Transport and Storage of Coarse and Fine Grained Sediment, Little Paint Branch Creek

Achyut Dangol
Senior Thesis Geol 394
Final Report

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Abstract:

A sediment budget shows the relationship between erosion, discharge, and deposition of sediment within a watershed or a reach of river. In a fluvial system, sediment budgets can respond to changes in sediment supply or to changes in the processes of transport and deposition, which affect the amount of material in flux. Sediment transport depends on differences in the shear stress available to the stream flow and the critical shear stress of the bed material particle motion. When the entire motion of the solid particles is such that they are surrounded by fluid, they are said to move in suspension. Once the sediments are in suspension they are kept up by the upward components of the turbulent currents. The Rouse equation analyzes the process of entrainment of grains from the bottom that is mainly determined by the water-flow velocity and the grain size; however the suspension ceases on the upper limit i.e., the water surface. The overbank deposits of quartz gravel on the floodplain surface in the upstream site on the Paint Branch Creek are observed approximately 2 m above the channel bed. No gravel horizons were observed in the downstream site; however, gravel bars of thicknesses ranging from 0.5 m to 1 m were deposited on the floodplain surface. Deposition of the gravel layer on the upper level of the channel bank may provide the physical evidence of inundation by large floods. Furthermore, the grain sizes exposed at a channel cross-section reflect the grain sizes that the stream was capable to transport in suspension. This follows that the grain sizes in suspension should be correlated with the grain sizes found on the bank.

1. Introduction and Previous Study:

In humid temperate regions, watersheds in their natural condition are permeable, which facilitates sub-surface flow and minimizes more erosive overland flows. This implies that sediment mobility and sediment yields in undisturbed watersheds are low (Allmendigner, 2007). An ever growing demand for human settlement has converted permeable land into impervious surfaces, which increases runoff volumes and peak flows, which can cause bank erosion, channel enlargement, and channel incision (Hammer, 1972). The Little Paint Branch creek originates in the Piedmont, and it flows through the Coastal Plain before it joins the Anacostia River. Research on the sediment budget for the adjacent Good Hope Tributary of the Anacostia River watershed shows two different land use patterns that can be tracked through three distinct fluvial stratigraphic units: a coarse angular sediment underlain by a deposit of fine-grained material in an organic rich horizon overlain by sediment from agricultural sources (Allemendiger, 2007). Grain sizes exposed in stream banks at a channel cross-section are assumed to reflect the grain sizes transported by bedload (basal deposits) and suspended load (upper deposits) by the stream (Pizzuto, 1985).

Urbanization often causes channel widening and incision (Hammer, 1975). The sediment eroded by these processes contributes to the sediment load at downstream locations in the watershed. The goal of this study is to examine the consequences of bank erosion on the sediment transport mechanics and storage of sediment in the Little Paint Branch creek, a gravel bed stream in the Anacostia watershed, with bank sediment that varies from clay, silt, sand to gravel. The downstream portions of the stream system contain significant gravel bar deposits.

Rivers are the cause of major landscape modification because they are erosional and depositional agents. In addition, morphology and flow mechanics of the channel determines spatial and temporal distribution of sediment within the channel i.e., where sediment will be deposited, and how long it will be stored. The flow regime and sediment transport characteristics of rivers are systematically correlated to temporal and spatial changes in channel geometry and bed material size. Thus, the sediment budget, which takes into account of the erosion and sedimentation, plays an important role in linking channel response to land use patterns (Hay, 1987).

Rivers transport sediments in different modes such as: dissolved load, wash load, and bed load. Dissolved load consists of sediment transported in solution. Wash load refers to suspended particles that move readily in suspension. The size of suspended sediments varies with flow conditions, but particles that are finer than 0.062 mm are transported as suspended load for most flows above baseflow conditions. Bed load usually does not include much material <0.062 mm; it includes all sediment sizes present in substantial quantities on the stream bed. Bed load is transported at velocity less than that of the surrounding flow by rolling, sliding, or saltating along the bed. When particles are transported and temporarily maintained in the main body of the flow by turbulent mixing processes, they are transported as suspended load.

2. Objectives of Research:

The objective of this study is to evaluate the effects of bank erosion on the transport and storage of sediment within the Little Paint Branch Watershed. In particular, I examined the size of sediment released due to stream bank erosion in an urbanized portion of Little Paint Branch creek, and evaluated whether this sediment was carried out of the watershed as suspended sediment load, deposited overbank (as suspended load) , or deposited as part of the bed sediment load. The downstream site of the Little Paint Branch creek is characterized by a wide floodplain and prominent gravel bars that indicate that the reach is a potential sediment storage area (reservoir) for sediment. The upper and lower boundaries of this sediment storage reach are defined by the constriction of the channel width and absence of formation of gravel bars upstream and downstream of it. Observations of the site indicate that coarse sediment (sand and gravel) is being deposited in the reach, whereas fine sediment is mobilized by bar formation, which causes channel widening and bank erosion (Kosiba, 2008; Blanchet pers. Com).

2.1 Problem:

The NE Branch of the Anacostia River has undergone progressive urbanization, with the largest increase in urbanization in the 1970's (Behrns, 2007). Urbanization has enlarged the stream channel of the Little Paint Branch creek (Behrns, 2007). This bank erosion releases sediment that is transported by suspended and bedload in the Little Paint Branch Creek. While the fining upward sequence is the characteristic of meandering channel, the gravel deposits on the upper fine grain unit in floodplain stratigraphy may indicate overbank deposition of bed-load gravels. In the upstream site on the Paint Branch Creek, the overbank deposits of quartz gravel on the floodplain surface are observed approximately 2 m above the channel bed. However, no gravel horizons were observed in the downstream site. Observation indicates that gravel bars are forming in downstream reaches of the Little Paint Branch creek, which suggests that significant amounts of coarse sediment have been mobilized by bank erosion. If there is a mass balance between the sediments eroded upstream and the sediments deposited downstream, then continued upstream erosion may result in continued gravel bar deposition. Therefore, the goal of this research was to determine the relationships between sediment mobilization and sediment storage within the lower Paint Branch Creek.

2.2 Hypotheses:

I. Erosion of stream banks in the Paint Branch Watershed contributes a significant amount of gravel to the stream system.

II. Sediment bars in the sediment deposition reach selectively store gravel-sized material.

III. The sediment released by bank erosion can be transported by either suspended load or bedload. The proportion of the total load moved as bedload material increases downstream in the Paint Branch watershed due to a reduction in gradient which affects the shear velocity and thus the Rouse number. The upper limit of the grain size moved by suspended load can be determined by use of the Rouse Equation.

3. Methods:

The study site, the Little Paint Branch creek, is a part of the Anacostia watershed, and it lies towards north of the University of Maryland Campus, Figure 1. The Little Paint Branch creek is a gravel bed river, and for the purpose of this study, I divided the reach into two segments: upstream erosion prone site, and downstream depositional site. Accordingly, data were collected from various sites (Sellman Road, upstream Cherryhill and downstream Cherryhill) within the reach.

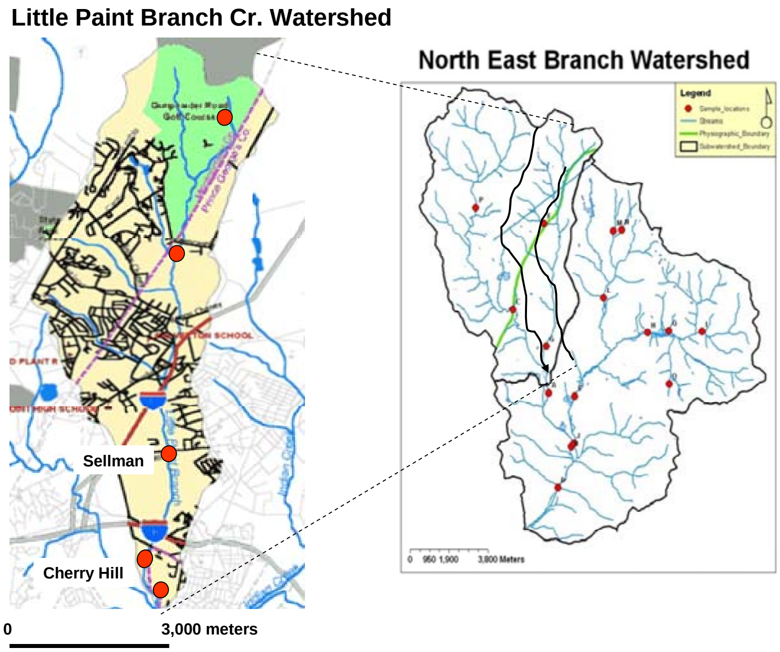

Figure 1: Little Paint Branch Creek watershed, with locations of study sites and the Sellman Road and Cherry Hill reaches identified.

