

## **Bankfull discharge estimation for Fishpot Creek**

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**Abstract:** Fishpot Creek has been investigated and bankfull discharge was calculated based on the collected data points obtained from 3D laser scanning of the stream. This report consists of two major parts. One is the 3D scanning and analysis the results, other part includes sampling of both bed and bank materials. In the first part, essential parameters of roughness coefficient based on Cowan's method were calculated as well as calculating the cross-sectional area and wetted perimeter based on the profile obtained from stream channel scanning. Leica Scan Station HDS 3000 scanner was used to visualize the cross-sectional shape of the stream based on a high-density scan technology and finally applied to the manning's equation to calculate the bankfull discharge. for sampling part both bed and bank materials were analyzed in lab, mechanical sieve test performed to investigate the gradation of bed and banks materials within the study area.

**Keywords:** 3D laser scanning, Fishpot Creek, Bankfull discharge, Bed and banks materials Sampling.

## **1. Introduction**

Calculation and estimation of bankfull discharge considered one of the critical aspects of river engineering which is done based on field investigation, includes data collection, bed and banks materials sampling Getting to know the geomorphologic of the reach is very essential in order to have a good estimation of roughness coefficients which replaced in Cowan's method. Fishpot Creek is a drainage network flowing through the Ozark Plateau in western St. Louis county, Missouri. In this report surveying data collected for bankfull discharge calculation. The objective was to examine one of the reaches with the length of roughly about 1682 ft. = 512.67 meters.

## **2. Model objective**

In this report, field observations in the above-mentioned reach of Fishpot Creek are presented including analysis of the channel morphology using LiDAR data obtained from the river bathymetry. Particle size distribution has been estimated using mechanical sieve analysis for both bed and banks materials. The roughness coefficient,  $n$ , of the channel has been estimated using Cowan's method. Bankfull discharge was calculated based on Manning's equation with information available on the slope of the main channel, roughness coefficient and the channel depth measurement obtained from LiDAR data.

### **3. Previous studies**

An assessment of Fishpot Creek Watershed in St. Louis County, has done in 2001 which was funded by Environmental Protection Agency. Prior engineering studies mainly focused on erosion problems and almost considered it as an isolated issue rather than interconnected processes in a drainage network.

This work applies the science of fluvial geomorphology which includes the study of river form and process based upon a broader, watershed-scale view. Here field assessment of over 19 miles of the open channel have been completed. Data were collected by digital camera and with the help of GPS and all were put into Arc View geographical information system (GIS) to analysis further.[1]

Fluvial geomorphologic findings of Fishpot Creek and its major tributaries presented in a report in 2003 by Saint Louis Soil and Water Conservation District (SWCD). They suggested that a geomorphological analysis would provide much more detail to have a more comprehensive watershed management plan. This investigation focused on flood, sediment and erosion sites with respect to hydraulic and hydrologic engineering by applying fluvial geomorphology approaches. Fluvial geomorphology includes the disciplines which describes how streams and rivers shape the land. [2]

### **4. Study area**

Fishpot Creek is a drainage network flowing through the Ozark Plateau in western St. Louis county, Missouri. Surveying data collected for bankfull discharge calculation based on a surveying trip organized on Monday, October 1<sup>st</sup>, 2018, to the area. The objective of the trip was to examine one of the reaches that extended from the culvert near Parkway High School (38°34'37.7"N 90°30'57.7"W) to the culvert on Big Bend Wood Dr (38°34'20.7"N 90°30'55.4"W). The length of

the examined reach was roughly about 1682 ft. It is designated to be used for livestock and wildlife protection (LWP), protection of warm water habitat (WWH), human health protection (HHP), and whole-body contact recreation category B (WBC-B). The location of the examined reach, Fishpot Creek, MO, U.S. (Figure 1.)

