Stoney Creek Ecological Restoration Post-Project Appraisal:

Soil Quality Survey

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Abstract

The state of the soil in the riparian area around an urban stream, Stoney Creek, in Burnaby, British Columbia was investigated. This site had recently been disturbed by a salmon habitat restoration project. Our study aimed to provide a first set of data for post-project soil quality assessments in this region. Four soil pits were excavated and various soil samples were collected. These samples were transported to the Soil Science Lab at Simon Fraser University for laboratory analysis, where soil texture, bulk density, acidity, water content and erodibility were assessed. Although no root growth limiting bulk density and pH levels were found, the results indicated that soil compaction had some effect on bulk density, acidity and water content. This set of soil data is limited in its comprehensiveness and therefore future soil quality monitoring projects are recommended.

Key words: soil, ecological restoration, texture, bulk density, soil compaction, acidity, pH, soil water, and erosion

Introduction

Stoney Creek is an urban stream in Burnaby, British Columbia (BC), Canada. Its head water starts on Burnaby Mountain and it feeds into Burnaby Lake **(Figure 1)**.

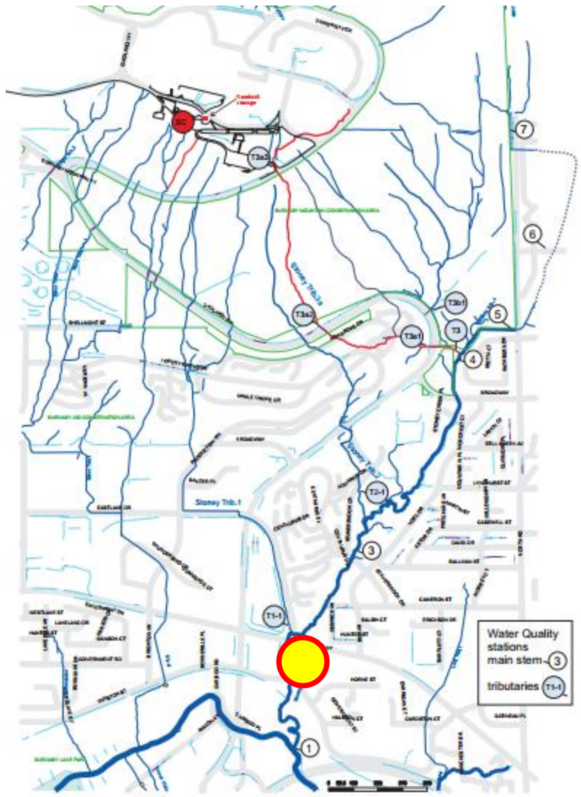

Figure 1. An overview of Stoney Creek and its tributaries. The thicker blue line represents the main stream of Stoney Creek. Stoney Creek enters Burnaby Lake at the bottom left corner of this figure. The large yellow circle displays the study area. (SCEC, n.d.)

As part of the 2012 Stoney Creek Restoration Project, the Stoney Creek Environment Committee (SCEC) cooperated with Pacific Salmon Foundation to build a pond for an off-channel salmon habitat in the area between Lougheed Highway and Government Street. Pipes were buried underground to drain water into the pond and the pond was reconnected back to the creek downstream. During the installation of pipes and other parts of the restoration project, heavy machines were utilized in the area and surface soil compaction was observed after the completion of the project.

The goal of this project was to establish an initial set of soil quality data for the restoration site and to investigate any relationships between soil quality attributes, soil compaction and overall soil wellbeing. Due to limitations in available time and resources for this project, a comprehensive soil survey, which would involve sampling a multitude of attributes over several years, was not possible. Our study involved the measurement of soil texture, bulk density, acidity, water content, and stream-bank erosion.

Soil Texture and Bulk Density

Bulk density is influenced by soil texture. The amount of clay present in a soil effects average pore size and resistance to root penetration (Brady & Weil, 2008). Root growth can be limited if bulk density is larger than 1.45 Mg/m^3 in clay soils, but begins to be limited at 1.85 Mg/m^3 for loamy sands soils (Jones, 1983). The normal range of bulk density also varies with different kinds of soil: 0.9-1.5 Mg/m^3 for clay and silt loam soils, and 1.3-1.8 Mg/m^3 for sands and sandy loam soils. Soil water potential, a measure of how difficult it is for plants to uptake water, is also effected by soil texture as the potential can be different with the exact same amount of soil water content (Saxton, Rawls, Romberger, & Papendick, 1986).