There are three main parts to this project: 1) to determine the size and amount of sediment derived from stream bank erosion, 2) to determine the size and amount of sediment stored in the bar complex reach, and 3) to determine the controls on suspended and bedload transport and storage in the lower portion of the watershed. Methods for each of these 3 main topics are described below:

I. Determination of the size and amount of sediment eroded from the stream banks.

   a. I examined channel bank stratigraphy, sampled bank sediment, and sieved grain sizes to determine percent sand, gravel, and silt in the stream banks.

   b. The amount of width enlargement, ΔW was determined by comparing the existing channel width to channel width of non-urban reference streams with similar drainage basin areas (data obtained from Prestegaard et al., 2001).

   c. The total volume of the sediment produced by bank erosion was calculated as,

$$\sum V_{eroded} = \Delta W_{bank} xLxH_{bank}$$

where,
ΔW = width enlargement
L = length of the channel section
H_{bank} = bank height

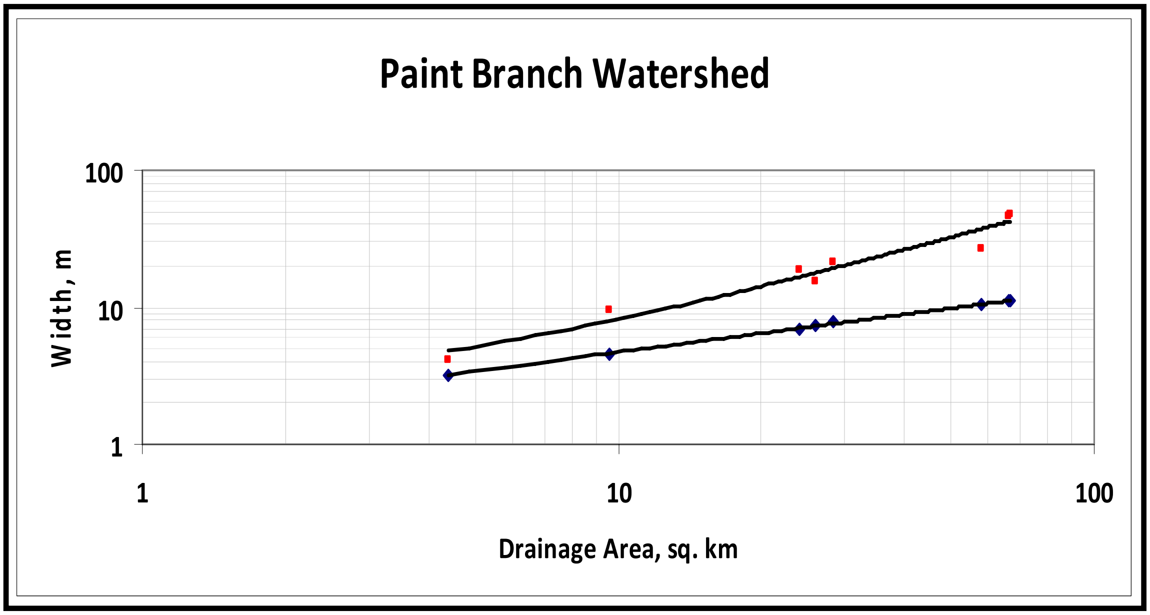

Figure 2: Channel width in Paint Branch Watershed (Blanchet, pers. Com) compared with reference data for non-urban sites (Prestegaard et al., 2001). Differences between the two trends in the channel enlargement due to urbanization.

II. Determination of the volume of sand and gravel deposited in gravel bars in the lower bar complex reach,

a. I measured the bar width along the channel at an interval of ½ of the channel width.

b. Bar thickness (H_{bar}) from field cross sectional area measurements of channel and bar depth were obtained from previous studies by Prestegaard et al., 2001 (fig. 2).

c. I sieved the sediment stored in bars to determine the volume of sand and gravel stored in the bars and the changes in composition that occurred with bar accretion.

$$\sum V_{deposited} = W_{bar} xL \ xH_{bar}$$

III. I calculated whether the grain sizes released by bank erosion can be transported as suspended load, the Rouse-Einstein equation is used to model the grain size moved as suspended load for various discharge events. The Rouse-Einstein equation evaluates the concentration of specified grain sizes at various depths above the channel bed.

$$\frac{C}{C_a} = \left[\frac{d-y}{y}\frac{a}{d-a}\right]^z$$

where, C is concentration, d is total depth, y is distance above the bed, and a is an arbitrary distance above the bed where measurement is made. The Rouse number, Z, is determined as:

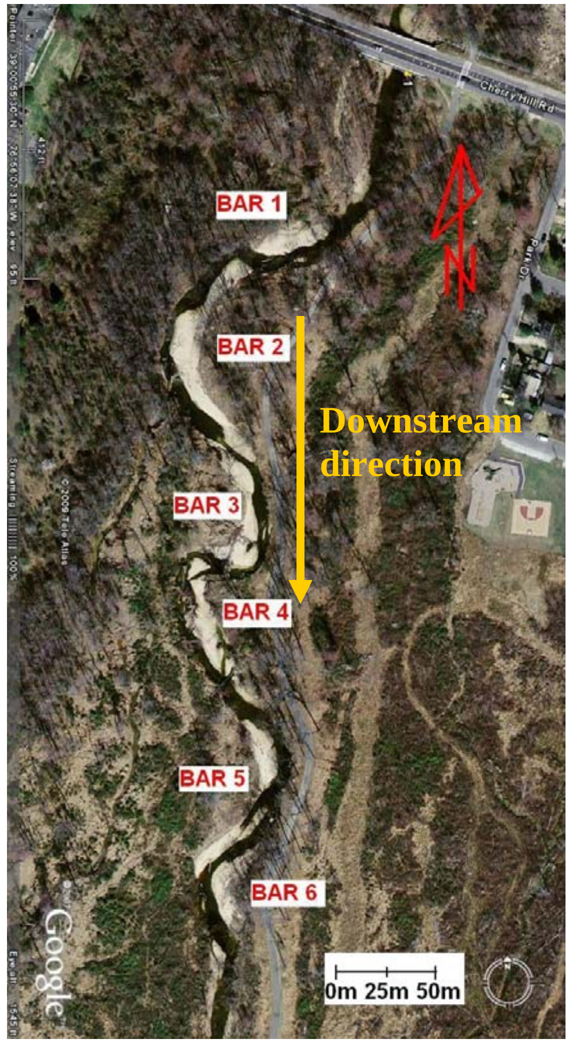

Figure 3: Downstream gravel bar complex

$$Z = \frac{w}{B\kappa U_*}$$

Where w is the settling velocity, B is a constant, k is von Karman's constant 0.4, and

$$U^* = \sqrt{gRS}$$

The settling velocity is largely a function of grain size and grain size distribution

$$W^2 = \frac{4gD}{3C_D}\frac{\gamma_s - \gamma}{\gamma}$$

where, C_D is the drag coefficient, which is a function of Reynolds number, g is the acceleration due to gravity, γ is the specific weight of water or sediment, and D is the median diameter of the grains. In general, the smaller the exponent z, (i.e. the higher the value of U*), the more evenly distributed the suspended sediment will be as a function of the flow depth. Thus, channel change may be driven by suspended sediment deposition as well as by erosion (a function of shear stress). The following calculations were made with the grain size distribution data of the banks and hydraulic information provided by Zach Blanchet:

1. Using the characteristics of the bankfull channel, I determined the bankfull shear velocity, u*, and made calculations of Z for various sized materials found in the channel bank. These calculations were used to determine whether the material will be transported in the water column or only near the bed for the bankfull flows. See example provided below:

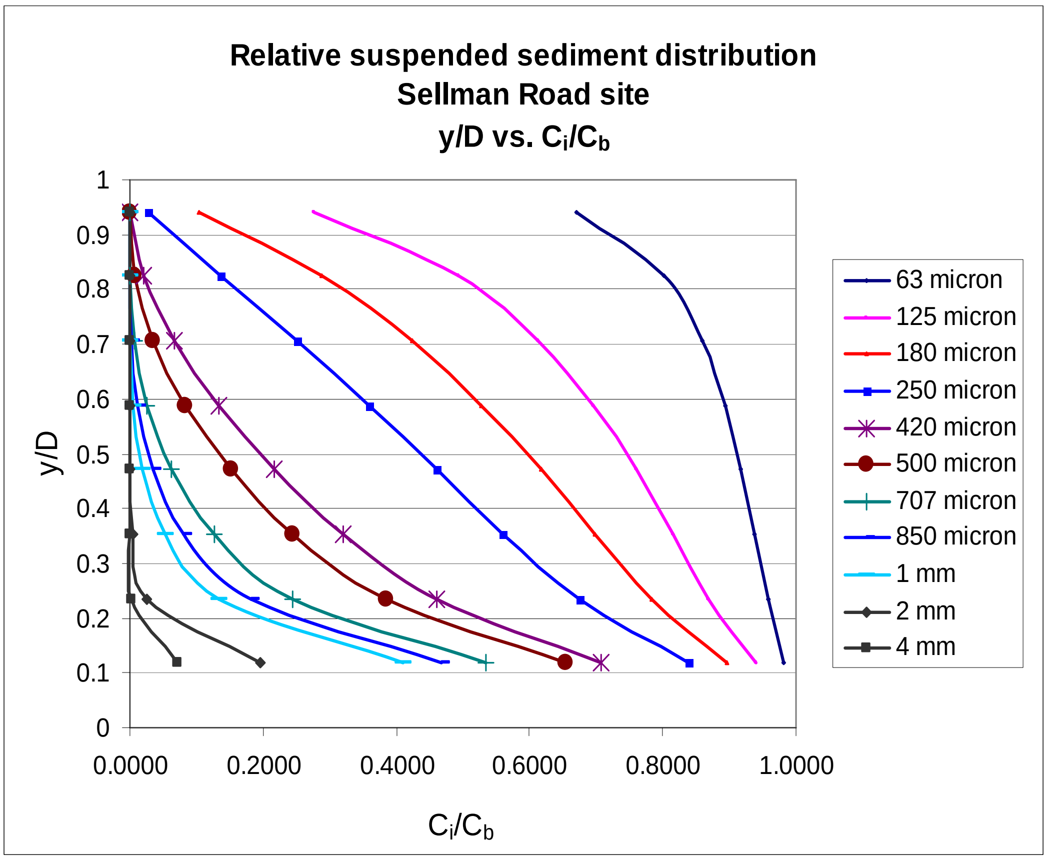

Figure 4: Example of a calculation of the sizes of sediment that can be carried as suspended sediment load at the Sellman Road site for bankfull events.

2. The stratigraphy provides information about the size of sediment that actually was deposited on the tops of the banks. These sediments were once suspended sediments, in some cases by recent floods, which were 6-8 times larger than the bankfull flood. For example, the 2005 floods were 100 year floods.

