GeoVirtual 2020 September 14-16
Resilience and Innovation

# Effect of water and organic contents on the index and compressibility properties of organic soils

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ABSTRACT
Twelve percent of Canadian landforms are covered with Muskeg. Muskeg is the landform that represents the organic terrain. Organic soils are distinguished by their high initial water content. The other two main properties of organic soils are organic content and fiber content. These three significant parameters are affecting the index and compressibility properties of organic soils. The effect of water content on the index and the compressibility properties of organic soils has been studied by many authors. However, the influence of organic content on these properties was not well examined. In this study, the effects of both the organic and water contents on different index properties (void ratio, bulk density, specific gravity, and liquid limit) and the compression index have been studied based on many data points gathered from literature for different organic soils studied in various countries. Fiber content, texture, and origin are affecting the properties of organic soils as well, but the available data for these features are not enough to be used in this study. The new relations that correlate the different index and compressibility properties with the water and organic contents are presented in this study. The results revealed that void ratio, liquid limit, and compression index are better estimated based on the water content, whereas, the unit weight and the specific gravity showed a better correlation with the organic content.

RÉSUMÉ
Douze pour cent des reliefs canadiens sont couverts de Muskeg. Muskeg est le relief qui représente le terrain organique. Les sols organiques se distinguent par leur forte teneur initiale en eau. Les deux autres propriétés principales des sols organiques sont le contenu organique et la teneur en fibres. Ces trois paramètres importants influent sur l'indice et les propriétés de compressibilité des sols organiques. L'effet de la teneur en eau sur l'indice et les propriétés de compressibilité des sols organiques a été étudié par de nombreux auteurs. Cependant, l'influence du contenu organique sur ces propriétés n'a pas été bien examinée. La teneur, alors que le poids unitaire et la gravité spécifique ont montré une meilleure corrélation avec la teneur organique. Dans cette étude, les effets du contenu organique et de l'eau sur les différentes propriétés de l'indice (rapport vide, masse volumique, densité spécifique et limite de liquide) et l'indice de compression a été étudié à partir de nombreux points de données recueillis dans la littérature sur différents sols organiques étudiés dans différents pays. La teneur en fibres, la texture et l'origine affectent également les propriétés des sols organiques, mais les données disponibles pour ces caractéristiques ne sont pas suffisantes pour être utilisées dans cette étude. Les nouvelles relations qui corrèlent les différentes propriétés de l'indice et de la compressibilité avec les teneurs en eau et en matières organiques sont présentées dans cette étude. Les résultats ont révélé que le rapport vide, la limite liquide et l'indice de compression sont mieux estimés en fonction de la teneur en eau, alors que le poids unitaire et la densité ont montré une meilleure corrélation avec la teneur en matières organiques.

## 1 INTRODUCTION

Organic soils are characterized by a ratio smaller than 0.75 between the liquid limit of the dry state and the liquid limit of the natural state (ASTM D2487-17). Whenever the organic content of organic soils is higher than 75%, the soil is called peaty soils (ASTM D4427-18). In Canada, peaty and organic soils are called Muskeg, which represents the landform of these soils. Muskeg soils cover around 170 million Hectares of the Canadian landscape (Tarnocai 2006; Xu et al. 2018; Moayedi and Nazir 2018). Muskeg soils are characterized by their high initial water content, high initial void ratio, high initial permeability, and low bulk density (MacFarlane 1969; Landva 1980; Robinson 2003; Mesri and Ajlouni 2007). All of these factors make Muskeg soils kind of problematic soils as they will undergo large settlements whenever they would be subjected to loads.

Many Failures occurred due to constructions on organic soils such as embankments failures (Den Haan and Feddema 2013), dikes failures (Bezuijen et al. 2005; Van Baars 2005; McInerney et al. 2006; O'Kelly 2008), and slope failures (Long and Jennings 2006; Boylan et al. 2008;

Long et al. 2011). These failures serve testimony to the difficulties in the engineering of organic soils and highlight the need to understand the mechanical behavior of such soils as a critical consideration in the design of building/lifeline infrastructure. Due to problems associated with the presence of organic soils, it would be useful to correlate the two significant properties of these soils, which are the water content $w_c$ and the organic OC, with other properties during the preliminary design stage of any project.

In this paper, various data points have been gathered from literature to cover the whole range of organic content. These data points have been used for checking the change of the index and compressibility properties of organic soils when the water and organic contents change. This paper is divided into two main parts. The first part presents the proposed correlations for some index properties (void ratio e, unit weight γ, specific gravity $G_s$, and liquid limit $w_L$) with the water content and organic content. The second part shows the change of the compression index $C_c$ with the change of the water content and organic content.