Soil Acidity

The acidic, basic, or neutral nature of a soil greatly influences the types of vegetation and organisms that can establish themselves within a soil (Brady & Weil, 2008). Some plants and organisms flourish in acidic conditions and some prefer basic environments, while others prefer neutral soils (Huda et al., 2009). Soil acidity can also affect the mobility of pollutants and therefore can be used in possible water contamination studies (Brady & Weil). The pH of a soil is an easily measured and helpful tool when evaluating an areas soil quality and well-being.

Soil Water Content

Soil is composed of three generalized parts: solid, liquid and gas. The solid part is not a continuous mass, but is broken into individual grains with soil pores between them that can be filled with water and air (McGarry, 2005). Soil water content is the amount of water contained in the soil. It plays a very important role in many agronomic, hydrologic and geotechnical practices (Or & Wraith, 2001). Soil water content can be expressed in two forms: mass and volume. Soil water content, expressed using mass, is the fraction of water mass to dry soil mass and, expressed using volume, is the volume of water per bulk volume of soil (Or & Wraith).

Stream-bank Erosion

Stream-bank erosion rates are frequently modeled using the excess stress equation:

$$E_r = K_d(\tau - \tau_c)^a$$

E_r is the erosion rate ($m*s^{-1}$), K_d is the erodibility coefficient ($s*m^{-1}$), τ is the applied shear stress (Pa), τ_c is the critical shear stress (Pa), and a is an exponent typically assumed as equal to 1 (Hanson & Simon, 2001). The erodibility coefficient and critical shear stress are considered soil properties for use in soil classification and design purposes. The goal was to compare root density on the bank face for riparian vegetation and to develop empirical models to predict the erodibility coefficient (K_d) of the bank. Relationships relating root volume ratio (RVR) and bulk density to soil erodibility have been quantified, thus allowing stream-bank soil erodibility for vegetated stream-banks to be predicted based on easily measured site parameters (Pollen, 2007). A simplistic model of K_d can be derived from rooting and bulk densities. A soil erodibility equation has been previously derived that predicts K_d from relationships of big roots (diameters less than 2mm) to volume ratio and bulk density (Wynn & Mostaghimi, 2006):

$$\log(K_d) = 0.52 - 0.31 * (\text{Bulk Density})^{2.5} - 0.06 * \ln(\text{BRVR})$$

Methods

Sampling

Samples for soil texture, bulk density, acidity and water content were collected at four different sites (**Figure 2**). The sites were chosen to represent areas of compacted or non-compacted soil. A site was determined to be compacted or non-compacted through visual evaluation, which would be further investigated through our soil quality attribute measurements. At each site either a pit was dug or a soil profile was exposed in order to obtain samples from varying soil depths. Two samples, A and B, were collected from each site for both soil bulk density and water content. The samples used for bulk density were also used for determining soil texture and acidity.