Sellman Road Stratigraphy

Location	SR1 R/B Sellman Road
Bank Ht.	2.3 m
Thickness (m)	Description
(dist. From surface)	Surface is overbank sand
0.10-0.50	Grey sand, gravel and silt
0.50-0.80	White sand, gravel, and silt
0.80-0.95	Grey clay with little gravel
	(moved laterally to 10m downstream to a better outcrop)
0.95-1.05	Gravel and sand
1.05-1.20	Mica rich clay (indicative of headward erosion during agriculture era)
1.5-1.80	Fragments of piedmont rock (schist) and gravel
	Base flow at 1.80 m

Figure 5: Stratigraphic relationships compared with Rouse calculations suggest that upper layers are sand sized and were therefore deposited by flood events significantly larger than bankfull.

4. Error Analysis:

Measurement error on aerial photograph:
The random error associated with linear measurement made on aerial photograph was approximately 3% both in the north-south and east west direction. This was concluded by verification of physical measurement in the field in contrast to measurement made in the aerial photography. Thus, in the calculation of aerial extent of gravel bars the random error propagates as being 4% per unit area. The uncertainty was calculated as follows:

$$Error(\sigma_f) = \sqrt{L^2\sigma_B{}^2 + B^2\sigma_L{}^2}$$

Where,
L = length,
B = breath, and
σ = uncertainty

Error in sediment sampling:

The error on the grain size analysis occurs mainly because of the lack of reproducibility of the grain size that depends on the amount of the sediment sample collected. Church et al. (1987) have set a criterion for collection of sediment sample. According to the criteria the length of the b-axis of the largest grain present in the sample should determine the size of the sample. This is especially important in the cases when there are fewer largest grains (since they will be the fewest in number, hence the least well represent).

The curve on this chart shows the criteria for error less than 5%. The data points in the Figure 6 represent the measurements of b-axes of gravels in my sample, which clearly do not meet the criteria set by the Church et al. In the sediment sample I collected the b-axes of the largest grain size are greater than 40 mm; and according to the criteria set by Church et al. I would need sample size of around 4 kilogram so that the results can be reproducible within 5% error. Each sediment sample in a stratigraphic interval that I collected for the present study was only about half a kilogram. The samples can be composited at each bank location to total sample sizes for the bank for 1-4 kg for a given stratigraphic layer. These sample sizes are sufficiently large to accurately determine the size distribution of stratigraphic layers that contain sediment less than 10mm in size. The composite results of each horizon are also sufficiently large to estimate the population of coarser gravel in the entire bank sediment at each site.

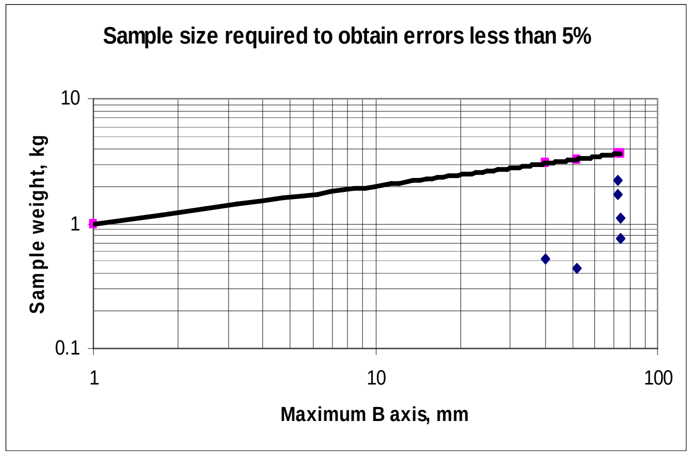

Figure 6: Uncertainty in sediment grain size

5. Results:

5.1 Grain size of stream bank material

Main result: Examination of the stream bank material indicated that most of the stream banks do not contain significant amounts of gravel-sized sediment. Most of the bank material is sand-sized or smaller sediment.

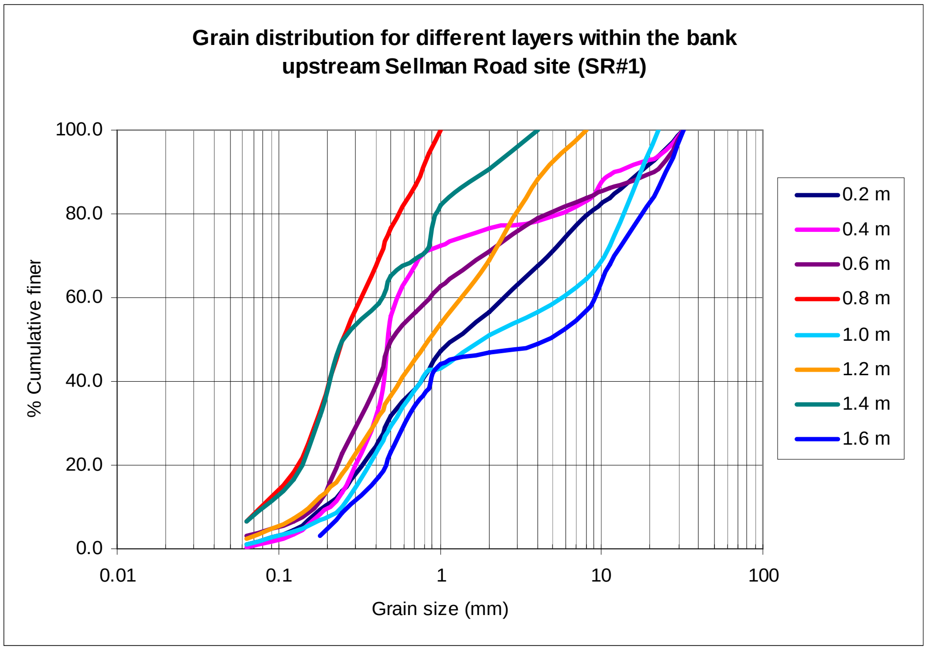

Figure 7: Bank material grain size distributions, Sellman Road site.
Note: for some of the lenses, up to 50% of the sediment is 1 mm or coarser.

The grain size distribution for channel banks (figures 7 & 8) from the upstream Sellman Road and Cherry Hill Road sites showed that for both of them D50 of much of the bank sediments are sand sized. However, the former has 40% to 60% deposits greater than 1 mm, and that amount decreases to less than 10% coming down to the Cherry Hill Road site. The hypothesis I states that 'erosion of stream banks in the Paint Branch Watershed contributes a significant amount of gravel to the stream system'. This hypothesis does not seem to be supported by the data, since little gravel is released by bank erosion.

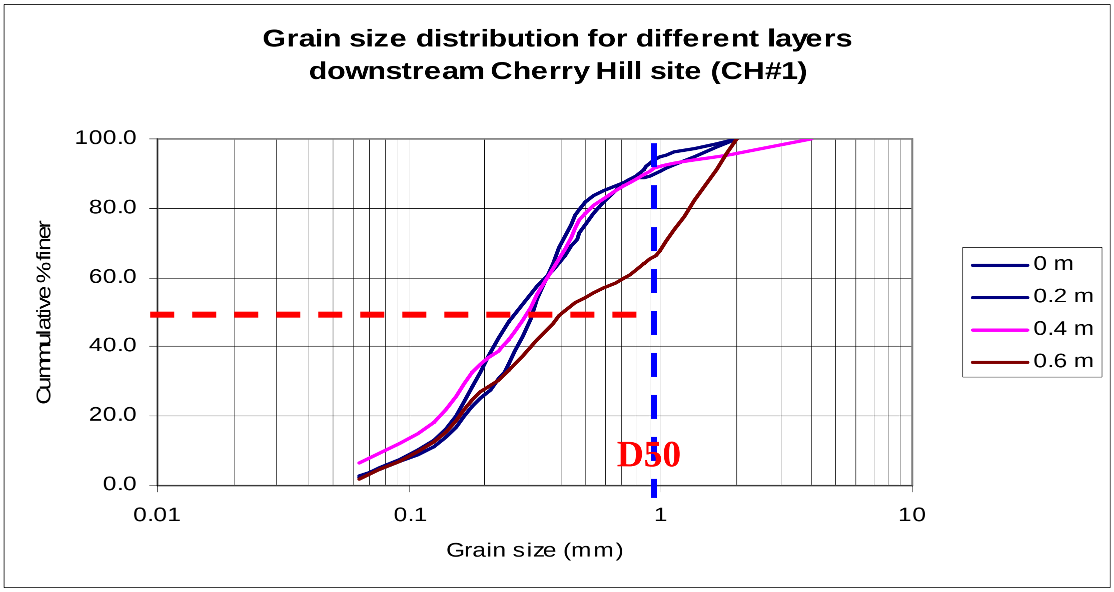

Figure 8: Grain size distribution at Cherry Hill indicates that less than 10% of the deposit is 1mm sand or larger (except for a basal gravel deposit).

The results showed that erosion of the stream banks mainly provides fine-grained material in upper and lower regions of the reach and sand-sized material in the mid-portion of the stream.

5.2 Amount of gravel and sand deposited in downstream bar complex

Figure 9 shows the major bar complexes in the study area, and the size of the gravel bars decreases with distance downstream.

