

# **Comparison of the flow hydraulics and bedload grain size distribution of the East and West Forks of Ashland Creek, Southwestern Oregon**

**Aleece M. Richter**

## **Abstract**

Soil erosion has tremendous impacts on many river systems throughout the United States by contributing sediments and creating siltation issues. Complex interactions between topography, soil types, climate, and land use in the Ashland Watershed, located in Southern Oregon, are leading to large accumulations of sediment in Reeder Reservoir - the municipal water supply for Ashland, OR. One of the goals of the multiagency stewardship project, Ashland Forest Resiliency (AFR), is to protect the clean water and aquatic habitat currently provided by the Ashland Watershed by reducing hazardous fuels and increasing forest resiliency. This project aimed at quantifying bedload grain size distributions along the Ashland Creek as a preliminary step in determining potential hot spots of landscape-level erosion that contributes sediments to the reservoir. The approach includes sampling key locations along the creek in the upper watershed, below the reservoir, and above the confluence of Ashland Creek and Bear Creek. The primary emphasis is on characterizing the finer grain sizes along the course of the creek since this material has a potentially greater impact on water quality treatments. As expected, results indicate that there is a trend for finer material in the lower East and West Fork and for coarser material in the upper portion of the watershed. There is an indication of smaller material in the East Fork and larger material in the West Fork. These findings create a baseline assessment of the sediment size distribution in the Ashland Watershed in relation to basic flow hydraulics and channel geometry parameters and can be incorporated into future assessments of sediment entrainment, transport and deposition as they pertain to water quality treatments.

## **I. Introduction**

The City of Ashland, Oregon utilizes drinking water from Reeder Reservoir within the Ashland Watershed. In the 20<sup>th</sup> century, approximately 10% of the watershed was affected by logging, road building, and the creation of the current Ashland Ski Area. In 1955 the watershed was placed under “multiple use” management by the Forest Service. A portion of the watershed underwent logging between the years 1958 and 1965. About 40-50 miles of road was built during

that time, and between 1960 and 1964 Mt. Ashland Ski Area was developed on 180 acres within the watershed.

In general, Reeder Reservoir experiences sedimentation build up, particularly after a heavy rainfall event (Acklin, P. *personal communication*). Dredging is done to protect storage capacity and the sediment is dispersed in settling ponds to trap the silt and gravel during sluicing. However, some of the material has adverse effects for the spawning of fish due to some of the sediment being put into Ashland Creek from the sluicing process (Alsing, A. *personal communication*).

The climate in the Ashland Watershed is Mediterranean with a mild winter and an average rainfall of approximately 19.3 in/yr (National Climate Data Center 2009). During the summer months of the dry season there are high temperatures among an intensely managed forest. The slope within the watershed is relatively low in some places, but tends to be very steep throughout the area and particularly in the headwaters and upper sections of the watershed. The foundation of the soil is granitic, thus tending to exhibit erosive qualities (Badura and Jahn, 1977). The high slopes and largely weathered granitic substrate create conditions for high amounts of sediment to be removed and transported through the system, creating water quality issues.

Historically, wildfires were common in the Ashland Watershed, which could have impacted Reeder Reservoir and altered its water quality. Before 1860 the watershed experienced very regular fires. It was during this time that the fires returned in seven year intervals on one site and on two other sites the fires took place in thirteen and seventeen year intervals ( Skinner, unpublished data). Native Americans did increase the frequency of fire, but lightning triggered fires as well. After 1860 the frequency of fires declined. Despite a management policy of fire suppression, notable large fires occurred in 1910, 1959, 1973, and most recently the Siskiyou Fire in 2009 (Metlen, 2011). Wildfire effects vary due to daily weather conditions, fuel moisture, and patterns of previous burns that change fuel loading and fuelbed structure.

Forests have an important role regarding water quality and wildfires can have a negative impact on soil. Depending on the soil type, sediment can be easily eroded compared to other soil types (Badura and Jahn, 1977). Manipulating a forest's canopy can create the surface of land to become more susceptible to the direct impact of raindrops and therefore, overland flow (Church, 2009). Trees, shrubs, other vegetation, and their roots reduce the amount of runoff from rain and

snow, and purify the water as it percolates through the soil. Also, forests decrease erosion rates and reduce the sediment entering into streams and rivers. It has been thought that a burned area is the most susceptible to fluvial adjustments. Fires remove vegetation, thus altering soil properties and increase runoff and sediment production in a basin impacted by fire (Edwards, 2007). That is why the AFR project is taking action to prevent a catastrophic wildfire from negatively impacting the soil. However, the impacts of these fuel treatments, by the AFR, need to be monitored as well to ensure that the removal of vegetation and loosened soil being deposited into the streams does not cause water quality issues.

Sediment is delivered to streams through two geomorphological processes: chemical and physical weathering. Chemical weathering involves the alteration of original material, therefore creating new material. Primary chemical weathering processes that are important in the Ashland Watershed include hydration, the breaking up of feldspar material into clays and silica. An example of this would be when the mineral Anhydrite changes to Gypsum. Carbonation and solution is the process of minerals dissolving into solution. An example of this would be marble and limestone exposed to carbonic acid. Lastly, hydrolysis takes place when minerals combine chemically with water (Ritter, 2002).

Physical weathering involves the collapse and disintegration of parent material and the diminution of grain size. Rock breaks down as stress is put on zones of weakness (Ritter, 2002). An example of physical weathering with high occurrence in this region is the process of unloading, especially during high rainfall months. Unloading takes place when erosion releases pressure, causing expansion within the large mass of rock and eventually pieces of material are eroded away. A process called frost action takes place during the winter months when water expands/freezes inside cracks exposing rock by breaking it apart. Lastly, the process of thermal expansion causes rock to break apart into wedges when exposed to extreme heat caused by the sun, or a fire (Ritter et al., 2002).

There are several factors that create erosion. When vegetation is removed from the land's surface erosion is increased. This is frequently the case in a climate with annual amounts of high rainfall that impact erodible soil types. Rain-splash erosion can be destructive to soils and is increased when the soil surface is exposed to the impact of the rain creating potential rills and gullies (Ritter, 2002). Soil compaction can also increase runoff production of soils. Often, this is

created by human actions. Using equipment on the land's surface can create compaction of soil and allow water not to permeate through the soil but to collect and run off the surface. Even though the AFR project is using low impact tools during treatments, soil compaction could still be an issue (Ashland, 2010).

The Forest Service is collaborating with The Nature Conservancy, Lomakatsi Restoration Project, and the City of Ashland on the Ashland Forest Resiliency Project (AFR). This project also fosters community involvement, building trust among stakeholders. Primary goals of AFR are to reduce fuel accumulations while still maintaining biodiversity (Conroy, 2009). The AFR project will conduct fuel reduction treatments on an estimated 7,600 acres on Forest Service land (Conroy, 2009). Treatments involve thinning the smaller trees and prescribed underburning within the watershed. These treatments are important because fire has the potential to alter the watershed and its water quality (Conroy, 2009).

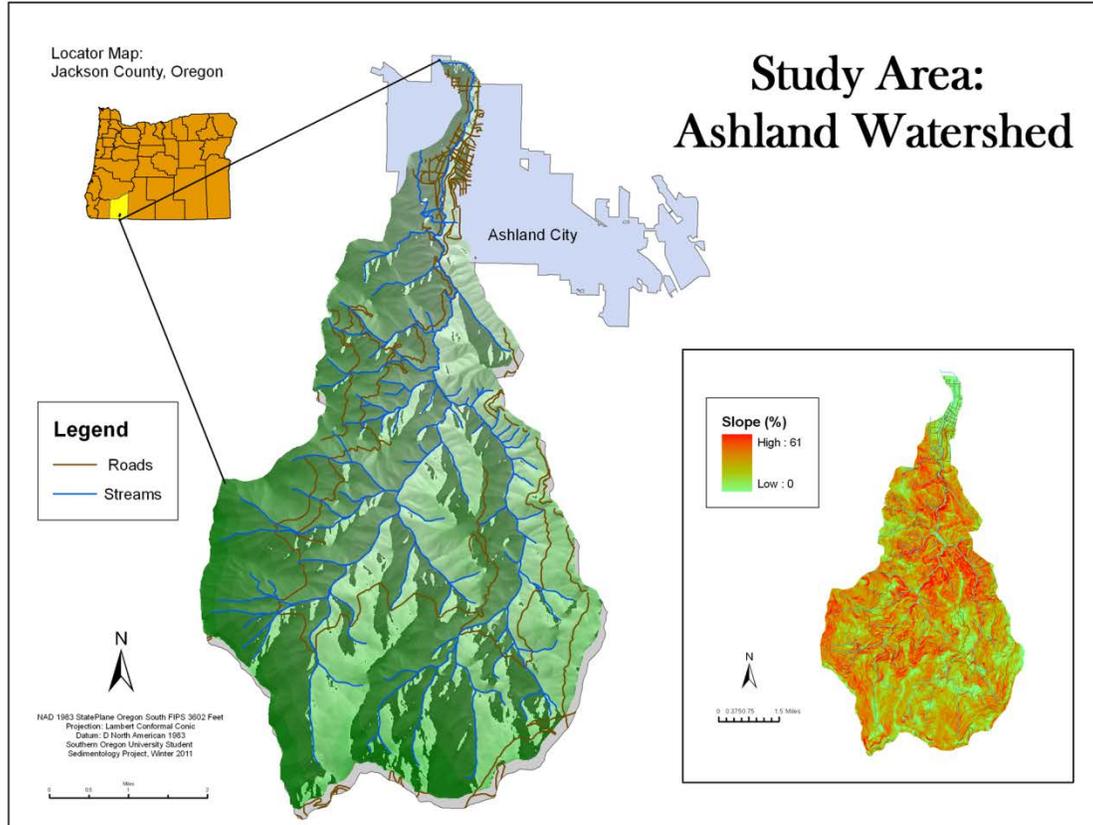
Sediments hold minerals which can alter the water quality treatments, thus understanding the link between forest thinning and other management practices and water quality is important for effective management of this water supply. The EPA has a set turbidity standard of not more than 1 Nephelometric Turbidity Unit (NTU) for drinking water. This turbidity standard is in conjunction with the Total Maximum Daily Load (TMDL) Program which states that drinking water can contain a specific amount of a pollutant and still meet the federal water quality standards. Also, the Clean Water Act of 1972 was established to protect interstate and intrastate waters. Turbidity can create problems with water quality because toxic chemicals can attach to suspended particles. Furthermore, turbidity can hinder drinking water treatments. Therefore, it is important to establish whether the AFR forest treatment practices are differentially impacting sediment movement through the channels and increasing the suspended sediment in the water column, known as turbidity (Church, 2009; Cech, 2005).