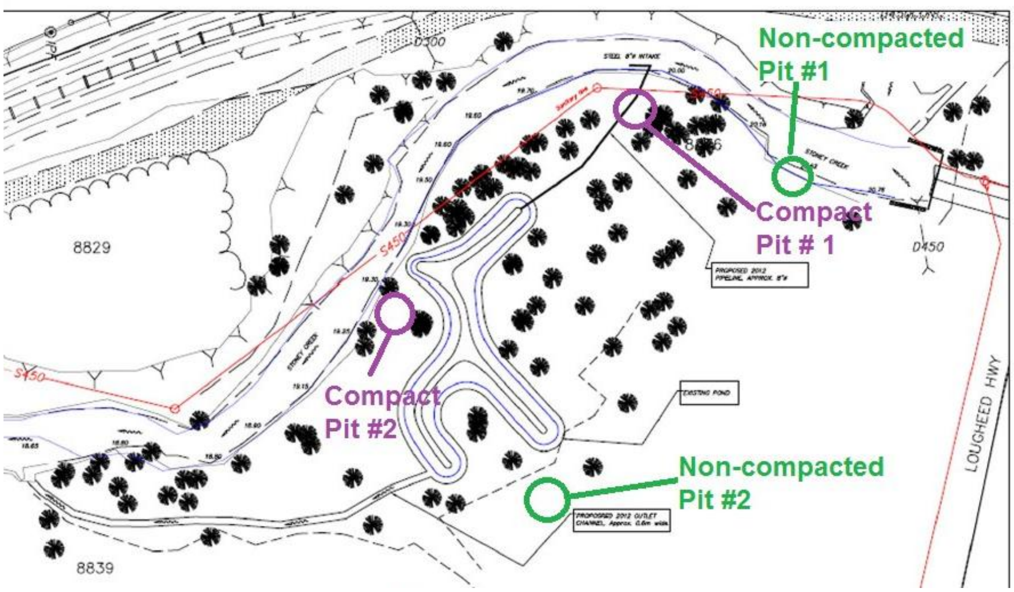

Figure 2. The area around the off-channel habitat pond. The four locations of soil sample collection are displayed. (SCEC, 2012)

Soil Texture

The hand analysis method was used to assess soil texture. This method is commonly used by soil scientists in the field and has been adopted by the BC Ministry of Forests, as well as the Ministry of Environment, Land and Parks, to assess soil texture. According to the flow chart in *Field Manual for Describing Terrestrial Ecosystems*, Appendix 2.4, by MELP and MoF (1998), the soil sample must be in a moist condition when using this method. The grinding of some soil between fingers can estimate the rough percentage of sand content in the soil. One will then try to make a cast: a strong cast relates to high stickiness and high clay content. From the grittiness and soapiness of the soil, we can estimate the silt content in the soil. The portion of sand, silt and clay determines the texture class of the soil.

Soil Bulk Density

Bulk density was determined via standard core sampling techniques. A metal corer, of known volume, was driven into the soil at specific depth to gather the sample. The sample was then placed in an oven at 105°C for 24 hours, followed by a 6 hour cool-down period before being weighed. This is the standard procedure as described in *Soil Sampling and Methods of Analysis* by Carter and Gregorich (2008).

Soil Acidity

Soil acidity was determined through pH measurements. The pH of soil samples were measured using store bought test kits, "CIL Lawn and Garden Soil Test Kit." To determine the pH of a soil sample, the guidelines described by the test kit were followed: 1) fill a provided vial to the first line with the sample, 2) pour the contents of a pH test capsule into the vial, 3) fill the vial with water up to the fourth line, 4) thoroughly mix contents and wait one minute before comparing the colour of the mixture to the pH legend.

Soil Water Content

According to McGarry (2005), he introduced four major methods used in measuring soil water content. The direct measurement uses the thermogravimetric method to determine the amount of water removed from the soil via oven dried samples. Neutron thermalization, FDR (capacitance), and TDR (time domain reflectometry) are indirect measurements which determine some physical and chemical properties of the soil affected by soil water content (McGarry). With appropriate comparisons between the strengths and weaknesses of the four measurement methods, the thermogravimetric method was chosen for our work as it: costs less; operates simply, both in the laboratory and on site; and is the calibration standard for indirect methods. A trowel was used to gather the soil samples and transfer them to a moisture-tin – an airtight container. It is essential to use an airtight container because samples are easily contaminated by water molecules in air. Wet (fresh) samples were weighed in their containers and were then transferred into an oven at 105°C where they dried for 24 hours, followed by a 6 hour cool-down time. The samples' dry weights were then determined. According to Or & Wraith (2001), the mass soil water content (θ_m) can be expressed as:

$$\theta_m = \frac{mass\ of\ water}{mass\ of\ dry\ soil} = \frac{(mass\ wet\ soil) - (mass\ oven\ dry\ soil)}{mass\ oven\ dry\ soil}$$

where the θ_m should be a fraction usually less than 1.

Stream-bank Erosion

Three different sites were selected along the Off-Channel Stoney Creek Restoration Project, as seen in **Figure 3**. These sites were selected along different reaches of the stream: site #1 was heavily colonized with grass; site #2 consisted of a primarily moss, with a mixture of English Ivy; and site #3 was almost bare of top vegetation, due to a recent pipe installation.