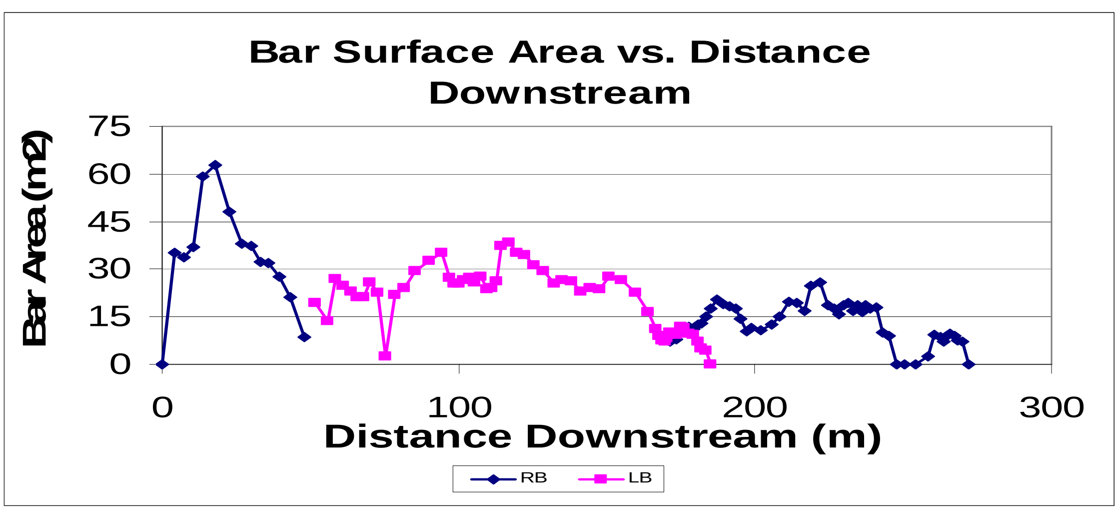

Figure 9: Picture showing downstream gravel bar com complex. Note: the surface of gravel decreases with increasing distance downstream.

The gravel bars are composed of alternating layers of coarse and fine-grained sediment, which suggests that they were formed by successive bedload sheets of coarse-grained sediment moving over sand-sized material. In general, the percentage of sand contained in the bar deposits increases as the bar accretes upward.

The accretion of increasing amounts of sand in the bars (20% to 60%) suggests that the bars were accreted during transport events during which gravel was mobilized by sand bedload (Wilcock, 2004).

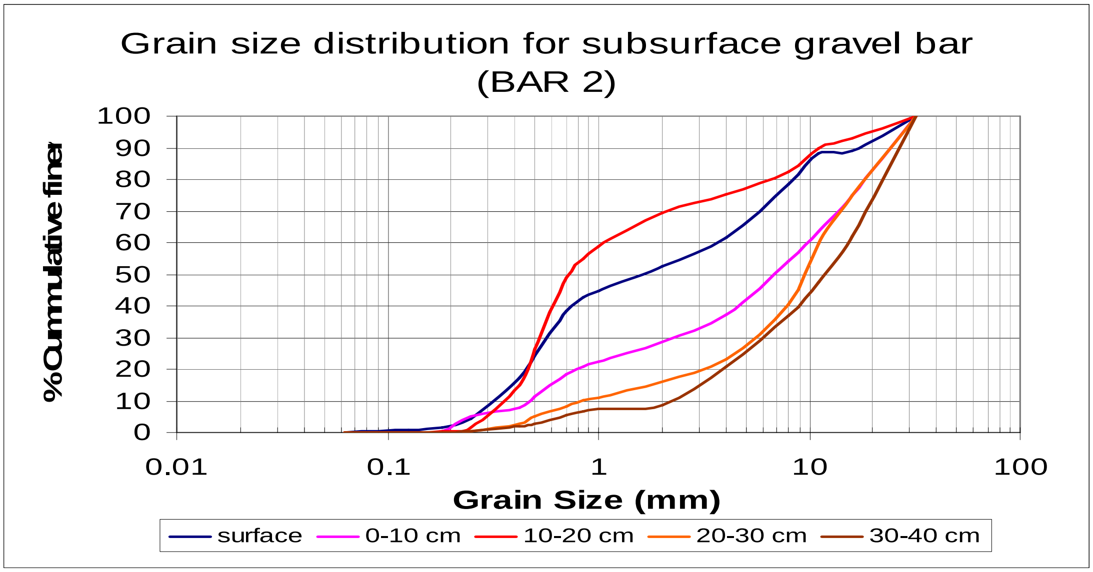

Figure 10: Example of grain size distribution for various depths within a gravel bar in the bar complex.

The approximate amount of sand and gravel stored in each of the three main gravel bars are shown in Table II. The relative amount of sand (size < 1 mm) and gravel (size > 1mm) are determined from the sieve analysis of subsurface sediment samples from the gravel bars (see Appendix).

Table I: Approximate amount of sand and gravel stored in the gravel bars

Gravel Bar	Surface area (m^2)	Volume (m^3)	% Gravel volume	% Sand volume
Bar 1	473	331	75	25
Bar2	1183	828	75	25
Bar 3	673	471	61	39
Bar 4	652	456	78	22
Bar 5	624	437	77	23
Bar 6	154	108	88	12

So, contrary to the original hypothesis that the gravel bars are selectively storage sites for gravel (coarse) material, the result indicated that they are also significant storage sites for sand-sized material.

5.3 Influence of bank sand on suspended and bedload material transport.

The data on the stream bank sediment size indicated that bank grain sizes decreases downstream. This raises the question of whether sand-sized material is carried out of the Paint Branch Creek Watershed as suspended sediment load. If the bank grain sizes record the size of suspended sediment load, then it suggests that much of the sand carried as suspended sediment load at Sellman Road is not carried as suspended load downstream at Cherry Hill. This sediment must be either transported through the reach as bedload, or stored in the reach, or a combination of the two.

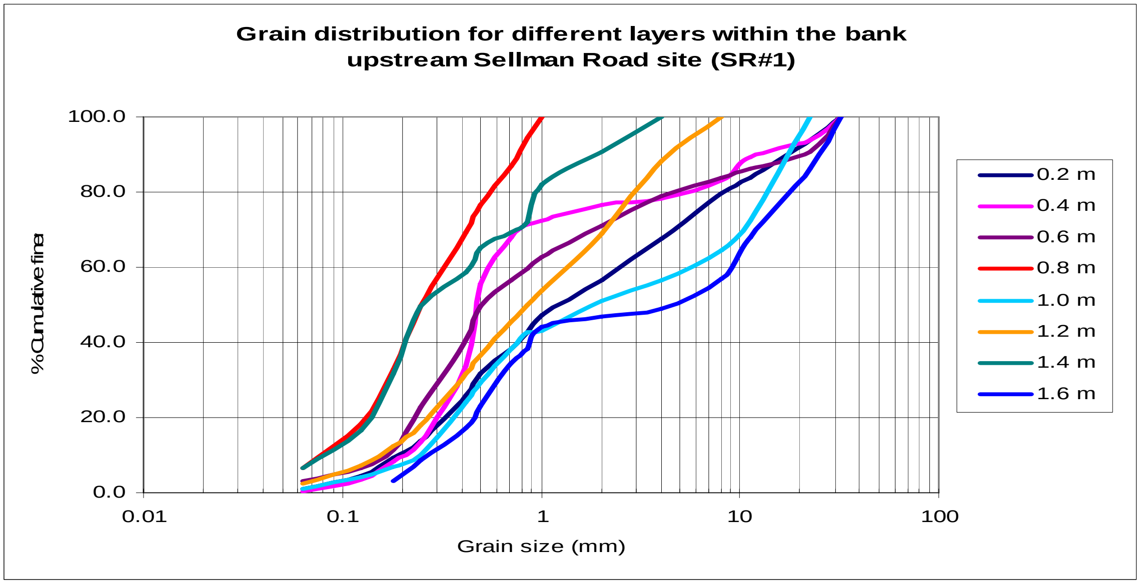

Figure 11: Bank material grain size distributions. Note that for some of the lenses, up to 50% of the sediment are 1 mm or coarser.

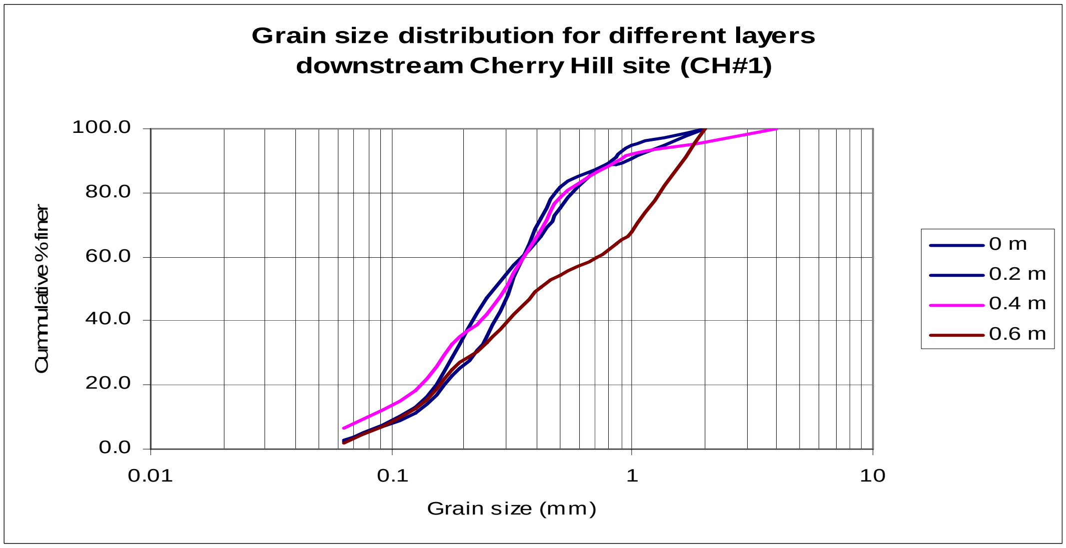

Figure 12: Grain size distribution at Cherry Hill indicates that less than 10% of the deposit is 1mm sand or larger (except for a basal gravel deposit).

The gravel bars record bedload that has been transported and deposited. The stratigraphy of the gravel bars indicates that the percentage of sand in the bar increases upward, suggesting that significant amounts of sand were available (perhaps from bank erosion). The critical dimensionless shear stress also decreased upward due to the increase in the percentage of sand (Wilcock, 2004). Figure 13 through 19 show the subsurface distribution of grain size on the gravel bar.