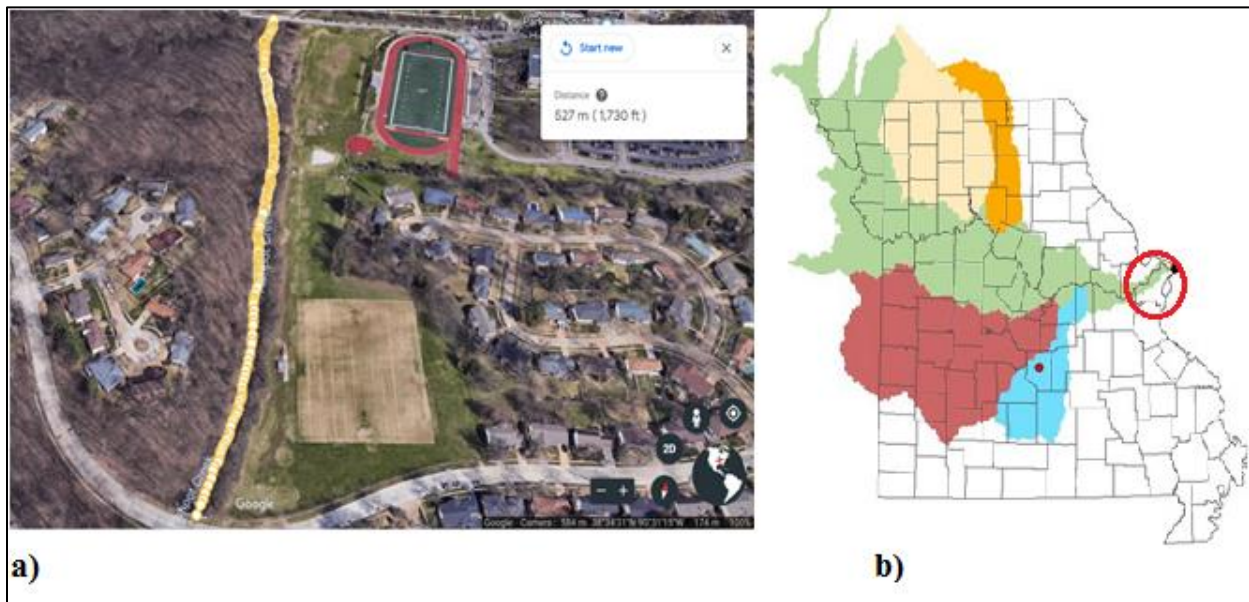


Figure 1. (a) Aerial photograph (from Google Earth) of Fishpot Creek examined reach, marked with the yellow dotted line. (b) Location of Fishpot Creek, circled in red.

The entire U.S. streams as well as HUC-10 and HUC-12 within the State of Missouri with the delineation of Fishpot Creek basin boundary. (Figure 2.) [3]

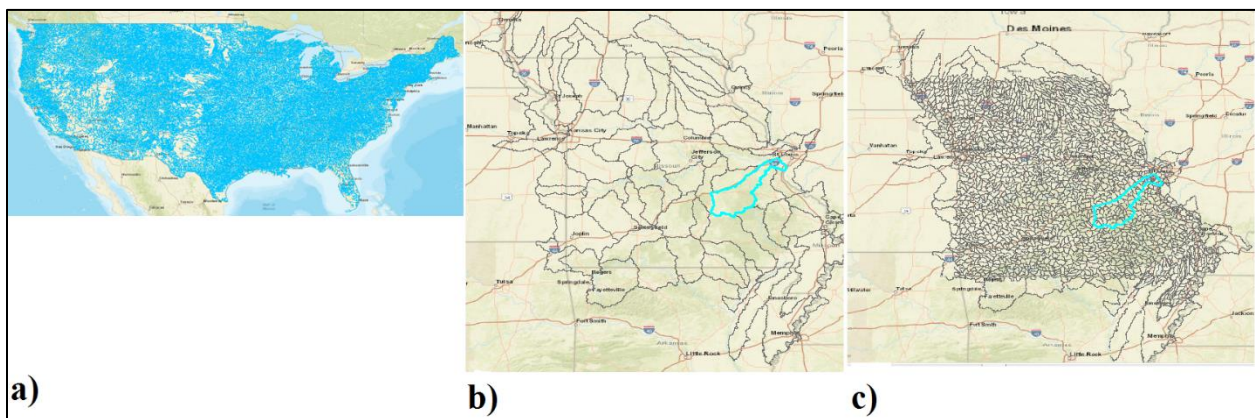


Figure 2. (a) All Streams U.S. (b) Fishpot Creek based on HUC 10. (c) Fishpot Creek based on HUC 12

## 5. Geomorphological characteristics

The Fishpot Creek, per a report made by Little River Research & Design is a drainage network with relatively steeper slopes and channels where supposedly the coarse sediment dominates the geomorphology. The field observations showed mostly coarse and medium gravel for bed rock materials (Figure 3.) [1].