Management actions associated with AFR and with the Mt. Ashland Ski Resort are designed to minimize impact on erosion rates and sediment in streams (Conroy, 2009). Due to possible impacts however, water quality is one of the main monitoring priorities in the AFR project (Metlen et al., 2012). The main objective of this project was to conduct an assessment of the spatial distribution of bedload grain size distribution along the length of Ashland Creek from the headwaters to the confluence of Bear Creek. This is part of an initial baseline assessment of

the channel morphology and bedload composition of both the West and East Forks of Ashland Creek aimed at understanding whether more sediment is being redistributed in the East Fork portion of the watershed (area where forest management practices are being conducted verses the West Fork drainage area where fire management practices are to be conducted in the future). The long-term goal will be to understand the impacts of the fuel treatments on water quality and to establish reference conditions of bedload composition before the planned extension of the Mt. Ashland Ski Resort. To understand the amount of sediment moved by the runoff, a future study will be completed of the connectivity between the hill slope and channel system in Ashland Creek (Pricope, 2009).

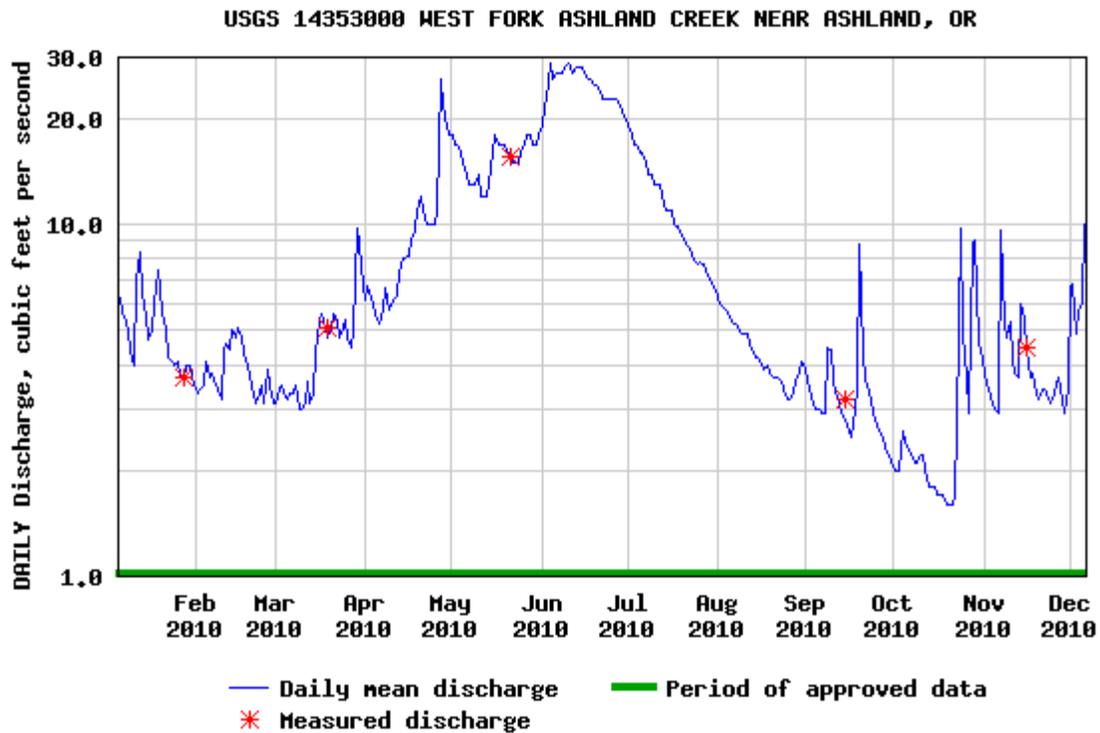
### **Study Area**

The study focused on bedload sediment sampling in the East and West Fork of Ashland Creek within the watershed. The soil type has a foundation of granite with other loam and sandy loam material, as well and quartz diorite. In some areas slope is moderate while other areas are steep to very steep (Badura and Jahn, 1977). This type of soil is highly erodible due to the bedrock being a granitic pluton which is very prone to disintegration. Below is an aerial view of the watershed showing the roads and steams as well as slope profile in percent- 0% being the lowest slope and 61% being the area with the steepest slope. Steepness of slope relates directly to the rate of erosion and sediment being transported by runoff and deposited into streams. The relation between slope and rate of erosion would be illustrated by the behavior of the rate of erosion increasing while water is running off a very steep slope compared to the behavior of a low rate of erosion due to water running off a moderate to low slope. Soil type is also an important component. The more erodible the soil is the greater the amount of sediment will be removed from the hill slope and deposited into the stream system.



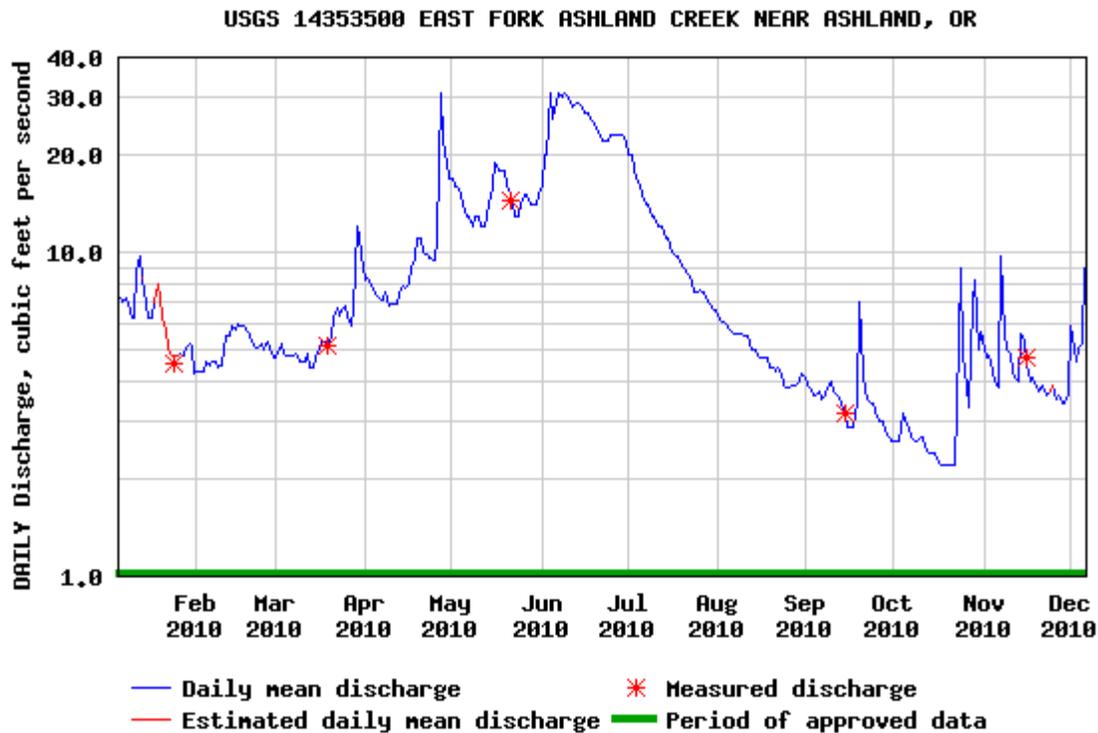
**Figure 1. Map of the Ashland Watershed (Created in GIS Software)**

The study area consists of Douglas-fir, White Fir, and Pacific Madrone with some Legacy Pines and Black Oak (Metlen, 2011). This study area is a late-seral forest. The area has a high risk of intense wildfire due to the abundance of legacy trees and dense vegetation (Conroy, 2009). The West Fork exhibits moderate to high slopes of 30% to 58%. The upper part of the watershed on the West side illustrates moderate to low slopes from 0% to 45%. The East Fork has a lower slope compared to the West Fork ranging from 0% to 35% with ridge line slopes of 55%- 59%. The City of Ashland area has a slope of 0% to 3% while the intermediate parts of the watershed have slopes ranging from 50% to 61%, and the upper region of the watershed exhibits slopes ranging from 0% to 58%. Below are two graphs of the West and East Fork illustrating the daily mean discharge of stream flow for the year 2010. The West Fork has a drainage area of 10.5 mi<sup>2</sup> and the East Fork has a drainage area of 8.14 mi<sup>2</sup> (U.S. Geological Survey).