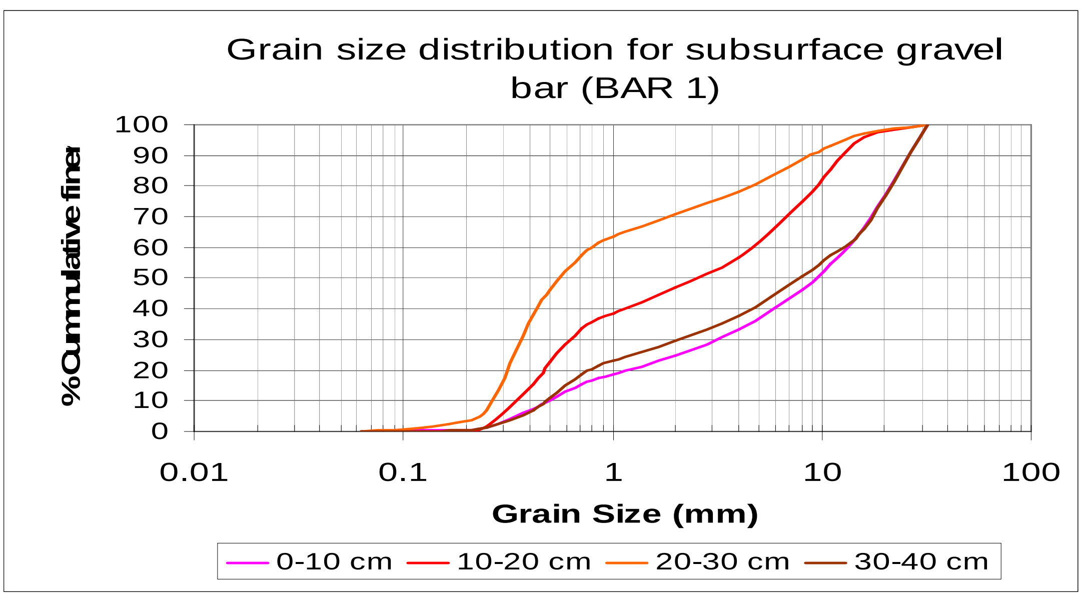

Figure 13: Subsurface grain size distribution for the gravel bar (BAR 1) shows significant quantity of sand in all layers.

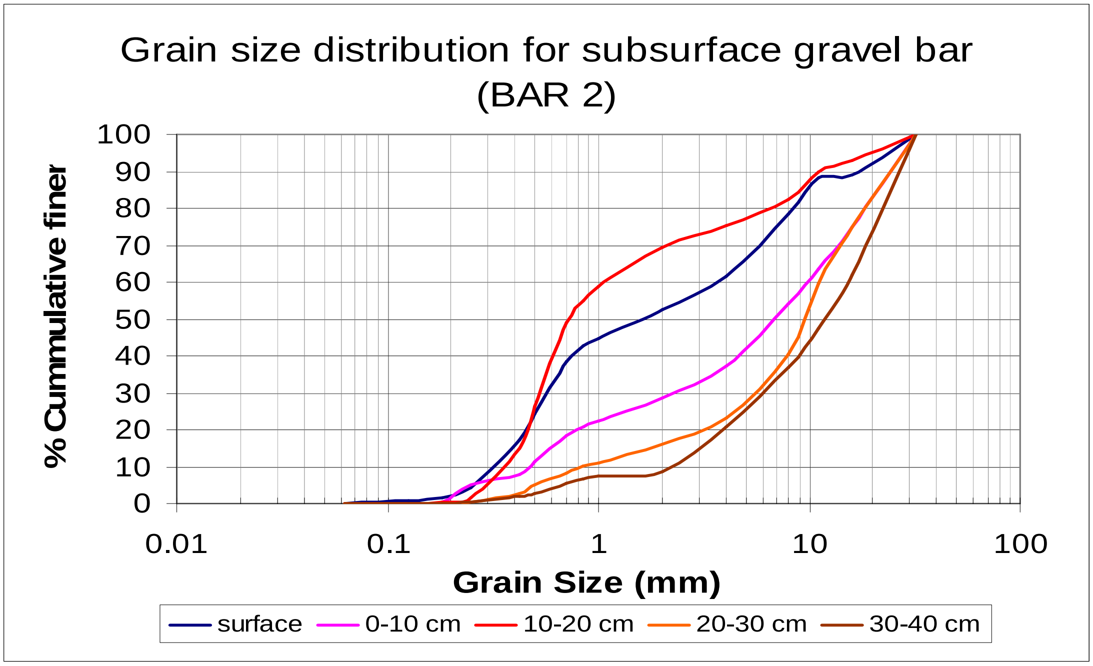

Figure 14: Subsurface grain size distribution for the gravel bar (BAR 2); the 10-20 cm layer alone contains approximately 60% fine sediments.

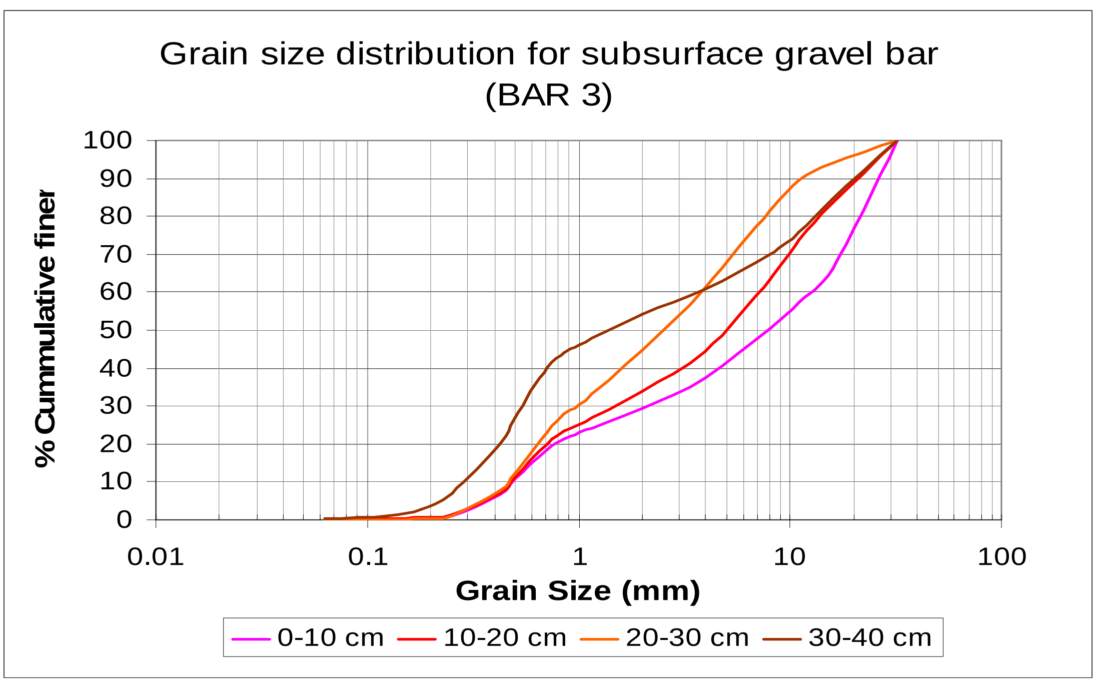

Figure 15: Subsurface grain size distribution for the gravel bar (BAR 3); sand content is significantly high in all subsurface layers.

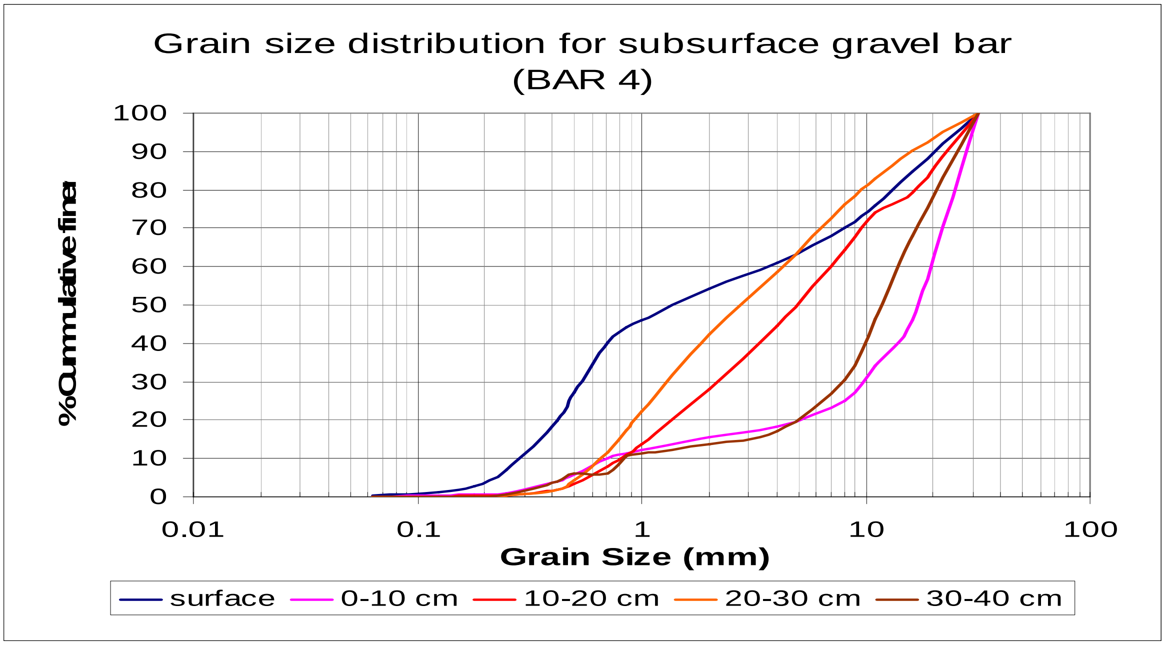

Figure 16: Subsurface grain size distribution for the gravel bar (BAR 4). The coarser and finer sediment layer alternates.