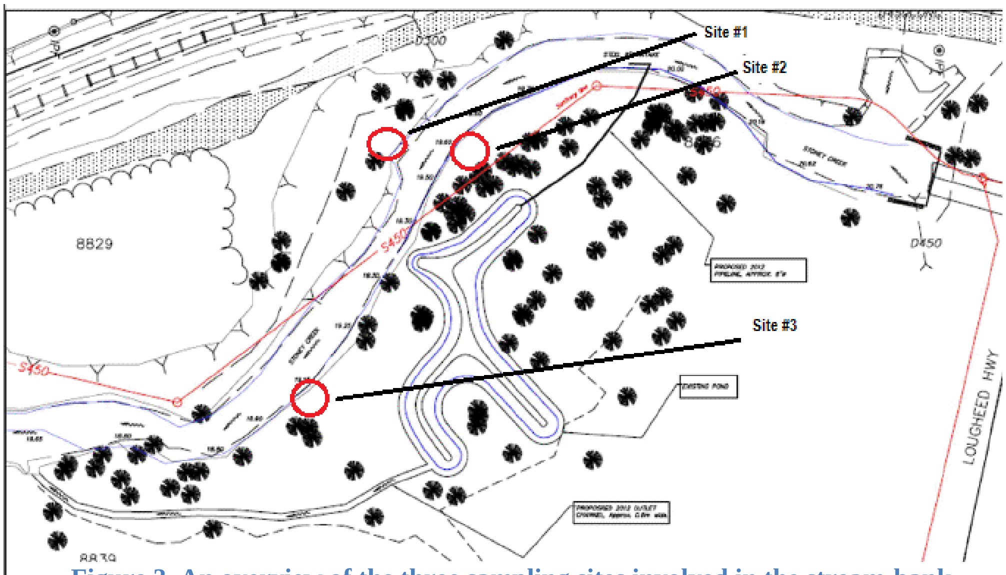

Figure 3. An overview of the three sampling sites involved in the stream-bank erosion investigation. (SCEC, 2012)

Root samples were taken from the lower stream banks (**Figure 4**). A 7cm diameter, 14cm long, soil cylinder was used to take a soil core sample at each site, on the lower bank (**Figure 4**). The amount of big roots (diameter greater than 2mm) were identified, since it is the big roots that have shown significance increases in a soil's resistance to erosion (Wynn & Mostaghimi, 2006). Bulk density was also measured for each of the sites because of its contribution to erodibility resistance. After performing bulk density measurements, samples were submerged in water to float any organic debris. Extracted roots were measured for length and diameter.

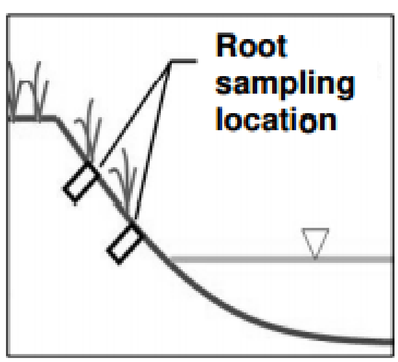

Figure 4. A depiction of the root sampling locations.

Results and Discussion

Soil Texture

The compacted sites exhibited mainly sandy soils. This result was expected, as this location was heavily disturbed less than half year ago and little time was available for soil development. The lack of vegetation and litter coverage reduces the organic acid available for weathering effects to occur. See **Figure 5** for the complete result of the soil texture assessment.

Sample	Horizon	Texture
Compact 1a	No-layering	Sandy loam
Compact 1b	No-layering	Loamy sand
Compact 2a	No-layering	Silt loam
Compact 2b	No-layering	Sandy clay loam
Non-compacted 1a	Ah	Loam
Non-compacted 1b	Bm	Sandy loam
Non-compacted 2a	Ah	Sandy Loam
Non-compacted 2b	C	Loamy sand