**Figure 2. Stream flow of the West Fork for the year 2010. (Source: U.S. Geological Survey).**

The above graph depicts the year stream flow of the West Fork, for the year 2010, illustrating the daily mean discharge (cfs) for that year. The first six months (Jan.-June) illustrate a steady increase in stream flow of approximately 29 cfs. By the seventh month (July), the graph indicates a decline in stream flow through July to the end of August. During this time the lowest recorded stream flow is approximately 3.3 cfs. The last four months (Sep.-Dec.) illustrate the stream flow steadily increasing again with a high flow of approximately 10 cfs; however, there is a decrease in stream flow shown in the middle of October with a flow of approximately 1.75 cfs.



**Figure 3. Stream flow of the East Fork for the year 2010. (Source: U. S. Geological Survey).**

The above graph depicts the stream flow of the East Fork, for the year 2010, illustrating the daily mean discharge (cfs) for that year. In the first six months (Jan.-June) there are two significant spikes indicating stream flow. The first high peak of flow was at the end of March with a flow of approximately 11 cfs, and the second highest stream flow during these six months was toward the end of May with a daily mean discharge of approximately 31 cfs. From the beginning of June to the middle of September, the daily mean discharge decreased to a low stream flow of approximately 2.8 cfs. The last four months illustrate several significant spikes of discharge ranging from approximately 6 cfs to 9.9 cfs.

## **II. Methods**

**II.A. Fieldwork Methods.** The study involved a cross-sectional profile of the stream, depth measurements, velocity readings, and bedload sediment samples taken at discreet locations along the entire course of the stream on both the East and the West Fork. Finding a site that is suitable for collecting data is important due to the fact that the sediment material sample needs to

be collected in the same site the velocity, depth and cross sectional profile were measured. The velocity was taken with a Pigmy flow meter. The velocity and stream profile is measured by standing downstream of the meter and placing the meter six-tenths the depth of the total stream depth. A string was tied to two stakes on each side of the bank of the stream to ensure that the velocity was measured in two foot increments. Then, a sample of the bed material was taken at the same location that the velocity readings were measured. This was done by placing a container up stream, under water, and scooping sediment. Each sediment sample was labeled so the exact location was known and the samples were then brought back to the lab for an analysis of sediment size distribution (Dackombe and Gardiner, 1983; Leopold 1978; McMahon and Finlayson, 1992; Kondolf, 2003).

**II.B. Quantitative methods.** Quantitative methods were used to analyze the observed stream velocities within the watershed. The Froude number is a dimensionless value and is used to define the velocity of water at given depth changes from slow to rapid determining whether the stream is a pool or a riffle (Boggs, 2001).

$$F = \bar{v} / \sqrt{(g \times \bar{d})} \quad (1)$$

$\bar{v}$  represents the average flow velocity,  $g$  acceleration due to gravity, and  $\bar{d}$  is the average depth. Velocity and the average depth are dependent upon the depth and rate of stream flow being measured; however, the acceleration due to gravity is fixed (32.2ft/s/s). The Froude Number can be used to tell whether there is a fish community within the stream due to the biotic habitat being strongly related by stream velocity and depth characteristics. Usually, to indicate whether a stream is a pool, the Froude numbers are 0.2 or less and to indicate whether a stream is a riffle, a Froude Number is 0.4 or higher.

We also used the Reynolds Number. This represents stream turbulence:

$$Re = \bar{v} \times r / \nu \quad (2)$$

$\bar{v}$  is the average flow velocity,  $r$  is the hydraulic radius, and  $\nu$  is the Kinematic viscosity of water. This equation is particularly useful in determining sediment erosion and entrainment from the bed. Usually, if the Reynolds Number is less than 500 then the flow is determined as laminar and when the Reynolds Number is greater than 2000 the flow is determined as turbulent (Boggs, 2001).

**II.C. Analysis of Grain sizes.** Grain size analysis determines how fine or coarse sediment is, relative to the rest of the sample and where the sample was collected. During analysis, shape and angularity are observed to aid in determining how far sediment has been transported to its depositional area. Coarseness of the sediment can aid in discovering the depositional area, for instance the depositional material may be from a marine or flood environment. Textural maturity is also analyzed to determine whether the sediment is well or poorly sorted. The angularity, matrix, and shape along with size are also observed during grain size analysis (Boggs, 2001). Within each sample of bedload material, there were different grain sizes. When material is transported farther it will become better sorted, as a function of size. Depending on the energy of the stream the grain sizes of the material were either well or poorly sorted (Boggs, 2001).

The phi  $\phi$  scale is a very important tool that gives information about the grain size so further analysis of the sediment characteristics (described above) can be done by sieving the material: ( $-\log_2 d$ ,  $d$  = grain diameter in mm). This is a simpler method of measuring grain size due to the use of whole numbers. Based on the phi scale, for example, clay has a phi of 10 and a pebble has a phi of -4. Smaller grain sizes have larger phi. A well sorted grain size has a phi of 0.35 and a very poorly sorted grain size has a phi of 2.00. In this case, the smaller the phi the better sorted the grain size will be (Boggs, 2001).

**II.D. Lab Methods.** Sieving techniques consisted of baking 500g of wet sediment from each sample and then sieving every dry sample using an electric sieve shaker. The sieves ranged from 8mm to 1mm size fractions in phi increments. Then each sieve containing material according to the phi increment was weighed in grams. The sieve data was used to calculate the Cumulative Weight Percent (percent of each phi size of individual grain sizes from each sample) and create Cumulative Weight Percent Frequency Curves for each sediment sample.

A frequency curve is generated by first calculating the Weight Percent of the material and then plotting it on a graph against the phi grain sizes on the X- axis. Skewness exhibits whether sediment is fine or coarse. If the curve is skewed positively then the sediment is finer and if the curve is skewed more negatively then the sediment is coarser. Kurtosis illustrates steepness of the curve. The more narrow and sharp the peak indicates how well sorted the sediment is. The mode exhibits how frequent a particle size occurs. The median shows the midpoint of the grain size

distribution and the mean is simply the arithmetic average. Lastly, Standard Deviation was used to illustrate how well or poorly sorted a sample of sediment was (Boggs, 2001). Post-sieving, the Weight Percent was used to calculate the statistical characteristics for each sample. This data was then studied and correlated against the East and West Fork of the Ashland Watershed for the comparison of sediment redistribution. Below is table 1, showing the formulas used to determine the statistical characteristics of the samples collected.

The Median and Graphic Mean illustrate the average grain size. The Median Size determines the midpoint (50<sup>th</sup> percentile diameter on the cumulative curve) of the grain size distribution for each sample and the Graphic Mean illustrates the arithmetic average of all particle sizes within each sample. The Inclusive Graphic Standard Deviation determines how well or poorly sorted each sample is. Lastly, Graphic Skewness illustrates how coarse or fine the sediment is in each sample (Boggs, 2001). The values calculated by using these formulas, according to each sample collected, are presented below in Table 2 and will be discussed in Part A of the Results.

**Table 1. Table of values illustrating the characteristics of each sample of sediment collected.**

| Statistic                            | Formula  |
|--------------------------------------|--|
| Median Size                          | $M = \phi_{50}$  |
| Graphic Mean                         | $M_t = (\phi_{16} + \phi_{50} + \phi_{84}) / 3$  |
| Inclusive Graphic Standard Deviation | $\sum_1 = \left( \frac{\phi_{84} - \phi_{16}}{4} \right) + \left( \frac{\phi_{95} - \phi_5}{6.6} \right)$                        |
| Graphic Skewness                     | $SkG = \frac{\phi_{84} + \phi_{16}}{2(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_5 - 2(\phi_{50})}{2(\phi_{95} - \phi_5)}$ |

**Table 2. Table of grain sizes to aid in grain size analysis for each sample collected.**

| Statistic                            | Sample A | Sample B | Sample C | Sample D | Sample E | Sample F | Sample G | Sample H |
|--------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Median Size                          | -1.8     | -1.1     | -0.4     | -1.1     | -0.1     | 0.4      | 0        | -0.25    |
| Graphic Mean                         | -0.683   | -1       | -0.4     | -0.933   | -0.133   | 0.466    | -0.186   | -0.383   |
| Inclusive Graphic Standard Deviation | -0.0019  | 0.417    | 1.39     | 0.726    | 1.281    | 1        | -0.07    | 0.8272   |
| Graphic Skewness                     | -2.917   | 3.6695   | 1.9      | 1.4      | 3.916    | 0.227    | -1.49    | 0.5833   |