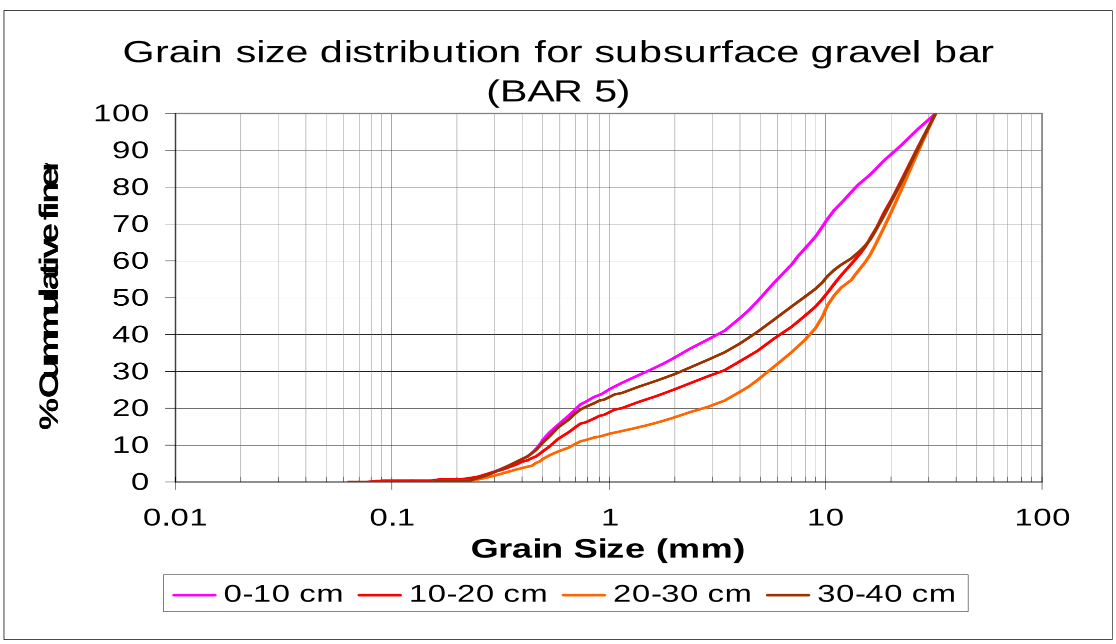

Figure 17: Subsurface grain size distribution for the gravel bar (BAR 5) shows alternating sequence of coarser and finer grained sediement.

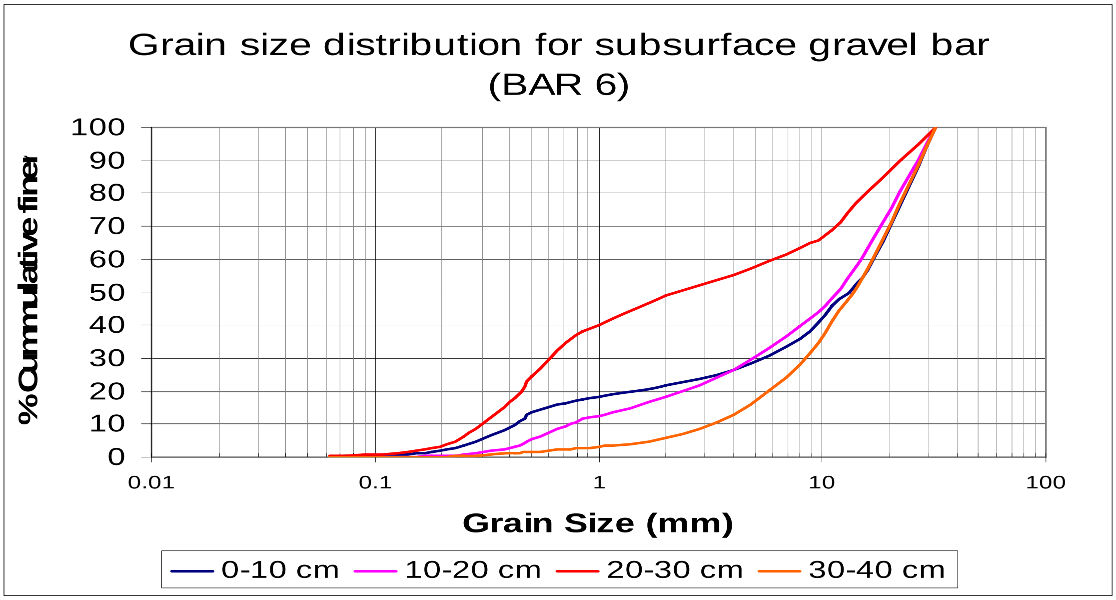

Figure 18: Subsurface grain size distribution for the gravel bar (BAR 6) shows significant quantity of sand 20 to 30 cm below surface. Presence of sand enhances the mobility of gravel bed by lowering the critical dimensionless shear stress.

Table II: Table showing the depth of the sediment in the bar and the amount of sand:

BAR	Depth below the bar surface (cm)	D50	% Sand Content	T*crit
BAR 1	0-10	9.4	19	0.02
	10-20	2.6	39	0.01
	20-30	0.6	62	0.01
	30-40	7.6	22	0.018
BAR 2	0-10	6.4	22	0.018
	10-20	0.7	11	0.035
	20-30	9.6	60	0.01
	30-40	12	9	0.037
BAR 3	0-10	7.6	24	0.016
	10-20	4	25	0.013
	20-30	2.6	30	0.01
	30-40	1.4	47	0.01
BAR 4	0-10	16	12	0.035
	10-20	5	14	0.03
	20-30	3.8	22	0.018
	30-40	12	11	0.035
BAR 5	0-10	5	25	0.013
	10-20	9	18	0.025
	20-30	11	22	0.018
	30-40	8.9	23	0.017
BAR 6	0-10	14	18	0.025
	10-20	12	12	0.035
	20-30	2.3	40	0.01
	30-40	15	4	0.04

The data in Table II were plotted on Figure 19, which shows the percentage of sand in the bar material. The amount of sand in the bedload would affect the critical dimensionless shear stress (Wilcock, 2004). Wilcock's relationships were used to estimate the critical dimensionless shear stress value that this sand would generate.

Although the upward increase in percentage of sand would tend to suggest an increase in bed mobility, the shoaling of the bed due to gravel bar formation would tend to decrease the mobility of the bar as it aggrades due to a decrease in depth and thus shear stress.

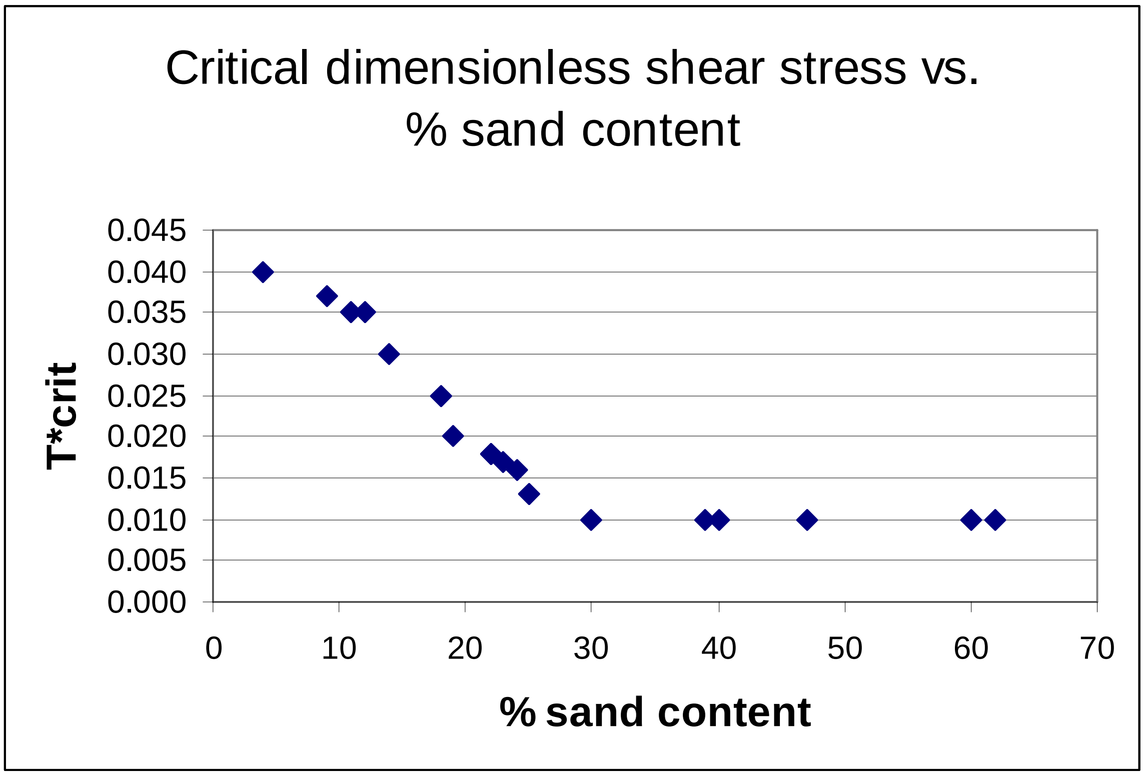

Figure 19: The gravel bars have little sand in the basal deposits and an increase in sand in subsequent deposits.

The channels on sides of the bars are coarse-grained with little subsurface material. This suggests that the bars were formed by highly mobile sand and gravel bedload. Blue dots indicate data for bar shown in Figure 19. Note that initially the bedload contained little sand and had a high critical dimensionless shear stress. Much of the bar was accreted by layers of sand and gravel with sand volumes 30% and higher, which leads to much lower critical dimensionless shear stress values.

