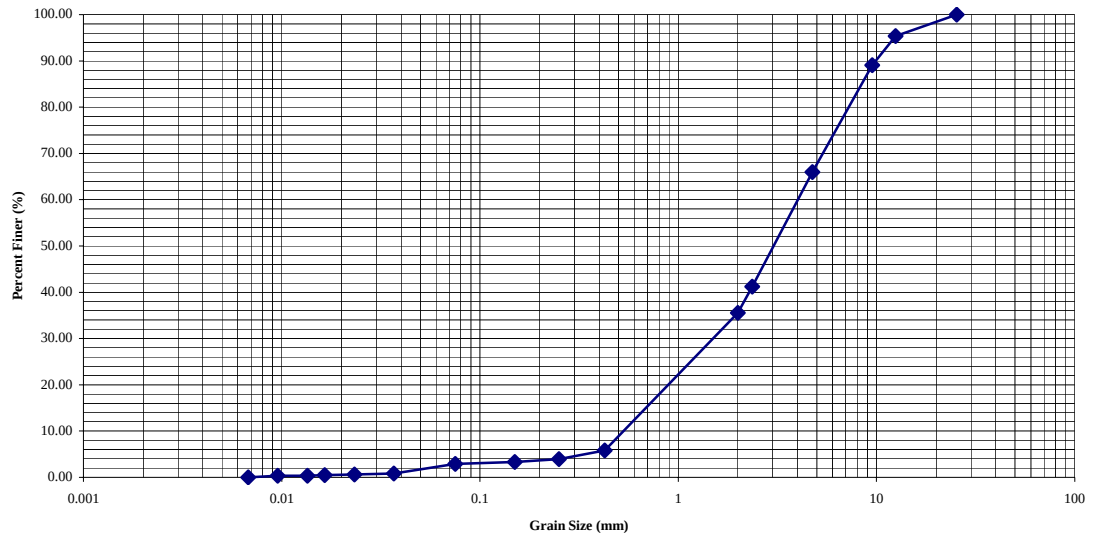
Particle Size Distribution for TURKE000.5HK



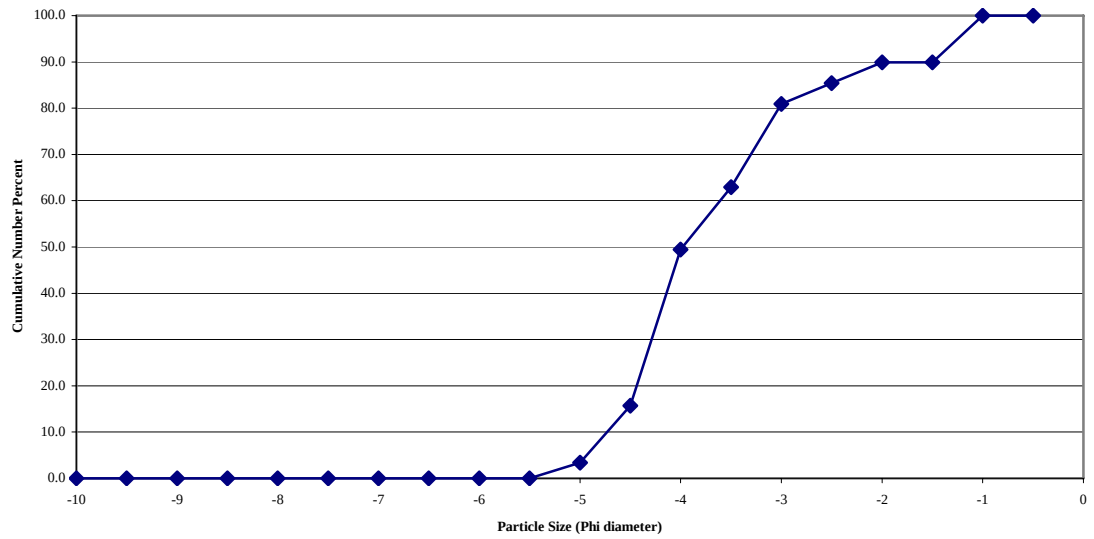
TURKE000.5HK Cumulative Frequency Plot



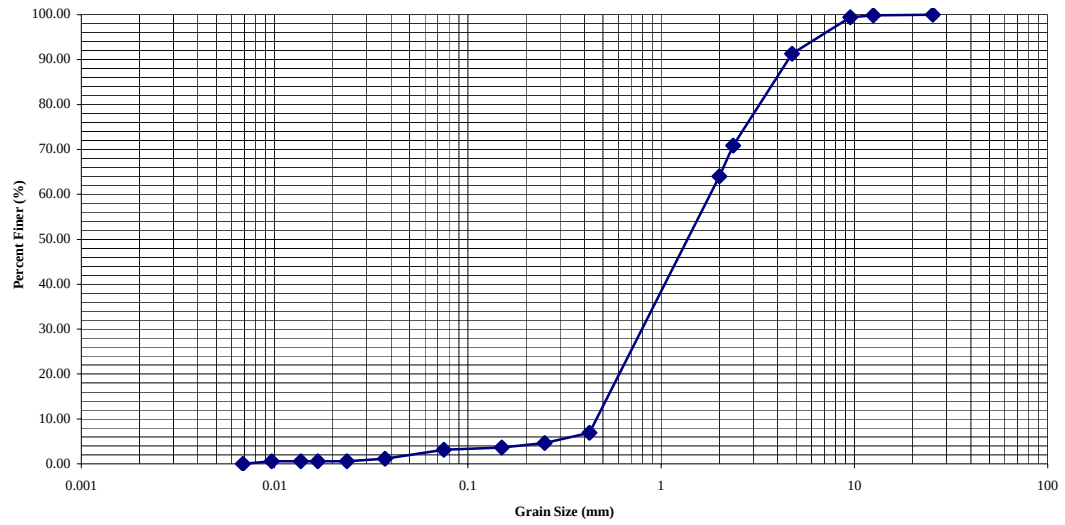
Particle Size Distribution for WFPAN000.1HK