### III. Results and Discussion

#### 1. Hydraulics.

| Sample A (Lower West Fork) |                         |            | Sample B (Upper West Fork)            |                         |            | Sample C (Lower East Fork)                |                        |            |
|----------------------------|-------------------------|------------|---------------------------------------|-------------------------|------------|---|------------------------|------------|
| Cross section (ft)         | Velocity (ft/s)         | Depth (ft) | Cross section (ft)                    | Velocity (ft/s)         | Depth (ft) | Cross section (ft)                        | Velocity (ft/s)        | Depth (ft) |
| B.E. 1.7                   | 0                       | 0.4        | B.E. 2.5 ft                           | N/A                     | N/A        | B.E. 3 ft                                 | N/A                    | N/A        |
| 3.7                        | 1.7                     | 1.2        | 4.5                                   | 0                       | 1          | 5   | 0                      | 0.4        |
| 5.7                        | 2.7                     | 1.2        | 6.5                                   | 0.763                   | 1.4        | 7   | 4.021                  | 0.6        |
| 7.7                        | 3.7                     | 0.8        | 8.5                                   | 1.473                   | 1.4        | 9   | 0.598                  | 0.5        |
| 9.7                        | 4.1                     | 0.6        | 10.5                                  | 1.252                   | 1.2        | 11  | 3.372                  | 0.9        |
| 11.7                       | 4.6                     | 0.6        | 12.5                                  | 2.136                   | 1.3        | 13  | 2.794                  | 0.6        |
| 13.7                       | 6.45                    | 0.4        | 14.5                                  | 1.698                   | 1.5        | 15  | 0.556                  | 0.7        |
| 15.7                       | 1.9                     | 0.2        | 16.5                                  | 0.48                    | 0.7        | 17  | 0.1                    | 0.4        |
| 17.7                       | 1.1                     | 0.3        | 18.5                                  | 0                       | 0.4        | B.E. 18.4                                 | N/A                    | N/A        |
| 19.7                       | 0                       | 0.4        | B.E. 20                               | N/A                     | N/A        |   |                        |            |
| B.E. 21                    | 0.54                    | 0.4        |                                       |                         |            |   |                        |            |
| Froude's Number            | Reynold's Number        |            | Froude's Number                       | Reynold's Number        |            | Froude's Number                           | Reynold's Number       |            |
| 0.5577 Subcritical Flow    | 135382.4 Turbulent Flow |            | 0.1629 Subcritical Flow               | 102471.6 Turbulent Flow |            | 0.3754 Subcritical Flow                   | 90196.4 Turbulent Flow |            |
| Sample D (Upper East Fork) |                         |            | Sample E (Below the Reeder Reservoir) |                         |            | Sample F (Above Confluence to Bear Creek) |                        |            |
| Cross section (ft)         | Velocity (ft/s)         | Depth (ft) | Cross section (ft)                    | Velocity (ft/s)         | Depth (ft) | Cross section (ft)                        | Velocity (ft/s)        | Depth (ft) |
| B.E. 6 ft                  | N/A                     | N/A        | B.E. 2                                | N/A                     | N/A        | B.E. 1                                    | N/A                    | N/A        |
| 8                          | 0.972                   | 0.3        | 3                                     | 0.158                   | 1.3        | 3   | 2.62                   | 0.75       |
| 10                         | 1.085                   | 1          | 5                                     | 0.902                   | 1.6        | 5   | 3.22                   | 2.25       |
| 12                         | 2.293                   | 1.1        | 7                                     | 1.433                   | 1.7        | 7   | 2.8                    | 2.2        |
| 14                         | 3.284                   | 0.9        | 9                                     | 1.296                   | 2          | 9   | 4.11                   | 2.3        |
| 16                         | 1.773                   | 1.2        | 11                                    | 1.334                   | 2          | 11  | 3.74                   | 2.3        |
| 18                         | 0.375                   | 0.85       | 13                                    | 1.036                   | 2.1        | 13  | 3.2                    | 2          |
| B.E. 20                    | 0                       | 0.4        | 15                                    | 1.044                   | 1.9        | 15  | 2.94                   | 1.6        |
|                            |                         |            | 17                                    | 1.201                   | 1.8        | 17  | 2.69                   | 1.2        |
|                            |                         |            | 19                                    | 1.112                   | 1.6        | 19  | 3.26                   | 0.95       |
|                            |                         |            | 21                                    | 0.858                   | 1.5        | 21  | 1.45                   | 1          |
|                            |                         |            | 23                                    | 0.862                   | 1.3        | 23  | 0.98                   | 1.25       |
|                            |                         |            | 25                                    | 0.587                   | 1.2        | 25  | 0.485                  | 1.25       |
|                            |                         |            | 27                                    | 0.36                    | 1          | 27  | N/A                    | 0.45       |
|                            |                         |            | 29                                    | 0.34                    | 0.75       | B.E. 28                                   | N/A                    | N/A        |
|                            |                         |            | 31                                    | 0                       | 0          |   |                        |            |
|                            |                         |            | B.E. 31.5                             | N/A                     | N/A        |   |                        |            |
| Froude's Number            | Reynold's Number        |            | Froude's Number                       | Reynold's Number        |            | Froude's Number                           | Reynold's Number       |            |
| 0.2704 Subcritical Flow    | 107761.1 Turbulent Flow |            | 0.1223 Subcritical Flow               | 114330 Turbulent Flow   |            | 0.8374 Subcritical Flow                   | 72317.8 Turbulent Flow |            |
| Sample G (High West Fork)  |                         |            | Sample H (High East Fork)             |                         |            |   |                        |            |
| Cross section (ft)         | Velocity (ft/s)         | Depth (ft) | Cross section (ft)                    | Velocity (ft/s)         | Depth (ft) |   |                        |            |
| B.E. 1                     | N/A                     | N/A        | B.E. 2                                | N/A                     | N/A        |   |                        |            |
| 2                          | 1.3                     | 0.3        | 3                                     | 1.5                     | 1.7        |   |                        |            |
| 3                          | 1.7                     | 0.42       | 4                                     | 1.9                     | 1.4        |   |                        |            |
| 4                          | 2.3                     | 0.45       | 5                                     | 2.1                     | 1.5        |   |                        |            |
| 5                          | 2.3                     | 0.55       | 6                                     | 3.2                     | 1.7        |   |                        |            |
| 6                          | 2.8                     | 0.65       | 7                                     | 2.5                     | 1.4        |   |                        |            |
| 7                          | 2.3                     | 0.95       | 8                                     | 1.7                     | 1.3        |   |                        |            |
| 8                          | 2.5                     | 1          | 9                                     | 1.7                     | 1.1        |   |                        |            |
| 9                          | 3.2                     | 1          | 10                                    | 1.7                     | 0.9        |   |                        |            |
| 10                         | 3.4                     | 1.2        | 11                                    | 0.9                     | 0.81       |   |                        |            |
| 11                         | 4.2                     | 1.3        | 12                                    | 0.6                     | 0.65       |   |                        |            |
| 12                         | 4.2                     | 1.5        | 13                                    | 0.2                     | 0.45       |   |                        |            |
| 13                         | 2.1                     | 1.1        | B.E. 13.3                             | N/A                     | N/A        |   |                        |            |
| 14                         | 1.3                     | 0.9        |                                       |                         |            |   |                        |            |
| 15                         | 1.1                     | 0.5        |                                       |                         |            |   |                        |            |
| 16                         | 0.6                     | 0.25       |                                       |                         |            |   |                        |            |
| 16.6 B.E.                  | N/A                     | N/A        |                                       |                         |            |   |                        |            |
| Froude's Number            | Reynold's Number        |            | Froude's Number                       | Reynold's Number        |            |   |                        |            |
| 0.4321 Subcritical Flow    | 149052.0 Turbulent Flow |            | 0.2649 Subcritical Flow               | 149810.0 Turbulent Flow |            |   |                        |            |

**Table 3. Results for Cross-sectional Area, Velocity, Depth, Froude, and Reynold's Numbers for all Samples A-H.**

The above table (3) shows the results for all the streams showing cross section values, velocity readings, depth measurements, Froude's Number (determines whether stream is a pool or a riffle) and Reynold's Number (determines whether stream is laminar or turbulent).

The stream for Lower West Fork has a channel width of approximately 19.3ft, the average stream depth is 0.59ft, the average velocity is 2.43ft/s, the Froude Number is 0.5577 and the Reynolds Number is 135382.4. These stream values indicate this stream has a riffle and with turbulent flow. The stream for the Upper West Fork has a channel width of approximately 17.5 ft with an average depth of 1.113ft and an average velocity of 0.975ft/s. The stream flow is turbulent with a Reynolds Number of 102471.6 and has a Froude Number of 0.1629, indicating a pool.

The Lower East Fork has a channel width of approximately 15.4 ft with an average stream depth of 0.586ft and an average velocity of 1.63ft/s. The Reynolds Number is 90196.4, indicating a turbulent flow and the Froude Number is 0.3754, indicating a moderate stream flow. The Upper East Fork has a channel width of approximately 14ft with an average stream depth of 0.821ft and an average velocity of 1.39ft/s. The stream has a turbulent flow with a Reynolds Number of 107761.1 and a Froude Number of 0.2704, indicating that the stream has a characteristic of a pool.

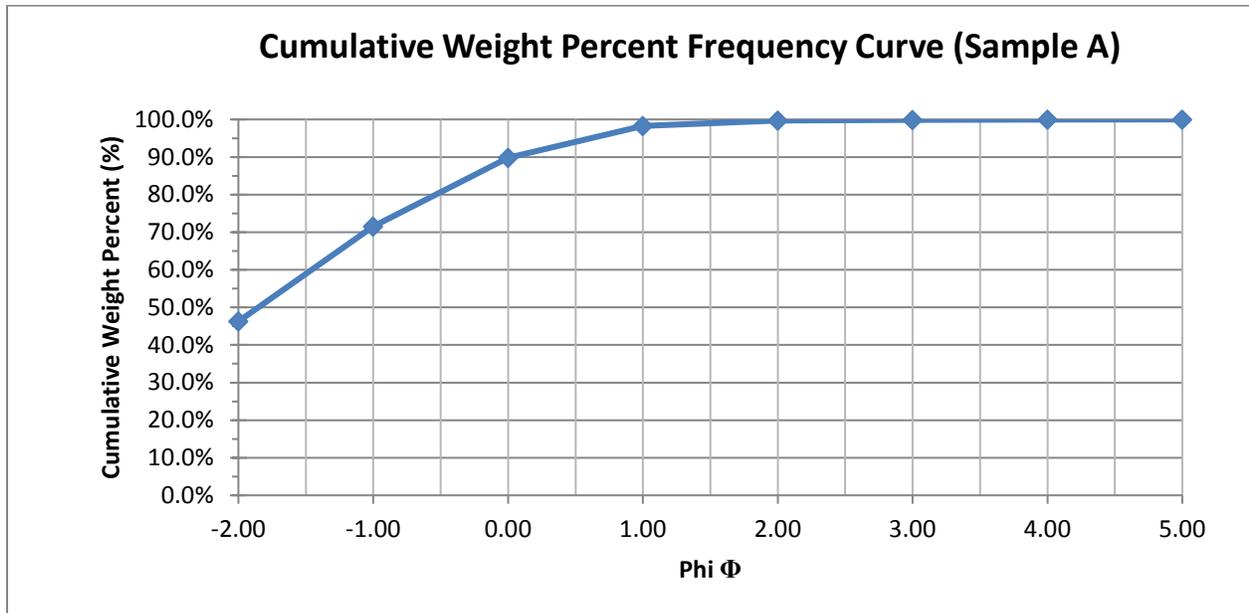
The channel below the Reservoir has a width of approximately 29.5ft with an average stream depth of 1.45ft and an average stream velocity of 0.835ft/s. The Reynolds Number for this stream is 11433.0, indicating turbulent flow with a Froude Number of 0.1223, indicating the stream has a characteristic of a pool. Above the confluence to Bear Creek, the channel has a width of approximately 27ft with an average stream depth of 0.3038ft and an average velocity of 2.62ft/s. This stream has a Reynolds Number of 72317.8, indicating turbulent flow with a Froude Number of 0.8374, indicating this stream has the characteristic of a riffle.