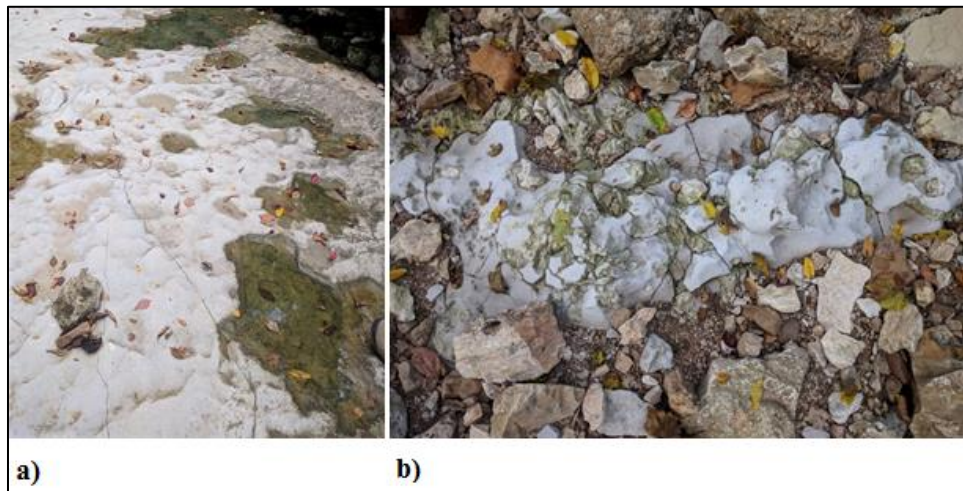


Figure 3. **(a)** The exposed bedrock of Fishpot creek showing carbonate rock-chert strata. **(b)** Coarse and medium gravel along with limestone (bedrock).

The channel was about 40 ft wide and 7 ft deep on an average with slight meandering along the course. Reach-averaged channel depth increases from about 5.0 ft. in Fishpot upland tributaries to only about 11.0 ft. in lower Fishpot.[1] There was significant bank encroachment in the form of vertical cutting shown in Fig 4.a). Observations near the meanders of lower parts of the outer bank seem to have eroded by the water, while inner banks showed corresponding deposition of sediment. Figure 4.b) shows a bank erosion due to root exposure of a tree sticking out close to the bank. Figure 5.a) shows an incision which is an indicator of vertical cut due to a culvert pipe

carrying urban runoff into the stream. In figure 5 b) a gabion observed which served as a bank erosion control structure. In some cases, upstream propagations of incision might result in channel instability.[4-8] Fishpot creek showed frequent occurrence of flash floods in the channel. (Figure 4). [9]

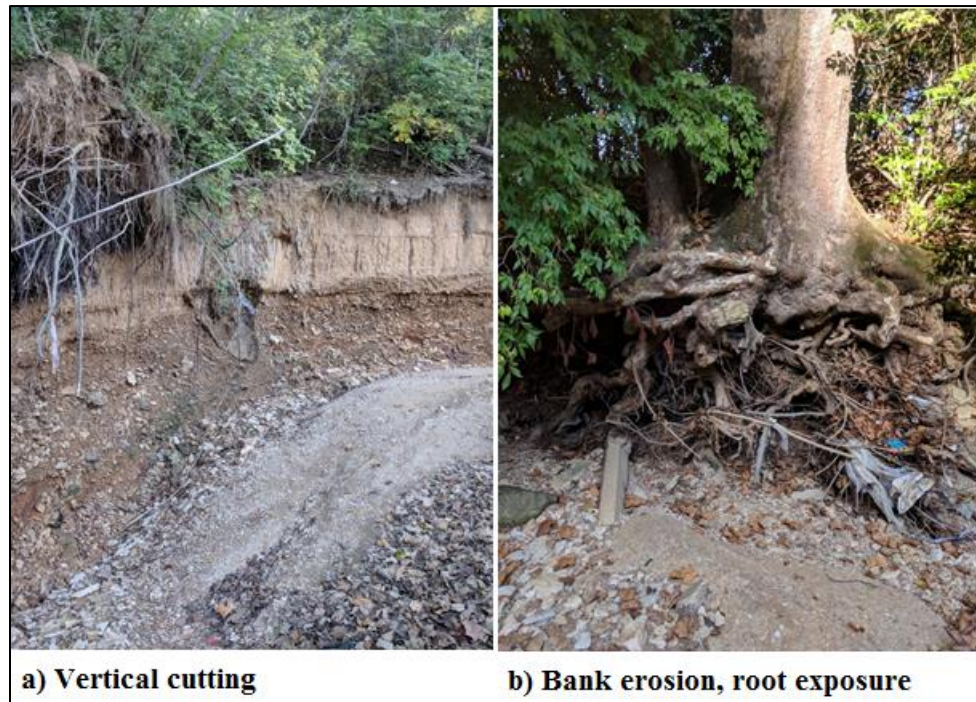


Figure 4. (a) Bank encroachment due to vertical cutting. (b) Erosion of bank material from under a tree exposing the roots