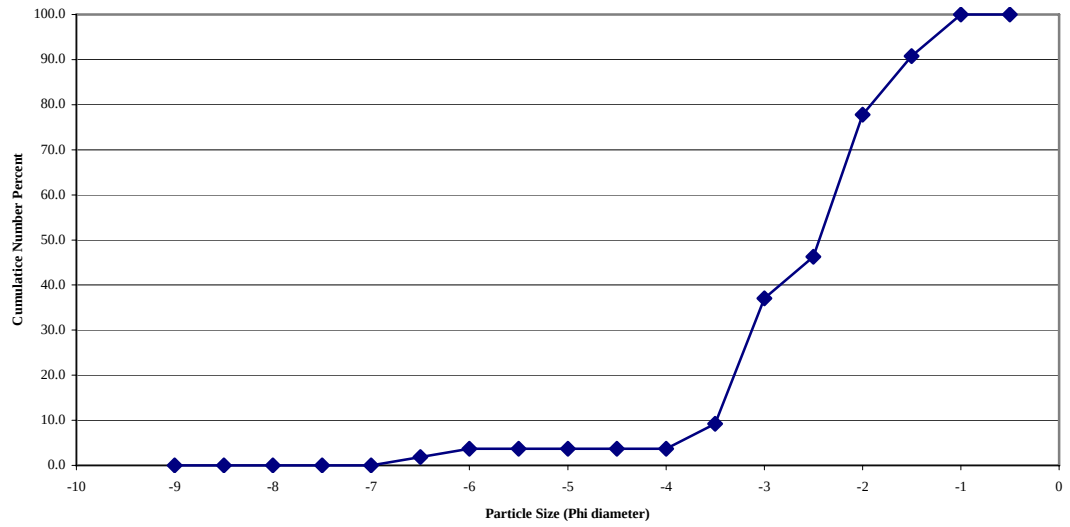
WFPAN000.1HK Cumulative Frequency Plot



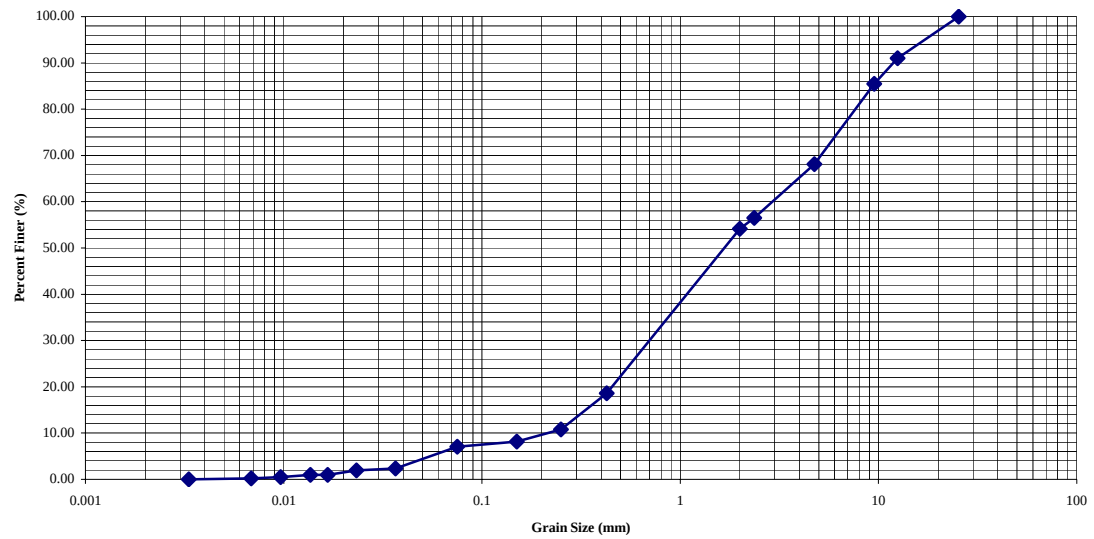
Particle Size Distribution for BEAVER CR @ HALLS PARK