6. Conclusions

1. Preliminary data suggest that bank erosion provided significant amounts of sand-sized material to the stream and some gravel sized material.

2. The grain size of bank material decreases from the Sellman Road Site to the Cherry Hill site. This suggests that sand sized material is usually not carried as suspended sediment load in the Cherry Hill sites. If it is not normally carried as suspended load it must either be stored or transported as bedload (or both).

3. Measurement of the gravel bars surface area, thickness, and grain size in the gravel bar complex indicates that there are 3 main bars that contain significant amounts of sand as well as gravel-sized material.

4. The stratigraphy of the gravel bars suggests that they were formed from successive layers of gravel and sand bedload. The upper bedload accretion layers have up to 60% sand, which would have significantly lowered the critical dimensionless shear stress.

5. Gravel bars become stabilized due to accretion and shoaling of the flow depth, not by accumulation of coarse sediment that is relatively stable.

6. Channel sites between gravel bars are depleted in sand-sized material and thus have higher critical dimensionless shear stresses.

7. The storage of sand-sized material in the gravel bars would serve to decrease availability of sand and thus the mobility of bed material in downstream reaches.

Acknowledgements:

I would like to thank my advisor Dr. Karen Prestegaard for her continuous guidance, invaluable suggestions, support, and encouragement. She guided me throughout the project in the field during data collection as well as in the analysis of the field data, and report writing. I would like to thank Zach Blanchet for his cooperation during field work, and for providing necessary data I needed.

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Appendix

Results from sieve analysis

Location	BAR 1											
Layer ht.	0-10cm			10-20 cm			20-30 cm			30-40 cm		
Grain Size (mm)	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer
32			100.00			100.00			100.00			100.00
16	305.70	33.80	66.20	31.80	4.02	95.98	23.80	2.69	97.31	80.00	9.65	90.35
11	104.30	11.53	54.67	82.10	10.39	85.59	37.20	4.21	93.10	109.10	13.17	77.18
8	78.50	8.68	45.99	85.10	10.77	74.82	40.00	4.52	88.58	94.70	11.43	65.75
4	116.10	12.84	33.16	142.20	18.00	56.82	92.90	10.50	78.08	130.80	15.79	49.96
2	77.40	8.56	24.60	78.30	9.91	46.91	63.40	7.17	70.91	60.20	7.27	42.70
1	54.80	6.06	18.54	66.80	8.45	38.46	66.20	7.49	63.42	41.70	5.03	37.67
0.850	11.40	1.26	17.28	14.20	1.80	36.66	15.20	1.72	61.70	10.10	1.22	36.45
0.707	15.90	1.76	15.52	23.60	2.99	33.68	37.70	4.26	57.44	16.30	1.97	34.48
0.500	47.10	5.21	10.32	86.80	10.98	22.69	98.70	11.16	46.28	83.50	10.08	24.40
0.420	27.40	3.03	7.29	59.30	7.50	15.19	73.80	8.34	37.94	47.40	5.72	18.68
0.250	53.80	5.95	1.34	105.90	13.40	1.78	274.20	31.00	6.93	113.90	13.75	4.94
0.180	7.80	0.86	0.48	10.70	1.35	0.43	35.00	3.96	2.97	22.50	2.72	2.22
0.125	2.40	0.27	0.21	2.40	0.30	0.13	16.80	1.90	1.07	9.80	1.18	1.04
0.063	1.60	0.18	0.03	0.90	0.11	0.01	8.70	0.98	0.09	7.10	0.86	0.18
pan	0.30	0.03		0.10	0.01		0.80	0.09		1.50	0.18	
Sample wt. (gm)	904.50			790.20			884.40			828.60		

Location **BAR 2**

Layer ht.	Surface			0-10 cm			10-20 cm			20-30 cm			30-40 cm		
Grain Size (mm)	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer
32			100.00			100.00			100.00			100.00			100.00
16	43.00	11.16	88.84	145.00	25.26	74.74	42.30	7.23	92.77	148.30	25.21	74.79	303.20	38.03	61.97
11	2.80	0.73	88.11	65.30	11.38	63.36	16.30	2.79	89.98	88.80	15.09	59.70	114.90	14.41	47.56
8	37.10	9.63	78.48	52.40	9.13	54.23	43.50	7.44	82.54	113.10	19.22	40.47	84.40	10.59	36.97
4	65.00	16.87	61.60	98.40	17.14	37.09	43.40	7.42	75.12	103.00	17.51	22.96	130.60	16.38	20.59
2	34.30	8.90	52.70	49.50	8.62	28.47	34.50	5.90	69.23	39.50	6.71	16.25	94.40	11.84	8.75
1	30.30	7.87	44.83	35.80	6.24	22.23	61.10	10.45	58.78	30.10	5.12	11.13	10.00	1.25	7.50
0.850	8.50	2.21	42.63	8.20	1.43	20.80	21.70	3.71	55.07	6.40	1.09	10.05	6.70	0.84	6.66
0.707	16.60	4.31	38.32	13.20	2.30	18.50	35.60	6.09	48.98	10.90	1.85	8.19	10.00	1.25	5.41
0.500	54.60	14.17	24.14	40.50	7.06	11.45	132.60	22.67	26.31	17.40	2.96	5.24	19.90	2.50	2.91
0.420	27.00	7.01	17.13	20.70	3.61	7.84	67.00	11.45	14.86	15.80	2.69	2.55	8.80	1.10	1.81
0.250	49.70	12.90	4.23	16.50	2.87	4.97	77.60	13.27	1.59	12.40	2.11	0.44	11.80	1.48	0.33
0.180	10.00	2.60	1.64	25.90	4.51	0.45	7.50	1.28	0.31	1.80	0.31	0.14	1.60	0.20	0.13
0.125	3.70	0.96	0.67	1.60	0.28	0.17	1.40	0.24	0.07	0.40	0.07	0.07	0.50	0.06	0.06
0.063	1.90	0.49	0.18	0.80	0.14	0.03	0.30	0.05	0.02	0.20	0.03	0.03	0.30	0.04	0.03
pan	0.70	0.18		0.20	0.03		0.10	0.02		0.20	0.03		0.20	0.03	
Sample wt. (gm)	385.20			574.00			584.90			588.30			797.30		

Location	BAR 3												
Layer ht.	0-10cm			10-20 cm			20-30 cm			30-40			
Grain Size (mm)	Wt. (gm)	% wt.	Cummulative % finer	Wt. (gm)	% wt.	Cummulative % finer	Wt. (gm)	% wt.	Cummulative % finer	Wt. (gm)	% wt.	Cummulative % finer
32			100.00			100.00			100.00			100.00
16	120.20	16.45	83.55	31.20	4.21	95.79	50.20	6.07	93.93	84.63	15.84	84.16
11	71.00	9.72	73.83	15.60	2.10	93.69	37.10	4.49	89.44	75.94	14.22	69.94
8	76.40	10.46	63.38	23.60	3.18	90.51	66.50	8.05	81.39	69.98	13.10	56.84
4	137.90	18.87	44.51	57.20	7.71	82.80	168.20	20.35	61.04	60.92	11.41	45.43
2	77.70	10.63	33.87	45.30	6.11	76.69	135.10	16.35	44.69	54.12	10.13	35.30
1	63.50	8.69	25.18	52.10	7.02	69.67	117.60	14.23	30.46	46.19	8.65	26.65
0.850	14.00	1.92	23.27	15.40	2.08	67.59	20.40	2.47	27.99	44.07	8.25	18.40
0.707	25.30	3.46	19.80	32.50	4.38	63.21	40.60	4.91	23.08	40.15	7.52	10.89
0.500	61.80	8.46	11.35	112.80	15.21	48.00	88.60	10.72	12.35	27.02	5.06	5.83
0.420	32.20	4.41	6.94	96.10	12.95	35.05	39.00	4.72	7.64	19.93	3.73	2.10
0.250	40.50	5.54	1.40	214.60	28.93	6.12	54.80	6.63	1.00	6.94	1.30	0.80
0.180	5.80	0.79	0.60	29.60	3.99	2.13	5.80	0.70	0.30	2.81	0.53	0.27
0.125	2.20	0.30	0.30	11.60	1.56	0.57	1.50	0.18	0.12	1.19	0.22	0.05
0.063	1.60	0.22	0.08	3.20	0.43	0.13	0.80	0.10	0.02	0.25	0.05	
pan	0.60	0.08		1.00	0.13		0.20	0.02				
Sample wt. (gm)	730.70			741.80			826.40			534.15		