Culvert passing from one bank results in an Incision (Figure 5.a) and, bank protection structure (gabions) which holds the banks material in place as a one piece (Figure 5.b)



Figure 5. (a) Incision formed on the bank due to a culvert pipe. (b) Gabions for bank erosion control with geotextile to prevent smaller particles from being eroded from under the rocks.

## 6. Materials and methods

### 6.1. *Leica HDS3000 3D scanner for channel roughness and discharge estimation*

HDS stands for High Definition Surveying which referred to a 3D laser scanning. Leica HDS3000 is the first 3D laser scanner (Figure 6) from Leica's HDS product family which made the field serving much more effective wherever a wide range of surveying is needed for an engineering project. The distinguish feature of this scanner is the high-density data scanning in comparison to surveying based on discrete points method. When high-density data is viewed on a computer screen, enhanced with intrinsic color effects and 3D visualization, the technology provides unique "high-definition" information.[10-13]

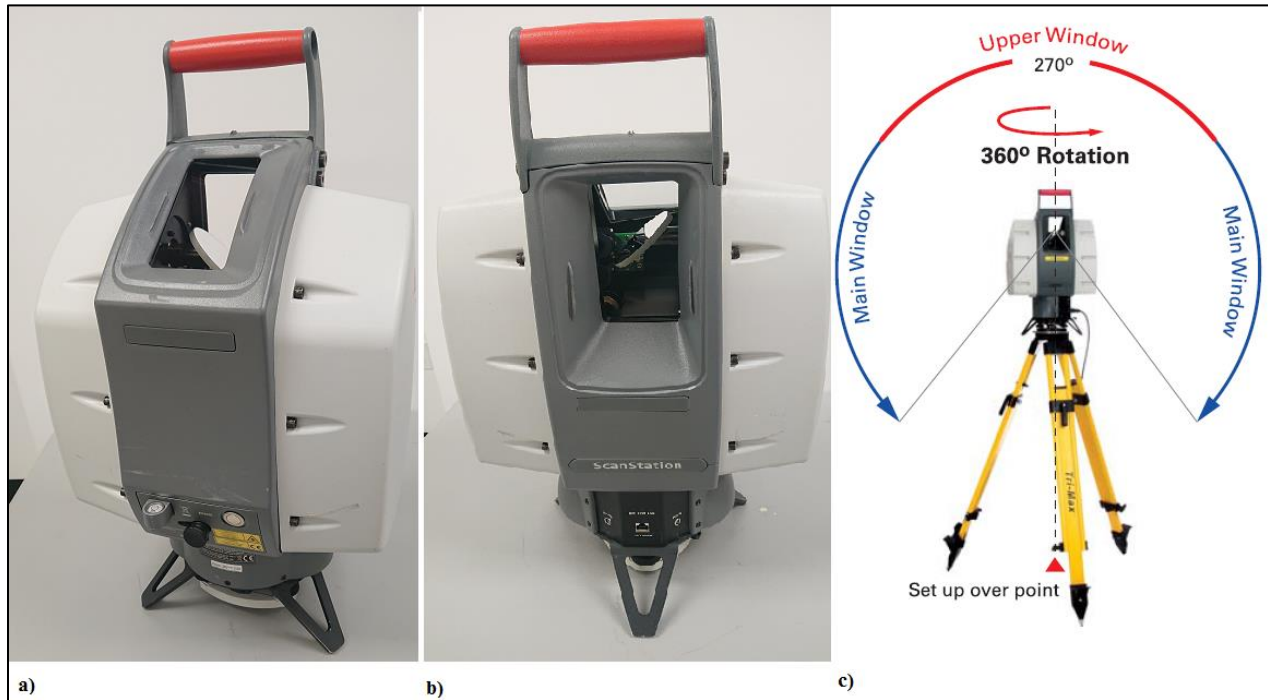


Figure 6. Leica Scan Station HDS 3000. (a) front View. (b) Back View. (c) 360° x 270° field-of-view.