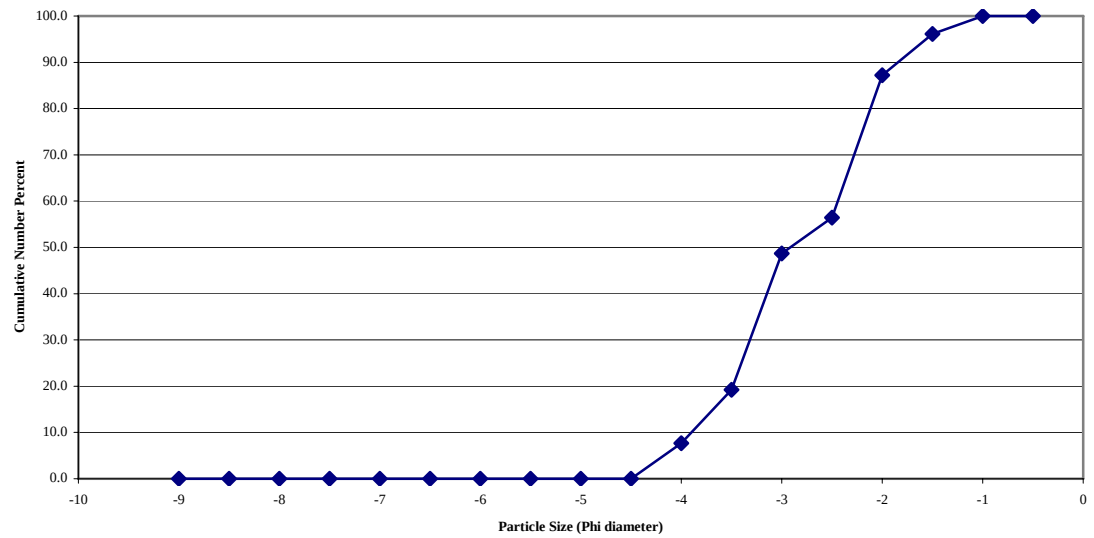
Beaver CR @ Halls Park Cumulative Frequency Plot



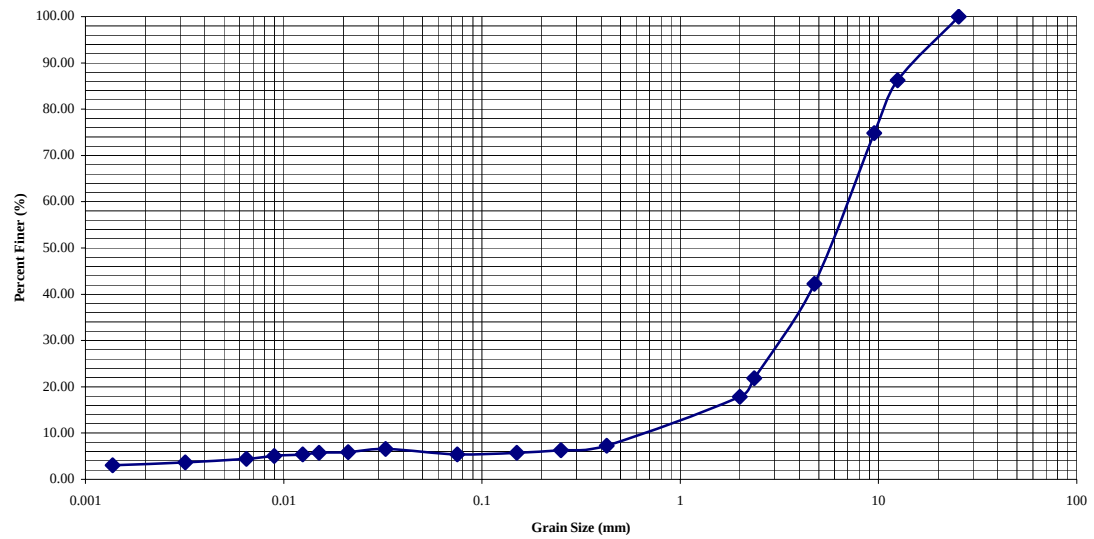
Particle Size Distribution for BEAVER CR @ BEELER RD



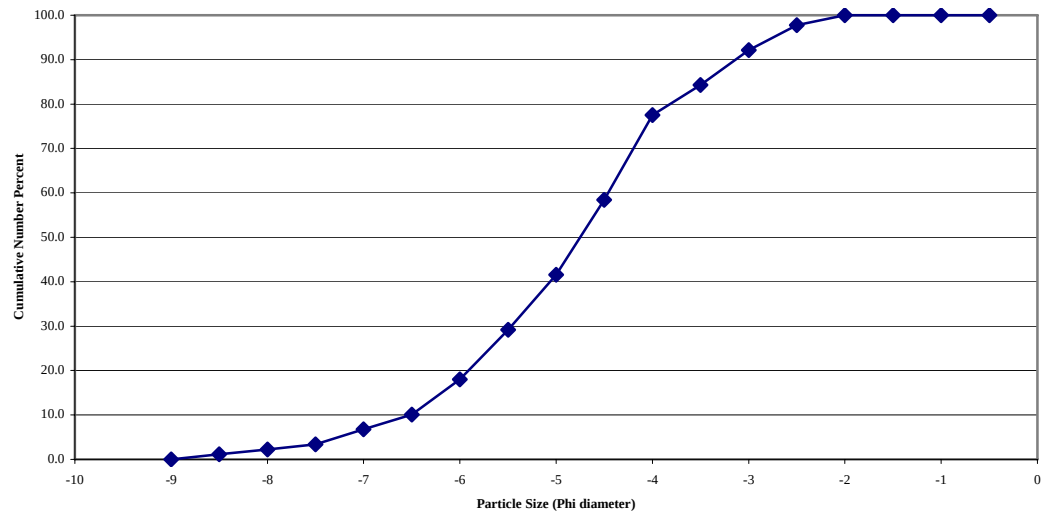
Beaver CR @ BEELER RD Cumulative Frequency Plot