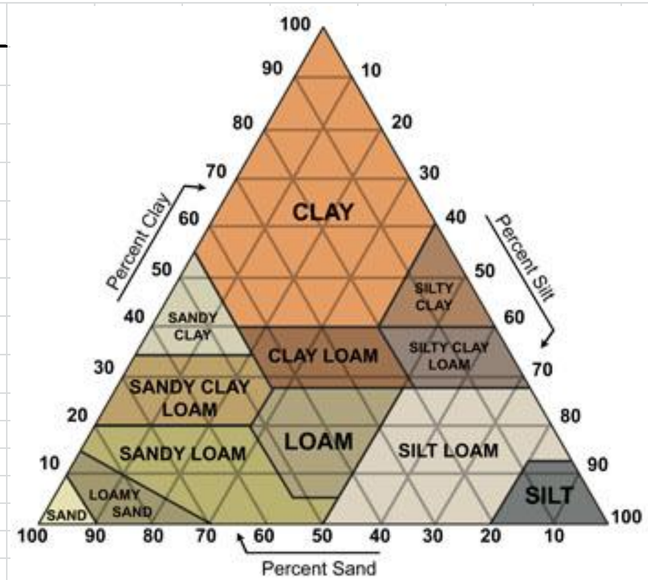

Figure 5. Soil texture assessment of samples collected in Stoney Creek area between Lougheed Hwy and Government St. (Brady & Weil, 2008).

The non-compacted pits are more consistent with loam to loamy sand type soils while the compacted sites have no consistent pattern (jumping from sandy loam to silt loam to sandy clay loam). These results, however, are not surprising. At the compacted sites, all soil was once removed to install the pipes. The processes of digging and filling soil greatly disturbed the vertical development in these locations (**Figure 6**). This random vertical distribution, or homogenization, of soil texture can impact soil water movement and ultimately plant nutrient and water uptakes.

Figure 6. Comparison of disturbed and undisturbed soils. Clear layering is shown in undisturbed soil but not in the disturbed soil.

Although more precise measurements of soil texture, such as the hydrometer method, are available, they are often more time consuming and expensive. For example, the hydrometer method requires using a hydrometer, sedimentation cylinder, sediment mixer and Amyl acid. The time required for each texture measurement is about 3 hours. In contrast, the hand method requires no instruments and little time. Additionally, trained soil personnel can have up to a 60% chance of finding the correct texture class, or at least a similar texture class if not correct (Post, Parikh, Papp, & Ferriera, 2006).

Soil Bulk Density

The measured value of bulk densities for all the samples collected are listed below in **Table 1**. Bulk density values were found to differ between the compacted and non-compacted sites. The bulk density of the compacted pits exhibit much less variation and are generally higher than that of the non-compacted pits (**Figure 7**). Lower variation is likely due to the soil homogenization that occurred when the pipeline and pond were constructed. Heavy machinery was used to move the soil; this greatly disturbed its vertical development and essentially reset the soil. Similar homogenization of soil and its properties were observed in Unghire et al.'s (2011) study of a restoration project in North Carolina. The greater bulk density measured at the compacted sites can also be attributed to the use of heavy machinery, as the weight of the machines can easily compact the soil past its natural state. Increased human traffic in the area is another possible source of compaction as our compacted pits were located directly beside well-developed paths leading to a monitoring station and the pond. Our measurements indicate that soil bulk density increases with depth. Brady and Weil (2008) explain that this is to be expected and is due to the weight of the soil above as well as less organic matter content and organism activity.

Table 1. The bulk density values for the samples collected at each site along with their depths.

Site\Sample	A	Sample Depth	B	Sample Depth
Compacted I	1.10	27.00	1.33	42.00
Compacted II	0.70	20.00	1.06	30.00
Non-Compacted I	0.48	5.00	1.05	60.00
Non-Compacted II	0.63	8.00	1.37	65.00