## 6.2. Data analysis using LiDAR and GIS

For further information on the geomorphology, data was collected using a light detection and ranging (LiDAR) instrument and analyzed using GIS and MATLAB soft wares. LiDAR is a remote sensing method used to examine the surface of the Earth. LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. LiDAR points collected from the Fishpot Creek channel. The collected points from LiDAR system were used to build 2D and 3D models of the geographic conditions of the reach. Shape file from points collected by the LiDAR system in Fishpot Creek (Figure 7.a). Triangular irregular networks (TIN) created from shape file viewed in GIS (Figure 7.b) From the shape files of points

and the boundary, a raster file has been created. This was visualized in a 3-dimensional format using Arc scene, which gave the 3D bathymetry of the Fishpot creek based on 3D analysis tool, cross sectional profile created from the tin obtained from previous step (Figure 7.c) Using Linear interpolation, we can have the cross-sectional profile. 3D bathymetry showing the points collected from LiDAR system and, finally (Figure 7.d) shows 3D Bathymetry in MATLAB.[3, 14-16]

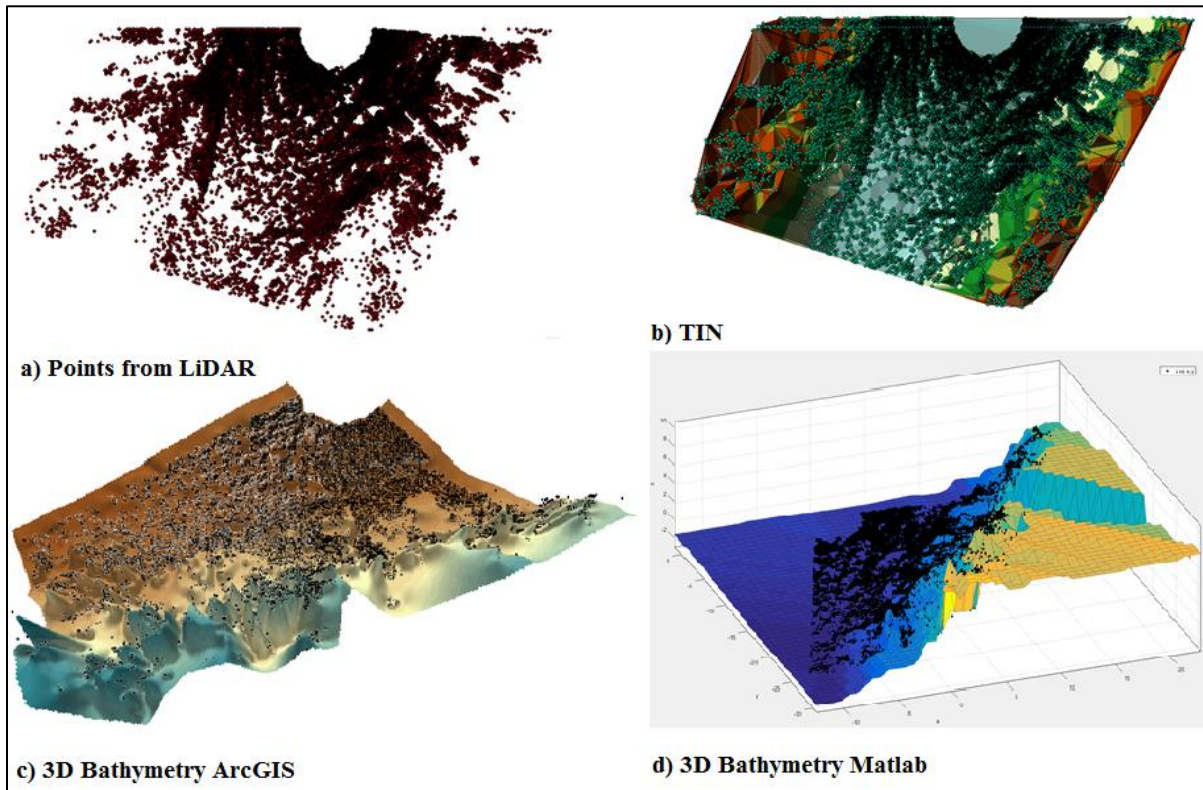


Figure 7. (a) Shape file from points collected by the LiDAR. (b) (TIN) created from shape file. (c) bathymetry showing the points collected from LiDAR system (Arc Scene) (d) 3D Bathymetry in MATLAB

### 6.3. Estimation of particle size distribution

Samples of the bed and banks materials collected from the channel were used to conduct mechanical sieve analysis to estimate particle size distribution in Fishpot creek. Standardized protocols of ASTM D 421, ASTM D 422, AASHTO T 87 and AASHTO T 88 were used to perform

the analysis. Sample of bank material collected during the survey (See S.I., Figure B-2). [2, 3, 17, 18]

#### **6.4. Method**

For each type of materials (bed and banks), a sample of 500g was taken and washed with water by placing the sample on No. 200 sieve. The washing was done until the water passing through the sieve looked clear.