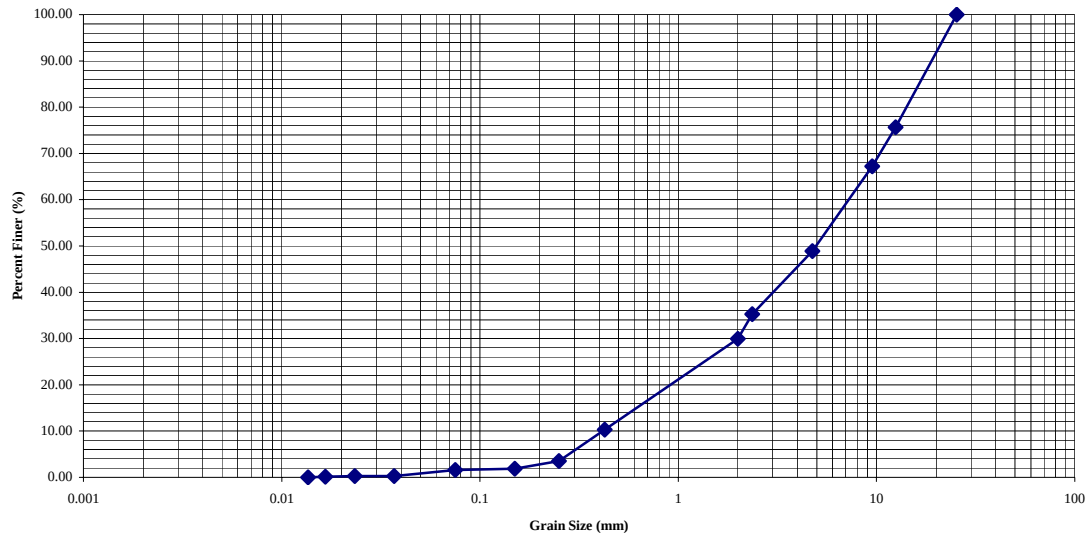
Particle Size Distribution for Beaver CR @ BROWN GAP



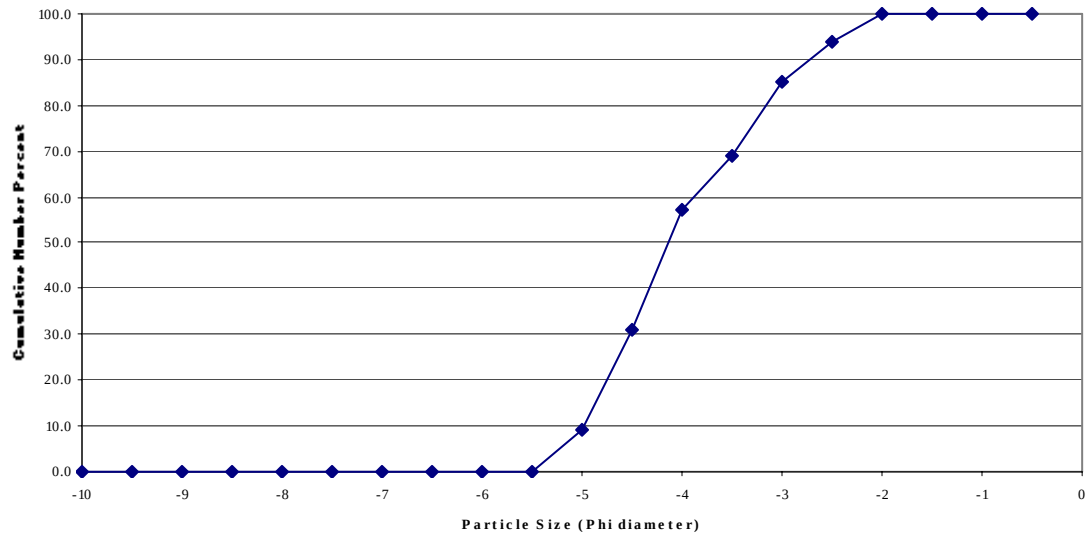
Beaver CR @ BROWN GAP Cumulative Frequency Plot



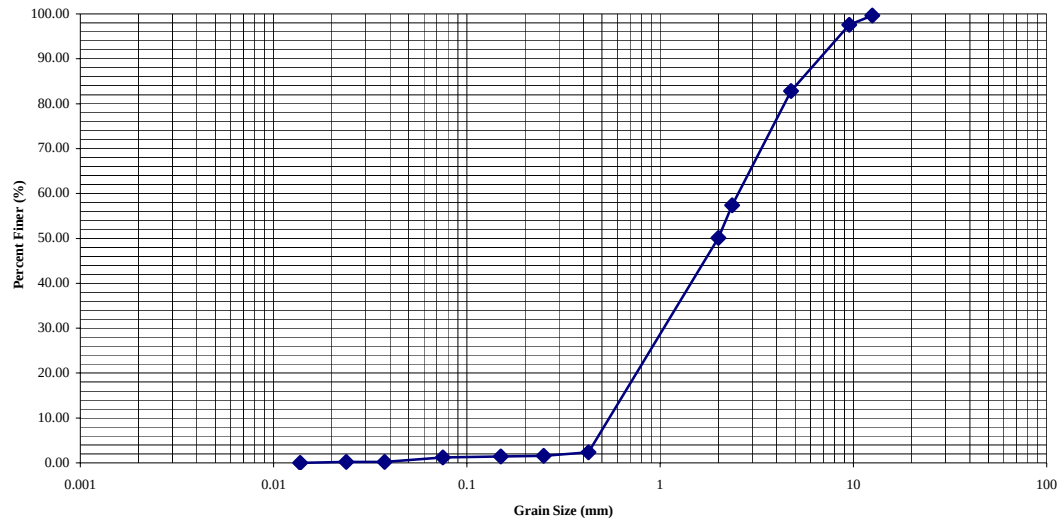
Particle Size Distribution for WILLOWFORK