Sample G (higher up West Fork) has a channel width of approximately 15.6ft with an average stream depth of 0.805ft and an average velocity of 2.52ft/s. The Reynolds Number for this stream is 149052.0, which indicates a turbulent stream flow and the Froude Number for this stream is 0.4321, which characterizes this stream as a riffle. Lastly, Sample H (higher up East Fork) has a channel width of approximately 11.3ft with an average stream depth of 1.19ft and an average velocity of 1.64ft/s. The Reynolds Number for this stream is 0149810.0, indicating a

turbulent stream flow and the Froude Number for this stream is 0.2649, which indicates an intermediate flow.

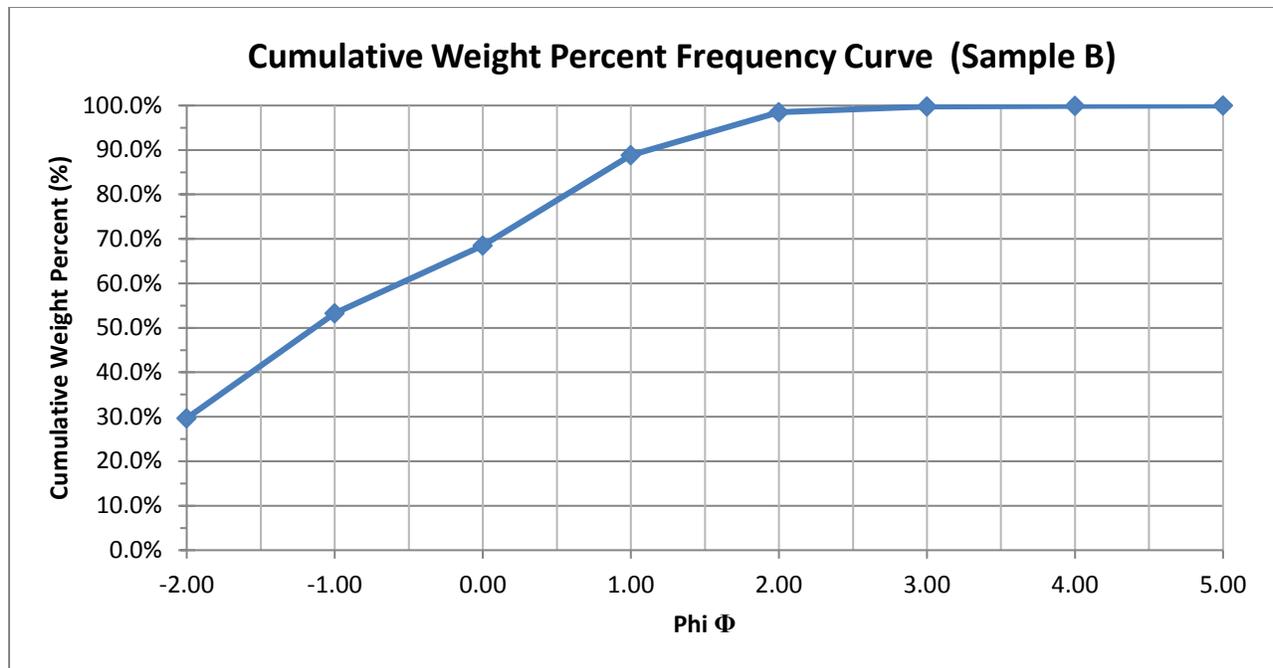
## 2. Bedload Sediment Analysis

From the study area there are a total of 8 samples collected, each characterized by a Cumulative Weight Percent Frequency Curve. A smaller phi value indicates a larger grain size (Boggs, 2001).



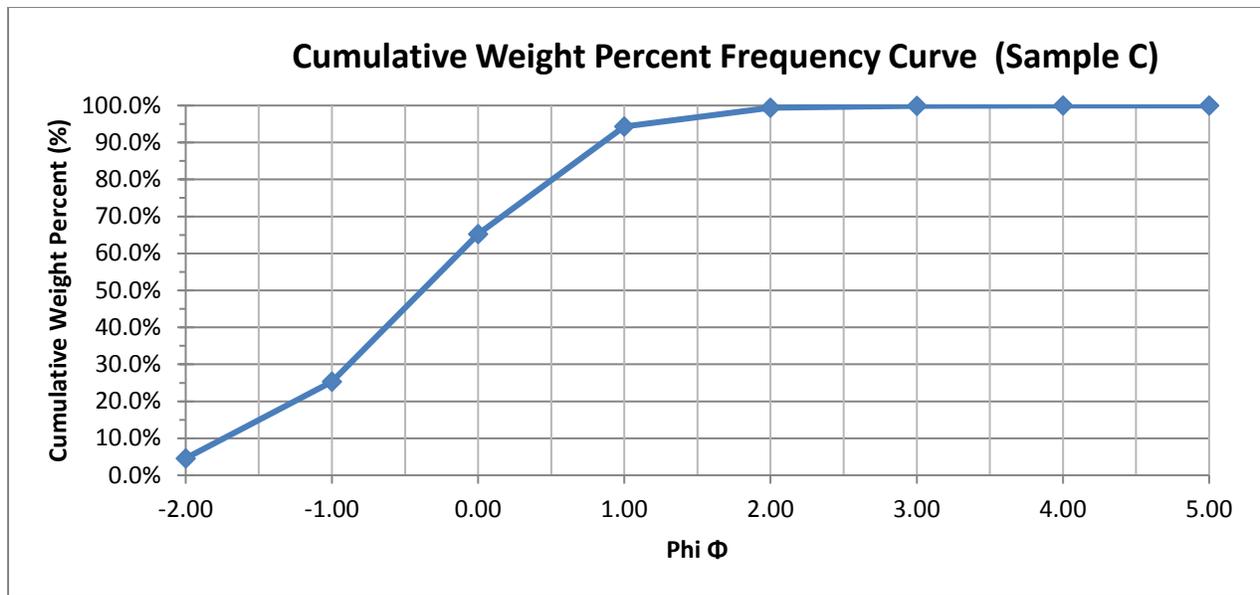
**Figure 4. Cumulative Weight Percent Frequency Curve for (Sample A) collected on the Lower East Fork.**

The Lower East Fork has a larger grain size (Figure 4). For instance, there is an approximate weight percent of 71% of the sediment that is between the phi values of -2.00 to -1.00 with the remaining 29% of the sample containing smaller grain sizes ranging from coarse sand to silt. Overall, the Lower East Fork had gravel/pebble sized material with some sand/silt sized deposits.



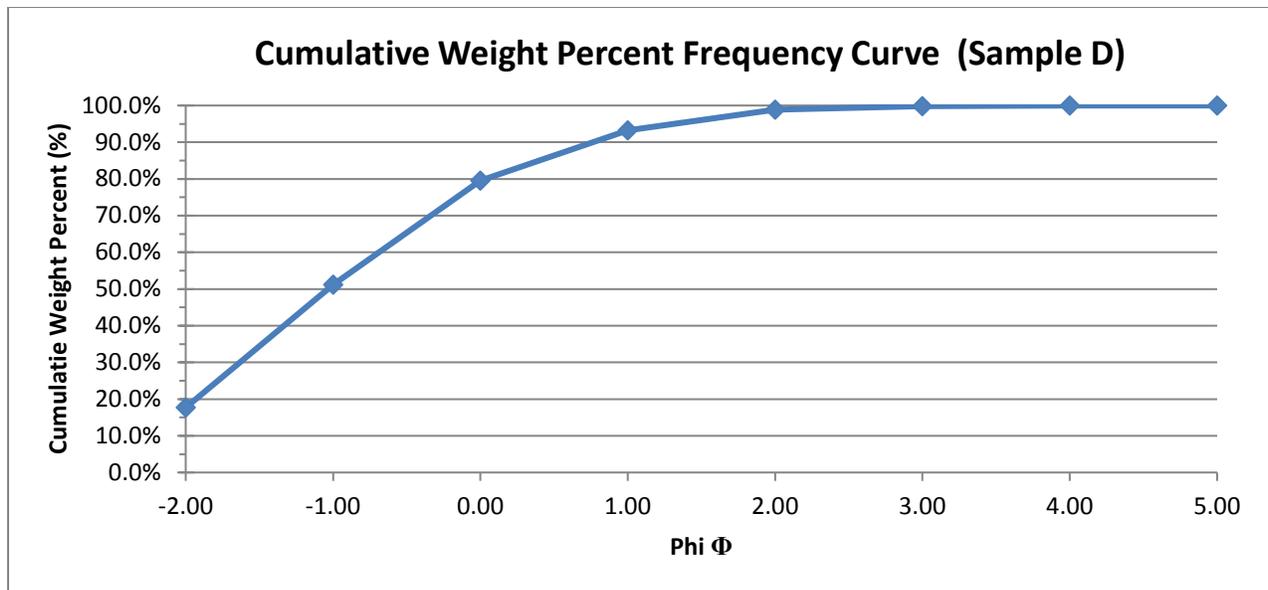
**Figure 5. Cumulative Weight Percent Frequency Curve for (Sample B) collected on the Upper East Fork.**

The Upper East Fork has larger grain size material (Figure 5). For instance, there is a weight percent of approximately 54% of the sample that has phi values between -2.00 to -1.00. The rest of the sample has a weight percent of approximately 46% with phi values between 0.00 to 5.00. Overall, there is an abundance of gravel/pebble sized material in the Upper East Fork, and is exhibiting moderate amounts of grain sizes indicative of course sand to silt sized deposits.