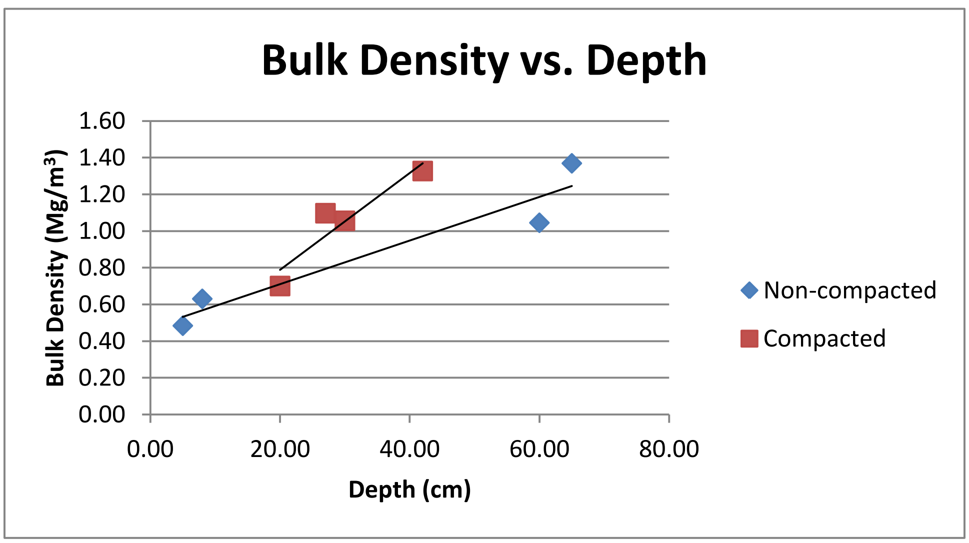

Figure 7. A plot depicting the relationships between bulk density and sample depth for compacted and non-compacted samples. Note the slope of compacted sites curve is steeper than non-compacted sites.

If soil becomes severely compacted it can inhibit the growth of plant roots. According to our measurements, none of our sample areas will experience difficulties in root growth as bulk densities did not exceed the 1.45Mg/m^3 or 1.85Mg/m^3 thresholds as described earlier. Even with distinct differences between the compacted and non-compacted sites, bulk density appears to have not experienced a significant enough of a change to prevent plant growth. However, the effects of soil homogenization can be investigated further to identify if distinct horizons in disturbed areas form once again.

Soil Acidity

The measured value of pH for all the samples collected are listed below in **Table 2**. For all sites, the samples closer to the surface exhibited lower pH values than the deeper samples, which is consistent with general soil pH characteristics (Brady & Weil, 2008). This is due to acidifying processes initially occurring near the surface and then working their way down through the soil's horizons (Brady & Weil). While the slopes of the individual best fit lines on the plots differ (**Figure 8**), when all the data is considered together it follows a very similar trend to that of the non-compacted sites'. Brady and Weil explain that the main controls of pH are "the humus and clay fractions and their associated exchangeable cations" (p. 398), which is directly related to the soil's parent material. The soils in this area all originate from the same parent material (Province of British Columbia, 2013) and therefore will have very similar pH values. Soil acidity may also vary greatly over small distances due to localized influences such as plant roots or the activity of other organisms (Brady & Weil); the outlier observed in our data can be attributed to such a factor.

Table 2. The pH values for the samples collected at each site along with their depths.

Site\Sample	A	Sample Depth	B	Sample Depth
Compacted I	6.75	27.00	7.00	42.00
Compacted II	5.00	20.00	6.80	30.00
Non-Compacted I	5.50	5.00	7.50	60.00
Non-Compacted II	6.30	8.00	6.80	65.00

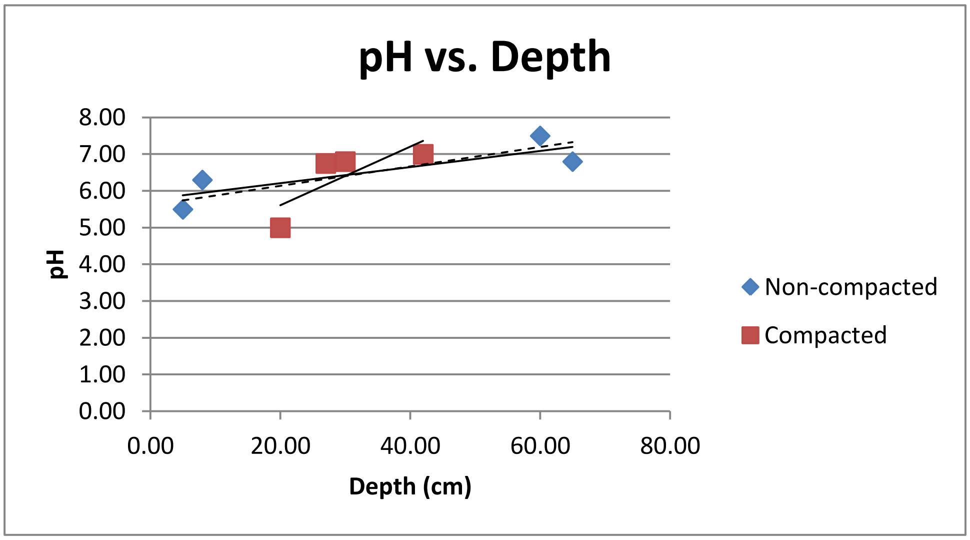

Figure 8. A plot depicting the relationships between pH and sample depth for compacted and non-compacted samples.