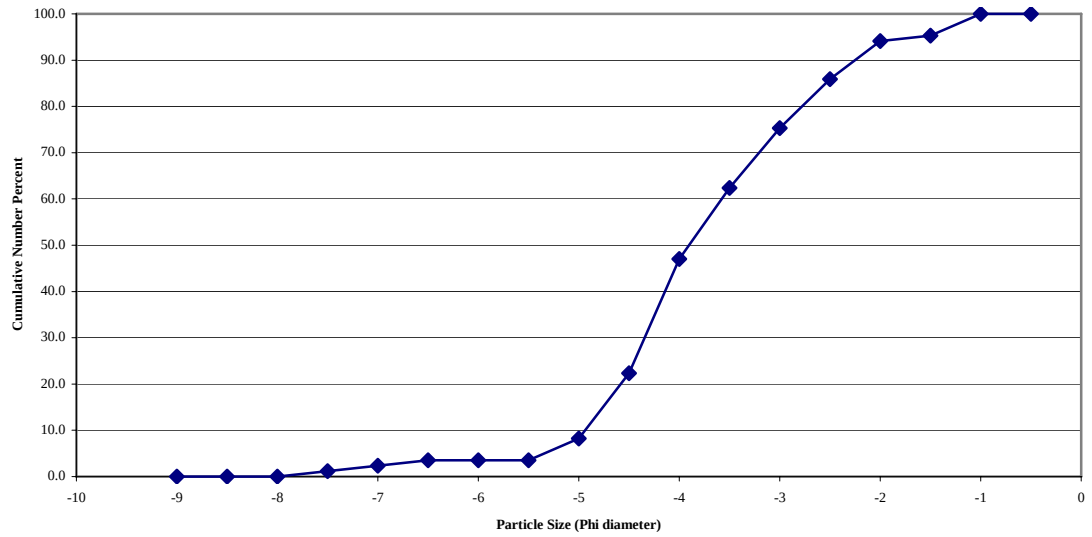
WILLOWFORK Cumulative Frequency Plot



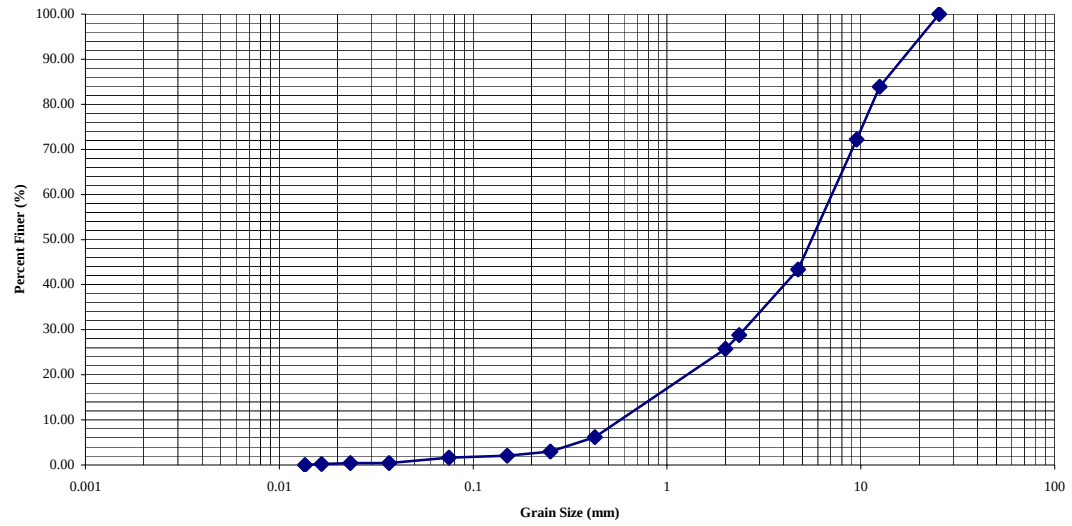
Particle Size Distribution for Beaver CR @ HINES BR