The washed sample was then dried in an oven at 110°C for at least 24 hours or until the sample achieved complete dryness. [17]

The sample was placed onto the sieve stack with standard sieves numbered from No. 4 to No. 200 and put on a mechanical shaker for 5 min. The segregated samples were collected from each sieve and weighed for size distribution analysis.[2]

#### **6.5. Results and data analysis for bed and banks materials**

The sieve analysis data for bed materials is presented in Table 1 and bank materials in Table 2. The analysis showed more reasonable coefficient of uniformity,  $C_u$ , for bed materials (Table 1), because the difference between  $D_{10}$  and  $D_{60}$  was smaller (Figure 8.) in comparison to banks materials. Bank materials includes bigger portion of fine materials hence showed a huge difference between  $D_{60}$  passing and  $D_{10}$  passing particle. The coefficient of curvature,  $C_c$  values showed a range of well graded particle sizes.

Well graded soil:

Gravel:  $C_u > 4$  and  $1 < C_c < 3$ . Sand:  $C_u > 6$  and  $1 < C_c < 3$ .

By this definition most part of the bed and banks material were representing well graded sand in terms of soil type classification. The results of bed and bank material particle size distribution are presented below.

### 6.5.1. Bed materials

$$D_{10} := 2 \text{ mm} \quad D_{30} := 4.75 \text{ mm} \quad D_{60} := 12.5 \text{ mm}$$

$$C_u := \frac{D_{60}}{D_{10}} = 6.25 \quad C_c := \frac{D_{30}^2}{(D_{10} \cdot D_{60})} = 0.903$$

Table 1: Particle size analysis using mechanical sieving (Bed Materials)

Sieve No.#	Diameter (mm)	Mass retained	Mass passing	% passing
2"	50	0	2082.85	100
1.5"	37.5	0	2082.85	100
1"	25	288	1794.85	86.17
0.75"	19	255	1539.85	73.93
0.5"	12.5	274.35	1265.5	60.76
0.375"	9.5	164	1101.5	52.88
4	4.75	420	681.5	32.72
10	2	404	277.5	13.32
20	0.85	189.5	88	4.222
40	0.425	59.3	28.7	1.38
60	0.25	15	13.7	0.66
200	0.075	9.5	4.2	0.20
Pan		4.2	0	
		2082.85		

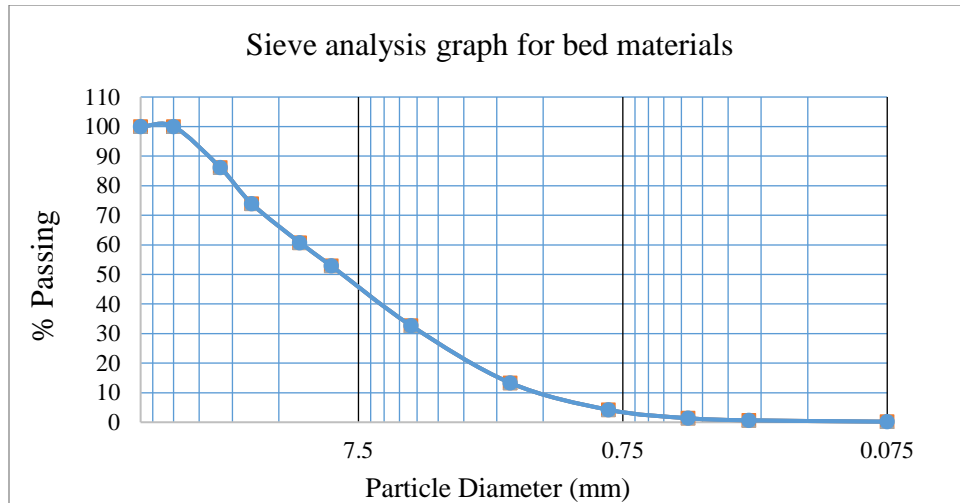


Figure 8. Graph showing grain size distribution for bed materials.