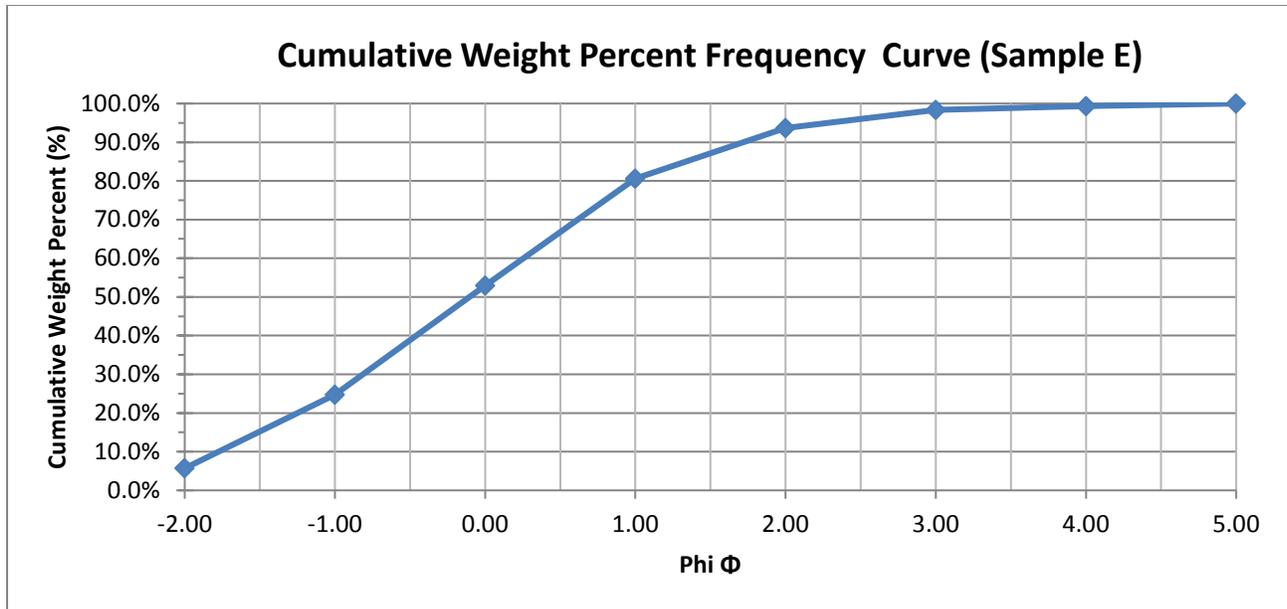
**Figure 6. Cumulative Weight Percent Frequency Curve for (Sample C) collected on the Lower West Fork.**

The Lower West Fork has some coarse gravel which indicates an abundance of course sand sized material (Figure 6). This is illustrated by the phi values between -1.00 to 1.00 having a weight percent of approximately 89%. The reaming 11% (with phi values of -2.00, 2.00- 5.00) of the sample showed less than 5% of the course material and less than 7% of the material exhibited silt deposits. Overall, the Lower West Fork has a grain size of very course sand to course sand, with little abundance of gravel grain sizes and silt deposits.



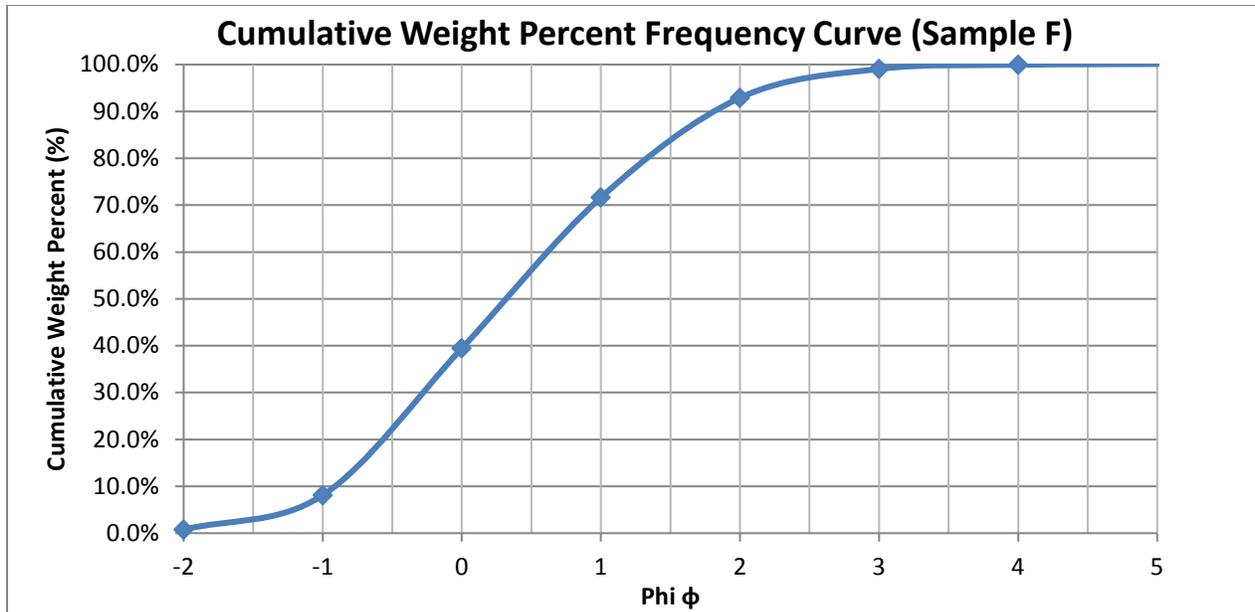
**Figure 7. Cumulative Weight Percent Frequency Curve for (Sample D) collected on the Upper West Fork.**

The Upper West Fork is relatively evenly distributed between large and moderately large grain sizes (Figure 7). This is illustrated by the phi values of -2.00 and -1.00 having a weight percent of approximately 50%, and the phi values of 0.00 and 1.00 having a weight percent of approximately 42%. The rest of the sample has phi values ranging from 2.00 to 5.00, having a weight percent of approximately 8%. Overall, this sample from the Upper West Fork ranges from gravel/pebble size material to very coarse to course sand sized material with a minuscule amount of silt.



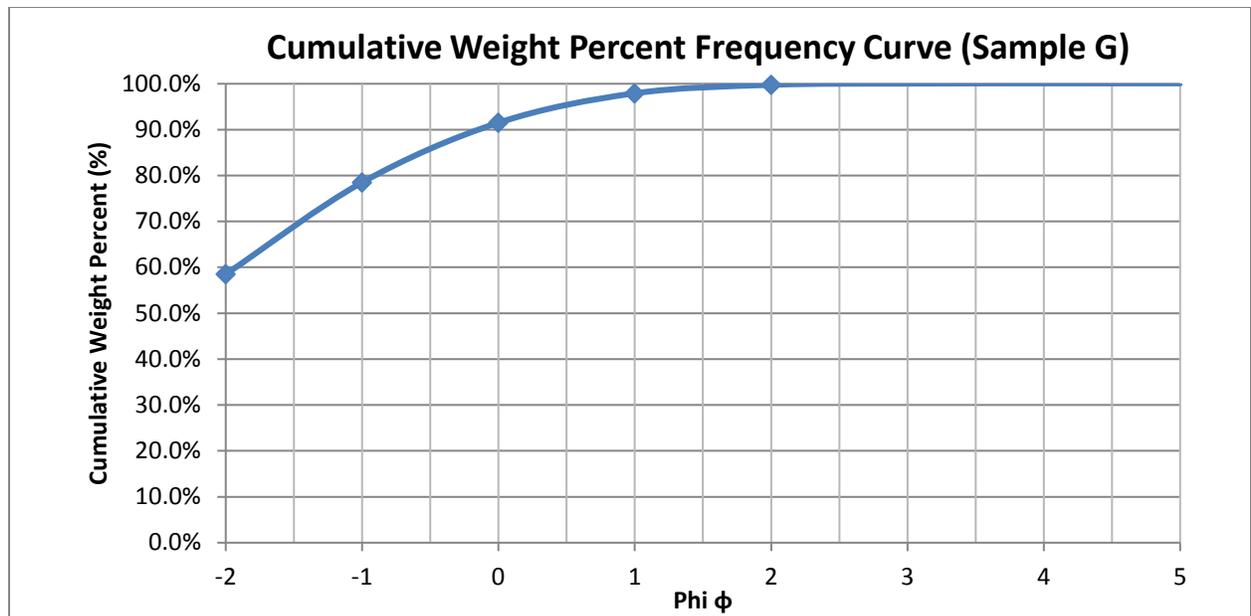
**Figure 8. Cumulative Weight Percent Frequency Curve for (Sample E) collected below the Reeder Reservoir.**

Below Reeder Reservoir the majority of the material is moderately large to fine grained (Figure 8). The phi values between -2.00 and -1.00 had a weight percent of approximately 25%. The phi values between 0.00 to 2.00 had a weight percent of approximately 68%, and lastly the phi values from 3.00 to 5.00 had a weight percent of approximately 7%. Overall, this sample below the reservoir exhibited less abundance of larger material and more coarse sand size material along with a more prolific amount of silt sized material then compared to the rest of the above samples A-D.