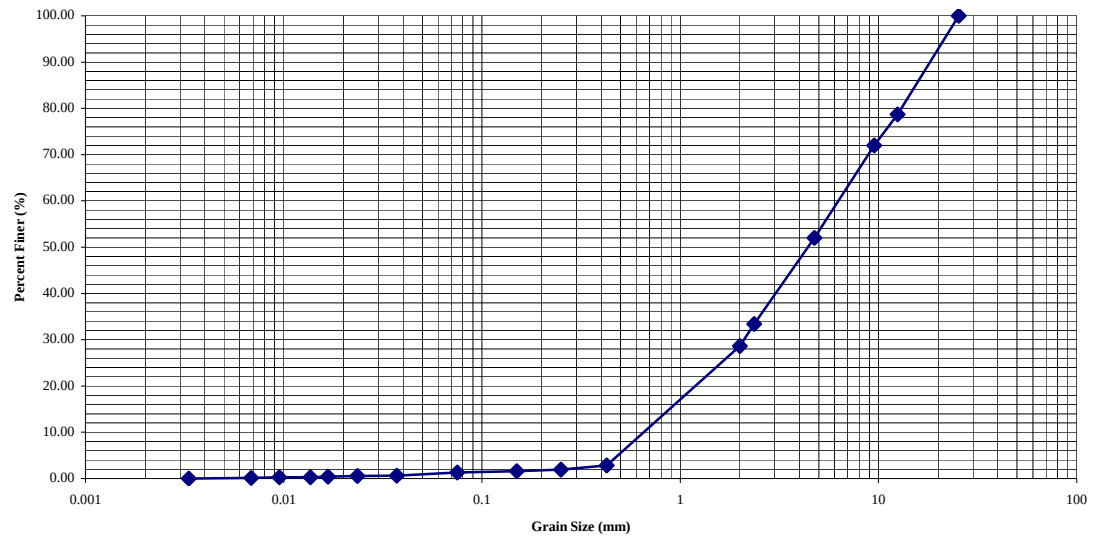
Beaver CR @ HINES BR Cumulative Frequency Plot



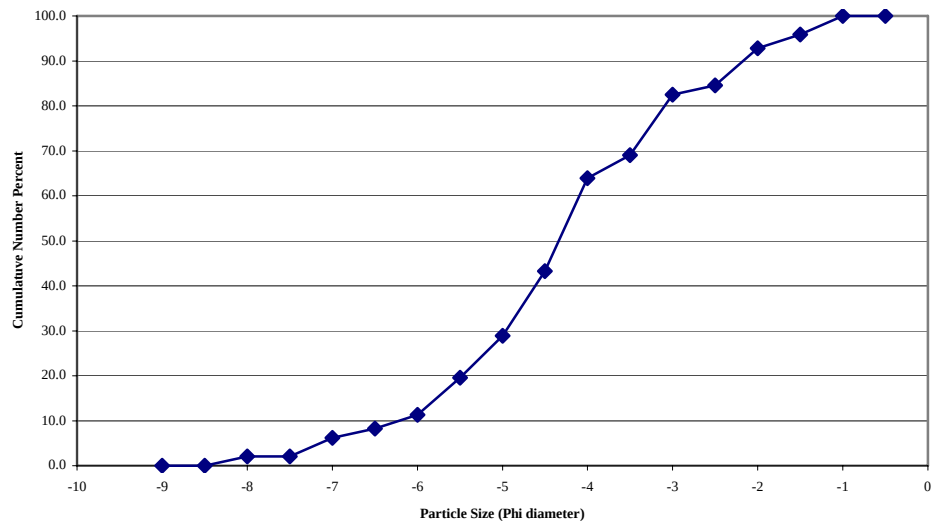
Particle Size Distribution for KNOBFORK



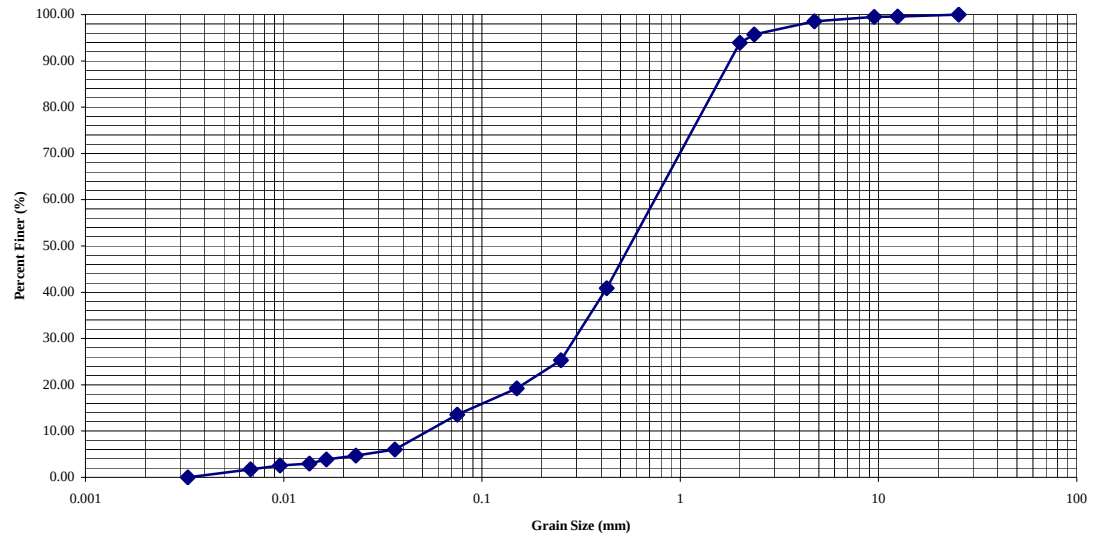
Particle Size Distribution for COX CR @ Brown Gap