### 6.5.2. Banks materials

$$D_{10} := 0.85 \text{ mm} \quad D_{30} := 4.75 \text{ mm} \quad D_{60} := 19 \text{ mm}$$

$$C_u := \frac{D_{60}}{D_{10}} = 22.353 \quad C_c := \frac{D_{30}^2}{(D_{10} \cdot D_{60})} = 1.397$$

Table 2: Particle size analysis using mechanical sieving (Banks Materials)

Sieve No.#	Diameter (mm)	Mass retained	Mass passing	% passing
2"	50	0	690.42	100
1.5"	37.5	46.83	643.59	93.22
1"	25	144.86	498.73	72.24
0.75"	19	60.03	438.7	63.54
0.5'	12.5	84.05	354.65	51.37
0.375"	9.5	36.57	318.08	46.07
4	4.75	84.33	233.75	33.86
10	2	88.23	145.52	21.08
20	0.85	65.07	80.45	11.65
40	0.425	31.55	48.9	7.08
60	0.25	17.68	31.22	4.52
200	0.075	30.2	1.02	0.15
		1.02		0
		690.42		

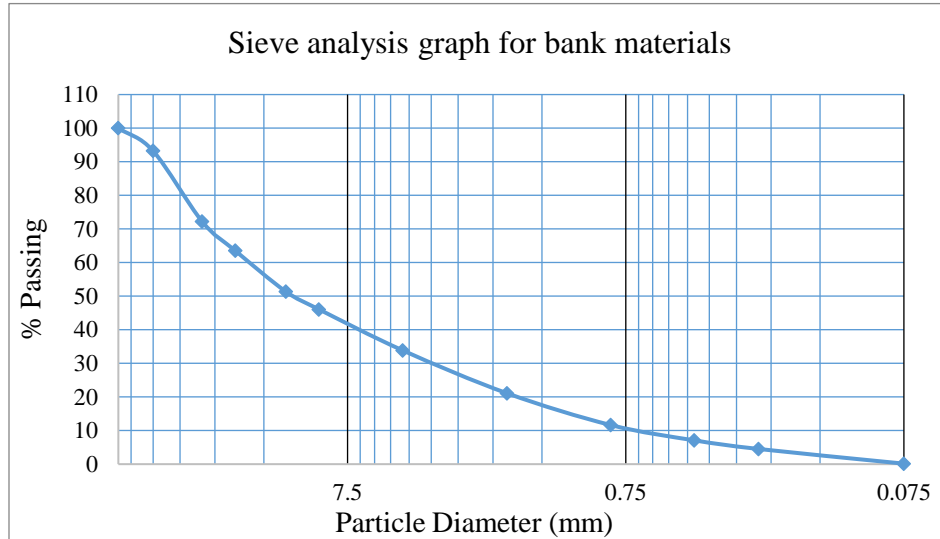


Figure 9. Graph showing grain size distribution for bank materials

## 7. Results

### 7.1. Estimation of Manning’s roughness “n”

To determine the roughness, the Cowan’s method was used.[19-21]. Cowan’s equation is as follows,

$$n = (n_0 + n_1 + n_2 + n_3 + n_4) * m.$$

where  $n_0$  = base value for a straight, uniform channel,  $n_1$  = additive value to account for effect of cross-section irregularity,  $n_2$  = additive value to account for variations in size and shape of channel,  $n_3$  = additive value to account for effect of obstructions,  $n_4$  = additive value to account for type and density of vegetation; and  $m$  = adjustment factor for the degree of channel meandering; determined by the ratio of channel meander length ( $L_m$ ) to valley or straight-channel length ( $L_s$ ).

Each value of the Cowan’s equation can be determined based on the tables presented in Figures A-1 to A-6 (Appendix A). Fishpot creek possessed a channel with fine and coarse gravel with a various size of rock spread. Based on the characteristics of the channel  $n_0$  can be determined by the middle value between 0.024 and 0.028 from the table. Thus,  $n_0$  is equal to 0.026. For the second n value needed from the Cowan equation, the degree of irregularity based on smooth,