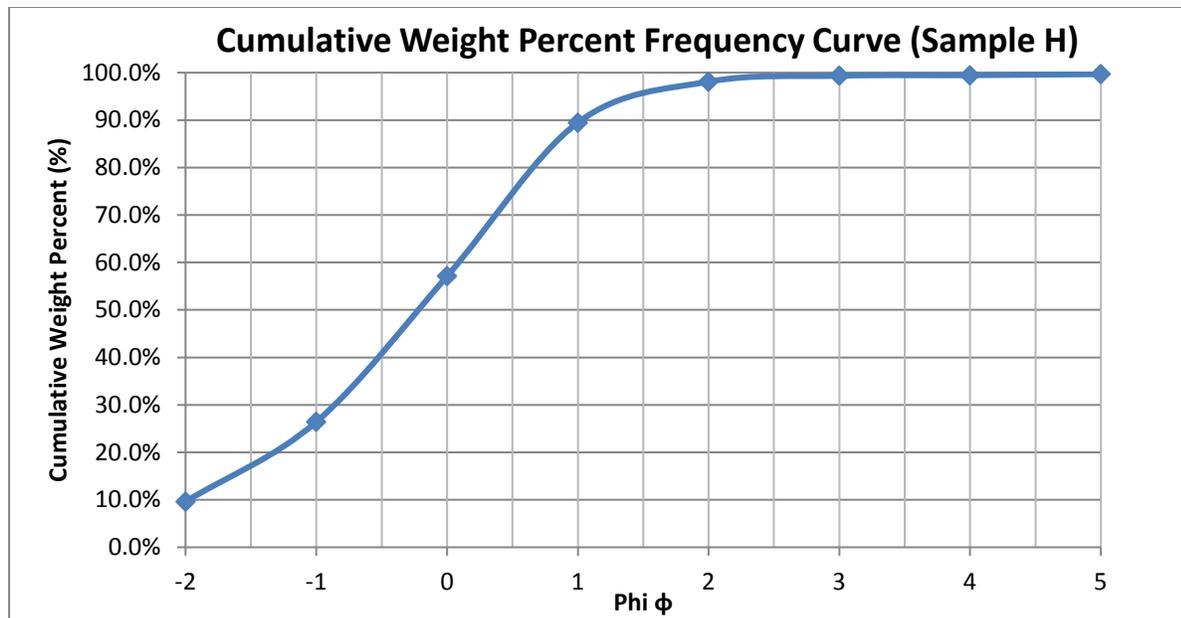
**Figure 9. Cumulative Weight Percent Frequency Curve for (Sample F) above the confluence of Bear Creek.**

Above the confluence of Bear Creek, there is a majority of moderate small grain sizes with some large grains (Figure 9). The phi values between -2.00 and -1.00 have a weight percent of approximately 9%. The phi values from 0.00 to 2.00 have a weight percent of approximately 84% and the phi values ranging from 3.00 to 5.00 have a weight percent of approximately 7%. The majority of the grains in this sample have a copious amount of course to medium course sized sand, while a small amount of the sample has grain sizes of course gravel, fine sand, and course silt.



**Figure 11. Cumulative Weight Percent Frequency Curve for (Sample G) collected at a higher point above the West Fork than the previously collected sample of the upper West Fork.**

At a higher point above the West Fork the majority of the material has large grain sizes (Figure 11). Phi values -2.00 to -1.00 have a weight percent of approximately 78%. Phi values from 0.00 to 3.00 have a weight percent of approximately 22% while the phi values from 4.00 to 5.00 have a weight percent of 0%. Overall, the majority of the sample has gravel to pebble sized material with a small amount of fine and medium sized material with an immeasurable amount of silt. This sample has the coarsest sized material out of the 8 sediment samples collected.



**Figure 10. Cumulative Weight Percent Frequency Curve for (Sample H) collected at a higher point above the East Fork than the previously collected sample of the upper East Fork.**

The upper East Fork is composed of moderate to large sized grains (Figure 10). Phi values of -2.00 to -1.00 have a weight percent of approximately 26%. The phi values of 0.00 to 2.00 have a weight percent of approximately 72% while the phi values of 3.00 to 5.00 have a weight percent of approximately 2%. Overall, this sample has an abundance of coarse to medium sand size material. There is a moderate amount of material that is pebble to gravel sized with a miniscule amount of fine sand and coarse silt.

Comparing the steepness of the slopes of Sample A (Lower East Fork) vs. Sample B (Upper East Fork), the curve of Sample A illustrates better sorted material due to the slight steepness of the curve compared to the slightly less steep curve in Sample B. For Samples C (Lower West Fork) and D (Upper West Fork), the stronger Kurtosis of these two curves is illustrated in Sample C, demonstrating better sorted material compared to Sample D. As for Sample E (below the Reservoir), based on the Kurtosis this sample shows the sediment fairly well sorted. Sample C (Lower West Fork) and Sample E (below the Reservoir) exhibit sediment that is well sorted based on the Kurtosis of the curves. All of these relationships correlate given the stream gradient and sample site locations within the watershed.

The Lower West Fork has a lower slope compared to the East Fork which would result in more sediment being carried more evenly, thus exhibiting more sediment that is better sorted.

Sample E also has a lower slope area compared to the other samples in the East Fork. Since Sample E is from below the reservoir, indicating that the sediment has farther distance to travel and to be deposited, this sediment is finer (Tables 2 and 3, accompanied by further explanations about each sample collected). This table illustrates the values of how coarse/fine the samples are, how well or poorly sorted each sample is and also determines the average grain size and midpoint of the grain size distribution of all particle sizes within each sample.

The last three figures 9-11 of Samples F-H also demonstrate how well or poorly sorted each sediment sample is. The steepness of the curves for Sample F (above the confluence of Bear Creek) and for Sample H (high point at East Fork) both had moderate sorted material based on the Kurtosis (steepness) of the curves. As for Sample G (high point at West Fork), based on the Kurtosis of the curve, the sediment was fairly poorly sorted compared to the Samples F and H.

#### **A. Discussion of statistical findings**

Sample A (Lower West Fork) has a phi value of -1.8 for the median size which means that the midpoint of this sample has grain sizes that were the same size of a granule. The Graphic Mean has a phi value of -0.683 which states that the mean of the grain sizes are the same size as very coarse sand. The Standard Deviation has a phi value of -0.0019 which means that this sample is very well sorted. The Skewness of this sample has a phi value of -2.917 which means it is skewed negatively demonstrating that the material is very coarse.

Sample B (Upper West Fork) has a phi value -1.1 for the median size which means that the midpoint of this sample has a grain size of a granule. The Graphic Mean has a phi value -1.0 which means that the average grain sizes of the sample are the size of a granule. The Standard Deviation has a phi value of 0.417 which indicates that the material in this sample is well sorted. The Skewness has a phi value of 3.6695 which indicates that the material is very finely grained.

Sample C (Lower East Fork) has a phi value of -0.4 for the median size which means that the midpoint of this sample has a grain size of very coarse sand. The Graphic Mean also has a phi value of -0.4 which indicates that the average grain size of the sample is very coarse sand. The phi value for the Standard Deviation is 1.39 which indicates that the sample is moderately sorted. The

Skewness has a phi value of 1.9 which illustrates that the sample has a greater amount of fine material.

Sample D (Upper East Fork) has a phi value of -1.1 for the median size which means that the midpoint of this sample has a grain size of a granule. The Graphic Mean has a phi value of -0.933 which illustrates that the average grain size of the sample is the size of coarse sand. The Standard Deviation has a phi value of 0.726 which shows that the sample was moderately well sorted. The Skewness has a phi value of 1.4 which shows that the sample has fine grained material.

Sample E (below Reeder Reservoir) has a phi value of -0.1 for the median size which means that the midpoint of this grain size distribution has a grain size that is indicative of very coarse sand. The Graphic Mean has a phi value of -0.133 which illustrates that the average grain size for this sample is a granule. The Standard Deviation has a phi value 1.281 which illustrates that the sample is moderately sorted. The Skewness has a phi value of 3.916 which indicates that this material is very finely grained.

Sample F (the confluence of Bear Creek) has a phi value of 0.4 for the median size which means that the midpoint of this sample has a grain size indicative of coarse sand. The Graphic Mean has a phi value of 0.466 which means that the average grain size of this sample is coarse sand. The standard deviation has a phi value of 1.0 which shows that the sample was moderately sorted. The Skewness has a phi value of 0.227 which indicates that the material was moderately fine grained.

Sample G (the point above the West Fork) has a phi value of 0.0 for the median size which means that of the grain size distribution the midpoint grain size is indicative of very coarse sand. The Graphic Mean has a phi value of -0.186 which means that the average grain size of this sample is a pebble. The Standard Deviation has a phi value of -0.07 which indicates that the sample is well sorted. The Skewness has a phi value of -1.49 which indicates that the material is very coarse.