Overall, the optimal range of pH for plant nutrient availability is 5.5 to 7.0 (Brady & Weil, 2008). The pH values observed in the study area generally fall within this range, indicating a healthy level of acidity. Brady and Weil also describe that seasonal changes in precipitation and organic matter decay rates can create large variations in soil pH over a year. Therefore to monitor any soil acidity change relative to our data, successive investigations should be performed during the first two weeks of April in order to achieve meaningful results and comparisons.

Soil Water Content

The typical range for mass water content is 0.3 to 0.4 for loamy to clay. The results we obtained ranged from 0.20 to 0.53, which is a wider distribution than the typical range (**Table 3**).

The mean sample soil water content was 0.34. With respect to the depth at which samples collected, the values show that soil water content decreases with increasing depth (**Figure 9**). This trend shows the effects that soil organic matter content, bulk density and texture have upon soil water content. A comparison between the compacted and non-compacted pits' soil water content was not able to be performed due the variation of sampling depths.

Table 3. Sample soil water content values at their associated depths.

	Compacted I A	Compacted I B	Compacted II A	Compacted II B
Depth(cm)	27	42	39	45
θ_m	0.38	0.24	0.36	0.31
	Non-compacted I A	Non-compacted I B	Non-compacted II A	Non-compacted II B
Depth(cm)	5	60	16	40
θ_m	0.53	0.20	0.40	0.30

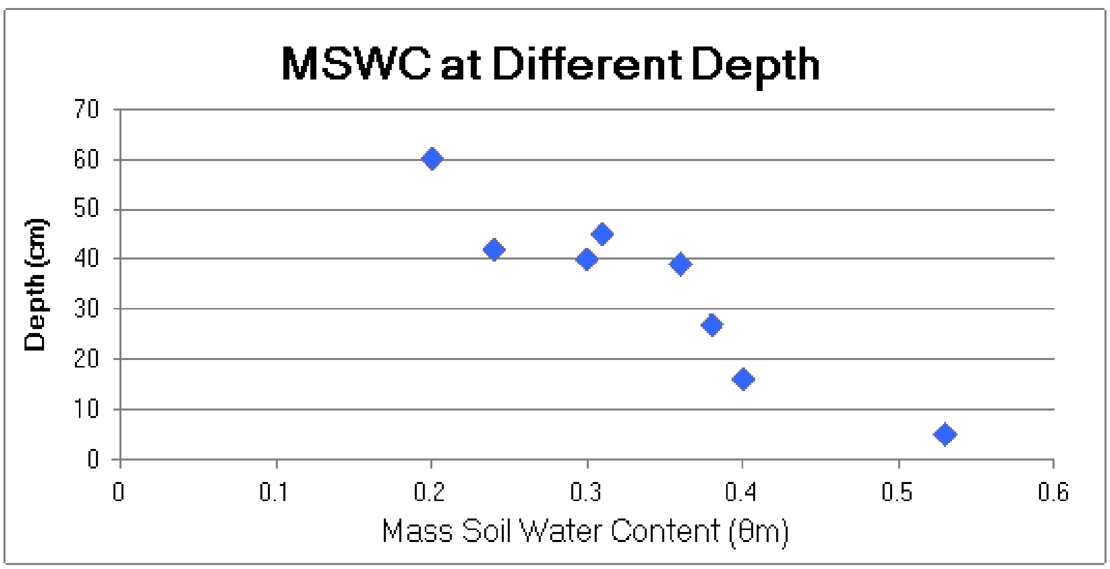

Figure 9. A plot depicting the relationship between Mass Soil Water Content (MSWC) and depth.