minor, moderate, or severe is used to produce the value. Fishpot creek contained many scour holes and undermining of trees when high velocity was present during high flow times. Thus, the  $n_1$  value is 0.020. Character of variations of size and shape of cross sections is how the third n value is produced. This is based on how often the cross section of the channel changes within Fishpot creek. When comparing the values from Fig.3. and the characteristics of Fishpot creek, the third n value ranged from 0.010 to 0.015. Since the creek energy line, and thalweg, changed sides frequently, but stabilizes at the downstream slightly, 0.010 value was used. The fourth n value, is determined based on the relative effect of obstructions within the creek based on negligible to severe categories. The creek consisted of several manmade structures, as presented in the introduction, and seemed to be a dumpsite for materials such as brick, pipes, metal, etc. Based on this fact, the appreciable range of 0.020-0.030 was used to determine the value of 0.025 for the fourth value. The fifth n value consisted of the vegetation effect on n. This value is determined based on the degree of vegetation within the channel and ranges from a low to a very high range. The channel did not possess vegetation within the channel, and very little on the banks, thus the low modifier was used to produce a value of 0.005. Lastly, the m value is determined based on the degree of meander within the channel. The range of this value ranges from minor to severe and is determined based on the ratio of meander length to straight length. Based on one of the meanders within the channel, the meander length (**Fig.10.a**) to straight length (**Fig.10.b**) ratio was 1.02. Degree of meander within the channel or m value was calculated.

$$\frac{\text{meander length}}{\text{straight length}} = \frac{L_m}{L_s} = \frac{527\text{m}}{513\text{m}} = 1.02, m=1.00 \text{ (Table A-6 Appendix A)}$$



**Fig. 10.** Image of Google Earth showing (a) meandering length and (b) straight length estimation of Fishpot Creek

Using one as the modifier, (m value), all six values were calculated, the roughness of the channel can be shown as follows:

$$n_0 := 0.026 \quad n_1 := 0.020 \quad n_2 := 0.010 \quad n_3 := 0.025 \quad n_4 := 0.005 \quad m := 1$$

$$n := (n_0 + n_1 + n_2 + n_3 + n_4) \cdot m = 0.086$$

$$n = (0.026 + 0.020 + 0.010 + 0.025 + 0.005) * 1 = 0.086$$

Thus, the overall roughness of the channel at Fishpot creek is estimated to be 0.086

## 7.2. Bankfull discharge

Fishpot creek has a mild slope of 0.006 and maximum depth of up to 7m. The cross-sectional area has been computed from the XS profile (Appendix B), using integration (by dividing the total area into smaller rectangular and triangular areas, Fig. B-1 in Appendix B). The cross-sectional area in the examined reach was roughly 228.5 m<sup>2</sup> and the wetted perimeter was approximately 62 m. This

gave the channel a hydraulic radius, R, of 3.68. Manning's equation was used to predict bankfull discharge of the channel.

### 8. Data analysis for bankfull discharge and

Fishpot Creek cross sectional profile sample calculation sheet presented in appendix B in supplementary materials. (See S.I. Figure B-1) The area simply divided into two smaller triangles and based on the scale of the graph the area and wetted perimeter were calculated.

$$A := 228.5 \text{ m}^2 \quad P := 62 \text{ m} \quad S := 0.006 \quad n := 0.086$$

$$R := \frac{A}{P} = 3.685 \text{ m} \quad V := \frac{1}{n} \cdot 3.685^{\frac{2}{3}} \cdot S^{0.5} \frac{\text{m}}{\text{s}} = 2.149 \frac{\text{m}}{\text{s}} \quad Q := A \cdot V = 491.008 \frac{\text{m}^3}{\text{s}}$$

With a roughness coefficient of 0.086 from Cowan's method as described above, the channel is estimated to have a total discharge of 491.00 m<sup>3</sup>/s under bankfull conditions.

### 9. Conclusion

To calculate bankfull discharge, calculation of area, wetted perimeter and hydraulic radius were needed. Estimation of such parameters resulted from bathymetric LiDAR data point helped us in computing cross-sectional area using integration method. Cowan's equation has been used to estimate the Manning's Roughness coefficient. **The** flow rate of 491 cms, seems to be reasonable considering geomorphology and wetted perimeter of the area according to previous report. [2] Field observation showed that erosion control structures were not in their best condition where the geogrid fallen apart in some of rip-rap structures. [22, 23] This means the stream needs maintenance with repair or replacement of existing erosion control structures. Some debris near the culvert need clean up to not obstruct the flow condition in bankfull discharge condition. Yet collecting more

LiDAR data point from upstream and downstream section of stream will help us to obtain average values for reach and provide more accurate results.

### **Abbreviation**

**A:** Area ( $m^2$ )

**P:** Wetted perimeter ( $m^2$ )

**S:** Channel Slope (m/m)

**n:** Manning's Roughness Coefficient

**R:** Hydraulic radius (m)

**V:** Flow Velocity (m/s)

**Q:** Discharge ( $m^3/s$ )

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