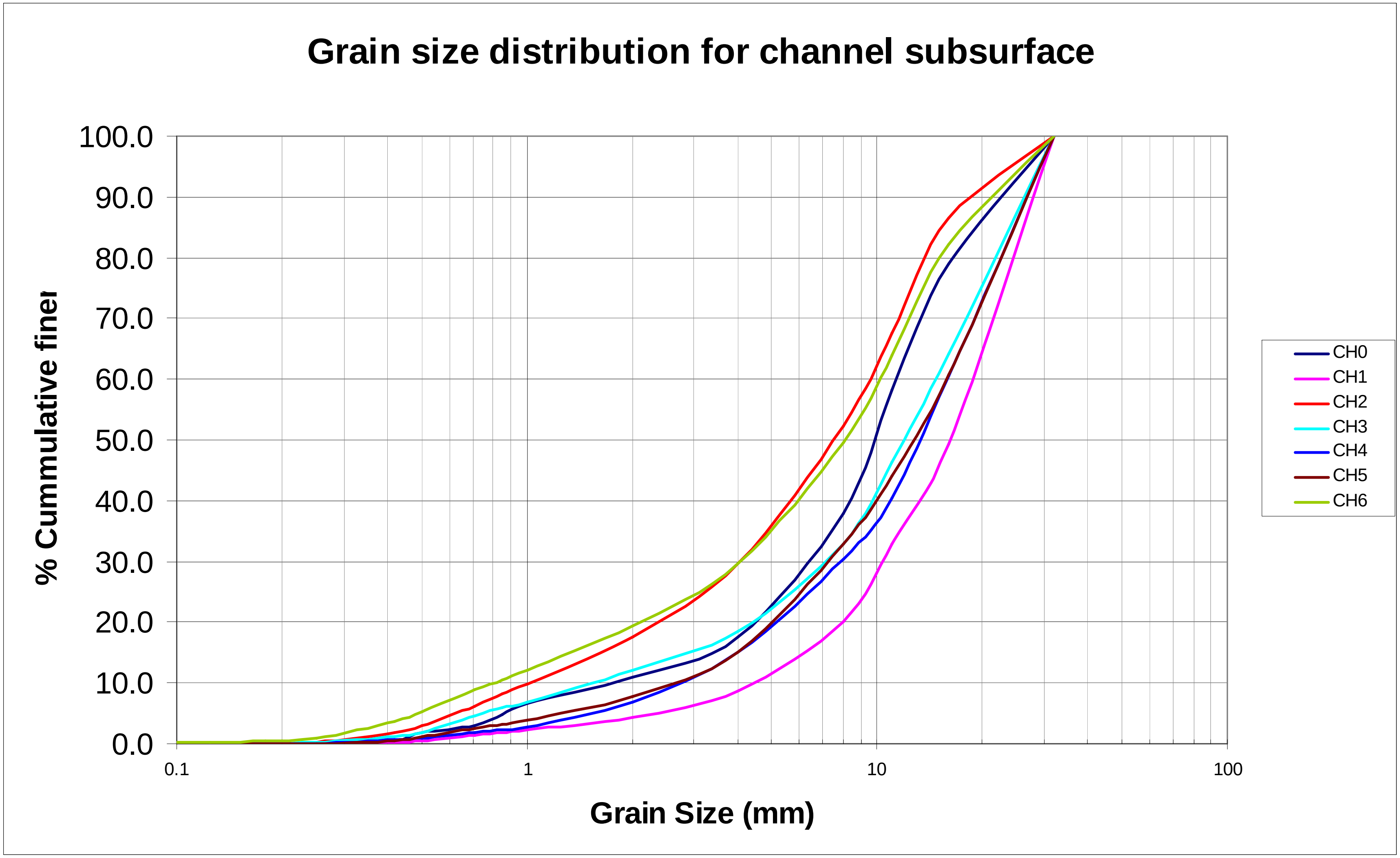
Location **BAR 4**

Layer ht.	Surface			0-10 cm			10-20 cm			20-30 cm			30-40 cm		
Grain Size (mm)	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer
32.0			100.00			100.00			100.00			100.00			100.00
16.0	74.80	15.37	84.63	276.70	53.93	46.07	85.70	20.77	79.23	52.70	9.73	90.27	152.50	31.98	68.02
11.0	42.30	8.69	75.94	60.50	11.79	34.28	21.50	5.21	74.02	40.40	7.46	82.82	103.90	21.79	46.22
8.0	29.00	5.96	69.98	47.70	9.30	24.99	39.40	9.55	64.48	35.40	6.53	76.29	74.60	15.65	30.58
4.0	44.10	9.06	60.92	34.60	6.74	18.24	82.00	19.87	44.61	96.80	17.86	58.42	64.30	13.49	17.09
2.0	33.10	6.80	54.12	13.90	2.71	15.53	68.50	16.60	28.01	87.70	16.18	42.24	15.90	3.33	13.76
1.0	38.60	7.93	46.19	17.40	3.39	12.14	58.50	14.17	13.84	107.60	19.86	22.38	11.60	2.43	11.33
0.9	10.30	2.12	44.07	4.50	0.88	11.26	11.60	2.81	11.02	26.70	4.93	17.46	3.50	0.73	10.59
0.7	19.10	3.92	40.15	6.90	1.34	9.92	13.00	3.15	7.87	31.10	5.74	11.72	21.10	4.43	6.17
0.5	63.90	13.13	27.02	21.40	4.17	5.75	18.20	4.41	3.46	40.40	7.46	4.26	0.50	0.10	6.06
0.4	34.50	7.09	19.93	9.90	1.93	3.82	6.70	1.62	1.84	14.00	2.58	1.68	10.70	2.24	3.82
0.3	63.20	12.99	6.94	14.70	2.86	0.95	6.30	1.53	0.31	7.90	1.46	0.22	14.90	3.13	0.69
0.2	20.10	4.13	2.81	2.50	0.49	0.47	0.60	0.15	0.17	0.70	0.13	0.09	2.70	0.57	0.13
0.1	7.90	1.62	1.19	1.50	0.29	0.18	0.30	0.07	0.10	0.20	0.04	0.06	0.50	0.10	0.02
0.1	4.60	0.95	0.25	0.80	0.16	0.02	0.20	0.05	0.05	0.20	0.04	0.02	0.00	0.00	0.02
pan	1.20	0.25		0.10	0.02		0.20	0.05		0.10	0.02		0.10	0.02	
Sample wt. (gm)	486.70			513.10			412.70			541.90			476.80		

Location **BAR 5**

Layer ht.	0-10 cm			10-20 cm			20-30 cm			30-40 cm		
Grain Size (mm)	Wt. (gm)	% wt.	Cummulative % finer	Wt. (gm)	% wt.	Cummulative % finer	Wt. (gm)	% wt.	Cummulative % finer	Wt. (gm)	% wt.	Cummulative % finer
32			100.00			100.00			100.00			100.00
16	236.20	22.56	77.44	312.20	33.69	66.31	421.30	38.11	61.89	230.00	34.03	65.97
11	131.30	12.54	64.90	114.70	12.38	53.93	123.80	11.20	50.69	57.50	8.51	57.46
8	103.40	9.88	55.02	82.60	8.91	45.01	132.70	12.00	38.68	47.40	7.01	50.45
4	180.70	17.26	37.77	114.00	12.30	32.71	158.20	14.31	24.37	87.80	12.99	37.46
2	23.00	2.20	35.57	68.80	7.42	25.29	74.90	6.78	17.60	54.30	8.03	29.43
1	191.30	18.27	17.30	60.10	6.49	18.80	49.60	4.49	13.11	43.10	6.38	23.05
0.850	16.60	1.59	15.71	13.60	1.47	17.33	11.70	1.06	12.05	10.70	1.58	21.47
0.707	25.90	2.47	13.24	23.50	2.54	14.80	19.20	1.74	10.31	19.20	2.84	18.63
0.500	58.60	5.60	7.64	60.10	6.49	8.31	45.50	4.12	6.20	52.70	7.80	10.83
0.420	20.90	2.00	5.64	22.00	2.37	5.94	21.30	1.93	4.27	27.40	4.05	6.78
0.250	44.00	4.20	1.44	43.60	4.71	1.23	38.80	3.51	0.76	38.50	5.70	1.08
0.180	8.10	0.77	0.67	6.50	0.70	0.53	5.10	0.46	0.30	5.00	0.74	0.34
0.125	3.40	0.32	0.34	2.60	0.28	0.25	1.80	0.16	0.14	1.30	0.19	0.15
0.063	2.60	0.25	0.10	1.70	0.18	0.06	0.90	0.08	0.05	0.70	0.10	0.04
pan	1.00	0.10		0.60	0.06		0.60	0.05		0.30	0.04	
Sample wt. (gm)	1047.00			926.60			1105.40			675.90		

Location	**BAR 6**											
Layer ht.	0-10 cm			10-20 cm			20-30 cm			30-40 cm		
Grain Size (mm)	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer	Wt. (gm)	% wt.	Cumulative % finer
32			100.00			100.00			100.00			100.00
16	202.40	43.11	56.89	206.10	36.43	63.57	303.20	49.32	50.68	303.20	42.84	57.16
11	51.40	10.95	45.94	87.60	15.48	48.09	120.50	19.60	31.07	113.70	16.07	41.09
8	46.90	9.99	35.95	46.60	8.24	39.86	73.60	11.97	19.10	92.60	13.08	28.01
4	44.70	9.52	26.43	75.00	13.26	26.60	69.40	11.29	7.81	108.70	15.36	12.65
2	22.60	4.81	21.62	46.60	8.24	18.36	15.00	2.44	5.37	49.10	6.94	5.71
1	15.40	3.28	18.34	32.80	5.80	12.57	7.40	1.20	4.16	17.90	2.53	3.18
0.8500	3.10	0.66	17.68	6.10	1.08	11.49	1.60	0.26	3.90	1.90	0.27	2.91
0.7070	5.60	1.19	16.49	11.80	2.09	9.40	3.00	0.49	3.42	3.20	0.45	2.46
0.5000	13.40	2.85	13.63	23.40	4.14	5.27	8.00	1.30	2.11	6.50	0.92	1.54
0.4200	17.50	3.73	9.90	11.10	1.96	3.31	4.10	0.67	1.45	2.90	0.41	1.13
0.2500	30.70	6.54	3.37	14.40	2.55	0.76	7.10	1.16	0.29	6.20	0.88	0.25
0.1800	8.00	1.70	1.66	2.70	0.48	0.28	1.10	0.18	0.11	1.20	0.17	0.08
0.1250	4.80	1.02	0.64	0.80	0.14	0.14	0.30	0.05	0.07	0.30	0.04	0.04
0.0630	2.50	0.53	0.11	0.60	0.11	0.04	0.20	0.03	0.03	0.10	0.01	0.03
pan	0.50	0.11		0.20	0.04		0.20	0.03		0.20	0.03	
Sample wt. (gm)	469.50			565.80			614.70	100.00		707.70	100.00	


Grain size distribution for channel subsurface
% Cummulative finer
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.1
1
10
100
Grain Size (mm)
CH0
CH1
CH2
CH3
CH4
CH5
CH6