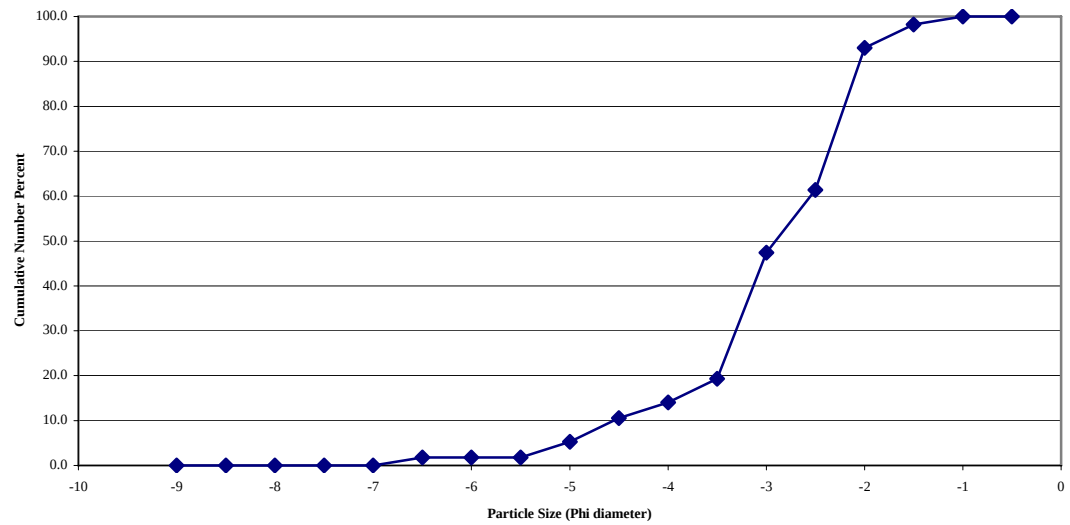
COX CR @ Brown Gap Cumulative Frequency Plot



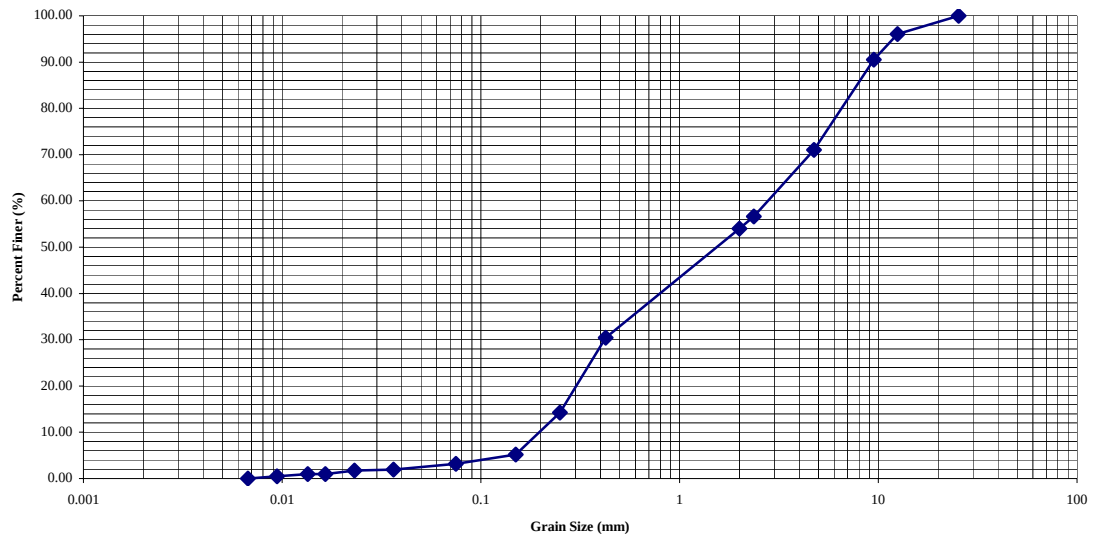
Particle Size Distribution for Beaver CR @ STORMER RD



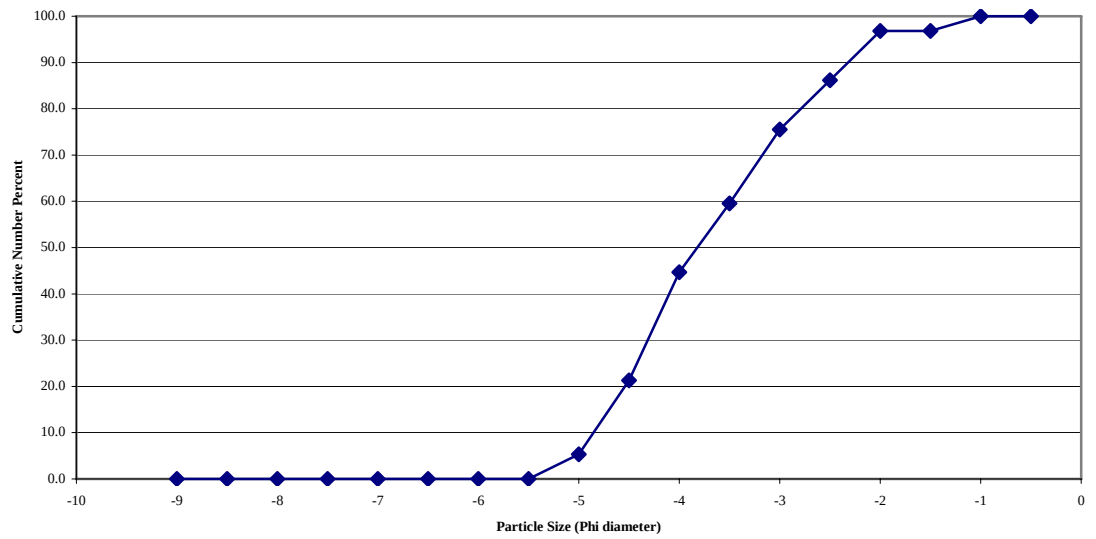
Beaver CR @ STORMER RD Cumulative Frequency Plot