According to NCDIA (National Climate Data and Information Archive, n.d.) the total amount of precipitation that occurred one week prior to collecting samples the first field day was 17.2mm and 38mm before the second field day. The differences in each week's precipitation could have caused fluctuations in soil water content as the precipitation in the second week was almost double that of the first week. It would be expected that the samples taken on the second week would have greater water content values than the first week's samples. This situation makes it difficult to make any assertions through comparing the samples. The large difference between topsoil and subsoil water content indicate that our data has possibly been skewed by the differences in rainfall; however, the mean sample water content was within the typical range.

Literature has found that soil water content can impact soil quality and other properties closely associated with the plant growth. It can be utilized to evaluate hydrologic water balance and monitor the changes in water storage within a specific region and time period (Or & Wraith, 2001). There are many soil properties affected by soil water content: soil bulk density, acidity, stability, and plant nutrient uptake are some of the notable attributes. Bulk density is a property needed for volumetric water content calculations. With regards to soil acidity, pH decreases with increasing water content (Brady & Weil, 2008). Soil stability is related to both bulk density and water content – soils tend to be more stable with greater bulk densities and less stable when water content is relatively low (Binkley & Fisher, 2012). Nutrients are dissolved in water and are absorbed via aqueous solutions by plants (Binkley & Fisher). This is an important subject to study, but due to the amount of time and expertise involved in such an area, we were unable to investigate this particular topic. If further studies at Stoney Creek are to be performed it is recommended that the relationship between soil water content and plant growth be investigated.

Stream-bank Erosion

Aboveground vegetation was linked to soil erodibility through big root volume ratio (BRVR) using an existing relationship (Wynn & Mostaghimi, 2006):

$$\log(K_d) = 0.52 - 0.31 * (\text{Bulk Density})^{2.5} - 0.06 * \ln(\text{BRVR})$$

Table 4. Site bulk density values.

Site #	1	2	3
Bulk Density (Mg/m^3)	0.78	1.07	1.26

Table 5. Site root volume ratio values.

Site #	1	2	3
Root Volume Ratio (cm^3/cm^3)	0.00602	0.00526	0.00346

Applying the above parameters into the equation we obtain values of log(K_d), our coefficient of erodibility:

Table 6. Coefficient of erodibility.

Site #	1	2	3
Log (K_d)	0.384	0.184	0.3075
K_d (s/m)	2.42	1.53	2.03

K_d, coefficient of erodibility in $cm^3/(N*s)$, is calculated for various points in the stream bank. The soils on all three sites fall within the K_d 1 to 10 which are extremely erodible. Full qualitative description of coefficient the result is listed below:

Table 7. – Qualitative description of progression of erosion for soils with specific erosion indices (Wahl., & Erdogan, 2008).

k_d, $(ft/hr)/(lb/ft^2)$	Description
> 10	Extremely erodible
1–10	Very erodible
0.1–1	Moderately erodible
0.01–0.1	Moderately resistant
0.001–0.01	Very resistant
<0.001	Extremely resistant

Since soil and vegetation properties are highly variable, it is recommended that the relationship for soil erodibility be used with caution and considered as only preliminary. The relationships presented here should be verified with the collection of more field data under a range of conditions before application for stream restoration design.

Conclusions

Root growth limiting bulk density varies with soil texture. With 1.45 Mg/m^3 being the root growth limiting bulk density for clay soils and 1.85 Mg/m^3 for loamy sands soils, none of our sites have a high enough bulk density to limit root growth. However, the depth to bulk density relationship reveals that bulk density in compacted sites increases faster than in non-compacted sites as depth increases. A similar pattern is seen in the depth to pH relationship where the compacted sites' curve has a steeper slope than the non-compacted sites' curve. The pH results show healthy soil acidity in this area. In general, water content decreases with increasing depth. Although some depths in the vertical profile show steeper change of water content, confident conclusions cannot be drawn due to the different weather conditions prior to soil sampling. A soil erosion assessment reveals that the bank's erodibility coefficients fall in the lower end of the *very erodible* category. Although it is not fully comprehensive, this set of data provides an important reference for future soil quality assessment in this area. Soil quality will change through time as this area's ecosystem evolves; therefore, continuous monitoring of soil quality is recommended.

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