Sample H (the point above the East Fork) had a phi value of -0.25 which means the grain size is indicative of very coarse sand. The Graphic Mean has a phi value of -0.383 which means that the average grain size of this sample resembles very coarse sand. The Standard Deviation has

a phi value of 0.8272 which indicates that the material was moderately sorted. The Skewness has a phi value of 0.5833 which shows that this material is very fine.

**Discussion:**

Samples A (Lower West Fork) and C (Lower East Fork) were collected in a riffle environment. The sample collected from the Lower West Fork is very well sorted and showed granule and some very coarse sand sized material. The Lower East Fork is moderately sorted and has finer sized material from coarse to very coarse. Again, this correlates with the steeper slope on the West Fork side compared with the moderate to low slope on the East Fork.

The results illustrated that the Upper and Lower West Fork showed a trend of the material steadily becoming smaller in size as the sediment is being transported downstream from the Upper to Lower West Fork. The same trend is illustrated for the Upper and Lower samples collected along the East Fork, although there is slightly bigger material in the Upper West Fork compared to the Upper East Fork.

Sample E (collected below the reservoir), is moderately sorted with coarse sand to medium sand sized material. The material was collected in a pool and down slope from above the watershed. This environment indicates that the finer material (transported from above stream) settled to the bottom of the stream channel. The material has an abundance of coarse sand sized material with a prolific amount of silt sized material.

Sample F (collected above confluence to Bear Creek) is also fairly finely grained and moderately sorted. This was collected from a riffle environment and in a place where sediment had farther transport time. This sample has coarse to medium sand sizes with a very small amount of silt sized material. Between Sample E and Sample F, the average grain sizes depict that Sample E had slightly larger material compared to Sample F. Again, this followed the trend of material (for Samples A-F) gradually being transported downstream and during the process getting reworked to smaller grain sizes.

Sample G (high point of West Fork) has the coarsest material out of all the samples. The material has a great abundance of gravel to pebble sizes. This followed the trend of Sample B (Upper West Fork) containing coarse sized material. Based on the data, this sample was very well sorted.

Sample H (high point of East Fork) has coarse material which was in keeping with the material from the Upper East Fork (Sample D). The sample is mostly very coarse to medium sand sized, and is moderately sorted with very little silt sized material. These characteristics make sense due to the location being so high up in the watershed; thus, material would not be very well sorted and not very finely grained. These samples, taken in the upper watershed, still followed the trend of material being smaller in size on the East Fork compared to the larger material on the West Fork.

Overall, these samples followed the trend of coarser material being in the upper and higher locations of the watershed while smaller sized material were found in the lower regions of the watershed. The Samples A and B followed a trend of better sorted material in the Lower West Fork compared to material in the Upper West Fork. Samples C and D both had moderate sorting from the Upper and Lower East Fork. The reasoning behind the East Fork not following the trend of the West Fork could be due to the difference in slope. The West Fork has a much higher percentage in slope compared to the East Fork which resulted in why the trend was not seen in the East Fork as it was in West Fork.

Samples E (below the reservoir) and Sample F (above the confluence) have the same pattern of sorting; however, it is very slight. Sample E is slightly less moderately sorted compared to Sample F. Again, this makes sense due to the slope steadily decreasing from these two locations starting below the reservoir and steadily declining toward the confluence to Bear Creek.

Sample G (higher point of West Fork) and sample H (higher point of East Fork) did not follow the trend of the material being in a similar sorting class as Samples F and E did. According to the statistical data, Sample G is well sorted and Sample H is moderately sorted. Sample H correlated well with the location of the sample being higher up in the watershed. However, Sample G did not correlate well with its location being high up within the watershed. This discrepancy will be discussed below.

The statistical data does not accurately illustrate how poorly sorted the material is for Sample G. Visually, it can be seen that this material was poorly sorted. Also, the statistical data does not correctly illustrate the degree of coarseness in Sample G. The material is skewed negatively; however, the data from Sample A shows that this material was more coarse than Sample G, which was not the case when analyzing the weight percents in Figure 4 (Sample A) versus Figure 11 (Sample G). Analyzing these figures shows that Sample G has phi values of -2 to -1 representing a higher weight percent of approximately 78% compared to the phi values of -2 to -1 from Sample A, representing a weight percent of approximately 71%.

Also, there is a discrepancy with the statistical data for Sample B (Upper West Fork). The Skewness value illustrates that it is skewed positively, indicating very fine material; however the weight percents presented in Figure 5 illustrate that there is a fairly even distribution of pebble and coarse sand sized material. Also, the value for sorting does not follow the common trend of Samples A-F. This illustrates similar sorting classes or better sorted material at the lower locations compared to the upper locations within the watershed.

These contrasting results for Samples B and G could be due to excluding a large amount of cobble sized material (phi values of -8 to -5) and only sieving material with larger phi sizes (smaller grain sizes ranging from  $-2\phi$  to  $5\phi$ ). The reasoning behind eliminating the smaller phi values is due to the fact that the cobble sizes do not tend to impact water quality treatment like the finer grain sizes do. Excluding these smaller phi values could possibly account for the contrasting results for these two samples; however, there could be other factors involved that are unknown at this time.

## **B. Visuals of stream channels for samples F-H.**

Below is a short collection of visuals of what the stream channels looked like for a few of the samples, F-H. It is easy to see the differentiation between the width of the stream channel above the confluence of Bear Creek compared to the narrow stream channels of the West and East Forks from the upper portion of the Ashland Watershed. The change in width is expected since Samples G and H are from a steeper location within the watershed compared to the more base level stream channel for Sample F.



**Figure 12. Facing downstream, above the confluence to Bear Creek, where sediment Sample F was collected. Approximate width of the stream channel was 27ft.**

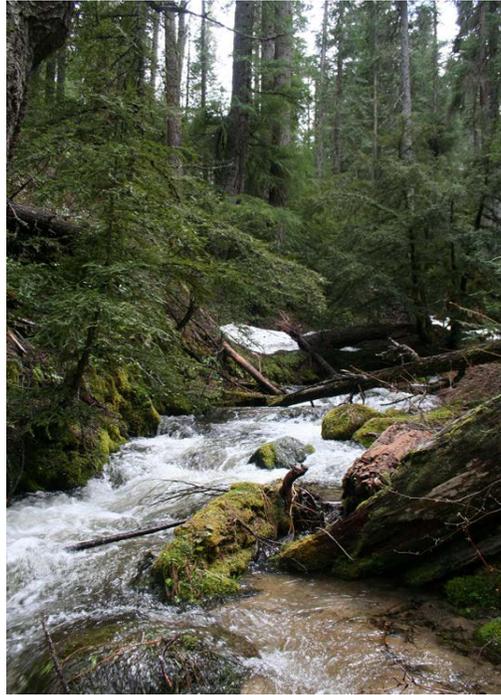


**Figure 13. Upper location of the watershed looking down stream of the West Fork (Sample G). Approximate width was 15.6ft.  
E 0523267, N 4665488**



**Figure 14. Upper location of watershed. Aerial view of the West Fork (Sample G).**

**Approximate width was 15.6ft.  
E 0523267, N 4665488**



**Figure 15. Upper location of the watershed looking up stream of the East Fork (Sample H).  
Approximate width of the stream channel was 11.3ft.  
E 0524008, N 4661784**



**Figure 16. Upper location of the watershed looking downstream of the East Fork (Sample H). Approximate width of the stream channel was 11.3ft.  
E 0524008, N 4661784**

#### **IV. Summary and Conclusions**

Historically the Ashland Watershed experienced frequent fire, but fire suppression has resulted in a dramatically lengthened fire return interval and associated changes in likely ecosystem response to fire. Currently, 7,600 acres of the watershed is undergoing fuel reduction treatments (thinning and burning) as part of the AFR project to help mitigate wildfire effects, sustain legacy trees, preserve water quality, and maintain the resiliency of the watershed (Conroy, 2009).

However, while the AFR project is taking place, there is the potential for more sediment than usual to be redistributed into the streams while the fire suppression treatments are taking place. Thus, multiparty monitoring is being developed to establish a baseline from which future changes in water quality of Ashland Creek can be evaluated (Metlen et al., 2012). A future study will be done to analyze whether more sediment is being deposited into the East Fork (where AFR project and thinning is being currently orchestrated) compared to the West Fork. The main objective of this project was to conduct an assessment of the spatial distribution of bedload grain

size distribution along the length of the Ashland Creek from the headwaters to the confluence of Bear Creek.

Overall, each of the stream channels from where the samples (A-D, G, and H) were collected follow the trend of the stream channels being narrower in the upper and high locations of the West and East Fork (Samples B,D,G,H) compared to the lower locations of the East and West Fork (Samples A and C). Also, the stream channels from below the reservoir (Sample E) and above the confluence of Bear Creek (Sample F) have significantly wider channels due to their surrounding location of lower slopes and being closer to base level.

The velocity and depth data also show common trends with shallower channels exhibiting higher stream flow velocity. The channels for Samples B and D showed a trend of the Upper East and West Fork being deeper channels compared to the channels for Samples A and C being shallower from the Lower East and West Fork. This makes sense due to the slope being steeper in the upper locations of the watershed and the channels being narrower.

Three out of eight sediment samples (B, D, and E) were collected in a pool environment. Samples B (Upper West Fork) and D (Upper East Fork) are from the Upper parts of the East and West Fork. Sample B is well sorted and has material that is mostly pebble in size with a moderate amount of coarse sand sized material. Sample D is moderately well sorted and has a fairly even distribution of granule and coarse sand sized material. This makes sense due to the fact that the West Fork is steeper and the East Fork has a low to moderate slope pattern.

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