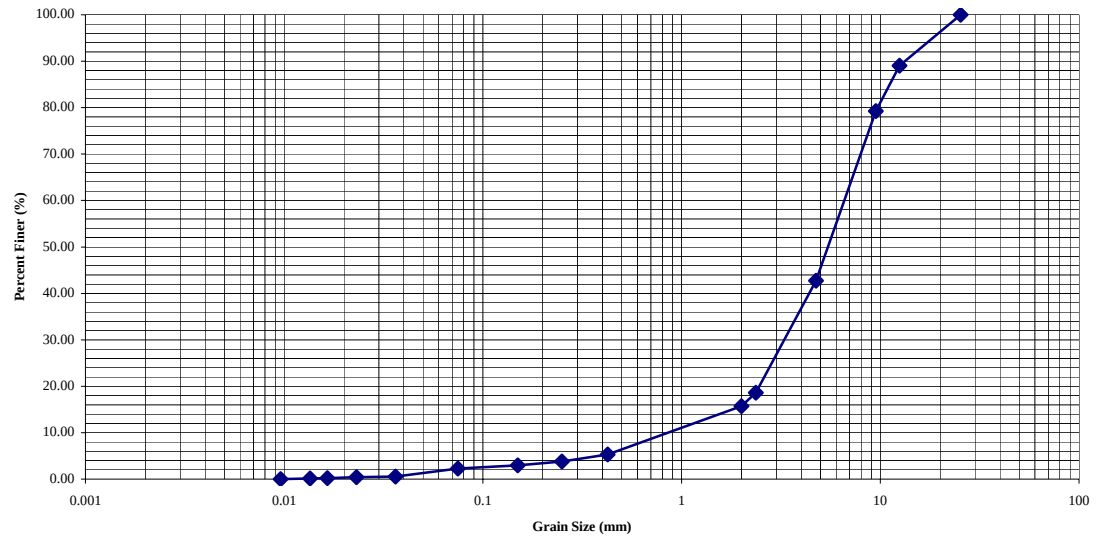
Particle Size Distribution for Beaver CR @ CLINTON HWY



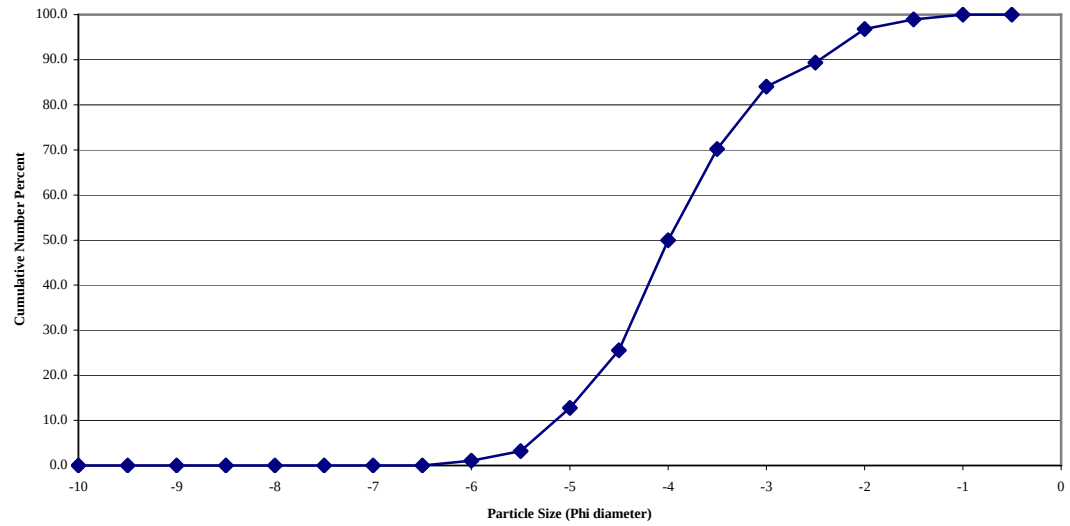
Beaver CR @ CLINTON HWY Cumulative Frequency Plot



Particle Size Distribution for MEADOWCREEK



MEADOW CREEK Cumulative Frequency Plot



Vita

Kelley H. Williams was born in Lafayette Louisiana as Kelley D. Haerer. She began her higher education in Colorado and later transferred to the University of Tennessee to pursue a bachelor's degree in Civil Engineering. While earning her degree she married Tony Williams and hence became Kelley H. Williams. Through the support of her wonderful husband and entire extended family she earned her degree with honors in May of 2004. She entered directly into graduate school, and through the help of her major professor, thesis committee, and the incredible support of her husband and family she will earn her Masters of Science degree in of Environmental Engineering (Water Resources) in December of 2005.