## 2 CORRELATION OF INDEX PROPERTIES WITH WATER AND ORGANIC CONTENTS

Organic soils are distinguished by their high initial water content compared to mineral soils. When mineral soils are encountered, the organic content of these soils is not of great importance and almost equals to zero. However, for organic soils, organic content is imperative in determining their behavior. The determination of organic content usually follows ASTM D2974-14. This standard requires the determination of ash content (mineral or incombustible components) in advance by ashing the oven-dried sample in the furnace to get rid of all the volatile components in the soil (organic content) at 440° C ± 40° C degrees then dividing the weight of the ashed soil over the weight of the oven-dried soil. Afterward, the organic content is determined by subtracting the ash content percent from a hundred percent.

Organic and water contents are the two main properties that characterize the organic soils in addition to the fiber content and the texture of the fiber. There is no much data available in the literature about the fiber content and the fiber texture that would help to cover the whole range of organic contents. That is why, in this study, the effects of fiber content and fiber texture on different properties are not accounted for.

Many index properties are essential in the preliminary design stages of any project, such as void ratio, bulk density, specific gravity, and liquid limit. Obtaining a tentative estimate of these properties, just from measuring the water and organic contents, would be helpful for all geotechnical engineers. Gathered data from the literature for the whole range of the organic content along with the water content are analyzed to facilitate the interpretation of the initial tentative values of these index properties.

### 2.1 Effect of water content $w_c$ and organic content OC on initial void ratio $e_0$

The initial void ratio is indispensable in the analysis of the consolidation settlement. Figure (1) shows the effect of changing the organic content OC and the water content $w_c$ on the values of the initial void ratio $e_0$ in the same graph.

The void ratio and the water content are mathematically related through the phase diagram relations. However, the scatter around the linear trend line highlights the heterogeneity of organic soils due to different aspects such as the preconsolidation pressure, the presence of fibers, and the presence of gases.

The organic content and the void ratio are not related to each other mathematically. However, the figure reveals a relation between them in an exponential form. The higher the organic content, the higher the initial void ratio. This could be attributed to the inconsistent structures of organic components, which in turn causes many gaps throughout the soil skeleton, and this leads to a high initial void ratio whenever these organic components decompose. For small organic contents, less than 30 %, the deviation around the trend line is not noticeable, but for high organic contents, between 75% to 100%, the deviation is remarkable. The proposed correlation using organic content is valid for organic content ranges between 5 % to 98 %.

The range of void ratio is vast, and it increases whenever the water content or the organic content increase. The maximum void ratio at high organic content is around 12. Whereas, the void ratio might reach up to 25 at high water contents (i.e., $w_c$ = 1700 %). The proposed equation using the water content is valid for water content ranges between 25 % to 1700 %.

The two proposed equations in the figure give tentative values for the initial void ratio in the concept or the preliminary design stages of any project, which should be confirmed in the subsequent detailed design stage by lab and field testing.

### 2.2 Effect of water content $w_c$ and organic content OC on bulk density (γ)

The bulk density of organic soils is low and close to the water's bulk density due to the organic nature of these soils. Figure (2) shows the effect of water and organic contents on the bulk density of organic soils for a wide range of organic contents. The general trend lines show a decreasing trend for the bulk density whenever the organic or the water content increase.

The bulk density of organic soils is fixed around 1 $gm/cm^3$, which is the same density of water, at high organic content (more than 75) and when the water content is higher than 500 %. The main reason for this behavior could be that the organic components in any organic soils are light in weight, and the presence of these components is intense at high organic and water contents (MacFarlane 1969; Hobbs 1986; Bell 2000). Besides, any significant increase in the bulk density of organic soils is attributed to the presence of mineral components.

The proposed two equations for the rough estimation of the bulk density based on water and organic contents are shown in Figure (2). The least-square errors of both equations reveal that the bulk density is better estimated through the organic content, not the water content. It would be useful for geotechnical engineers to check both values to get a range of bulk density and determine the most reasonable value to use based on their experience.

## 2.3 Effect of water content $w_c$ and organic content OC on specific gravity ($G_s$)

The specific gravity of organic soils could be determined in the lab using the water or gas pycnometer methods. Determining the specific gravity of organic soils is difficult due to the presence of fibers, which impede the full removal of the entrapped air.

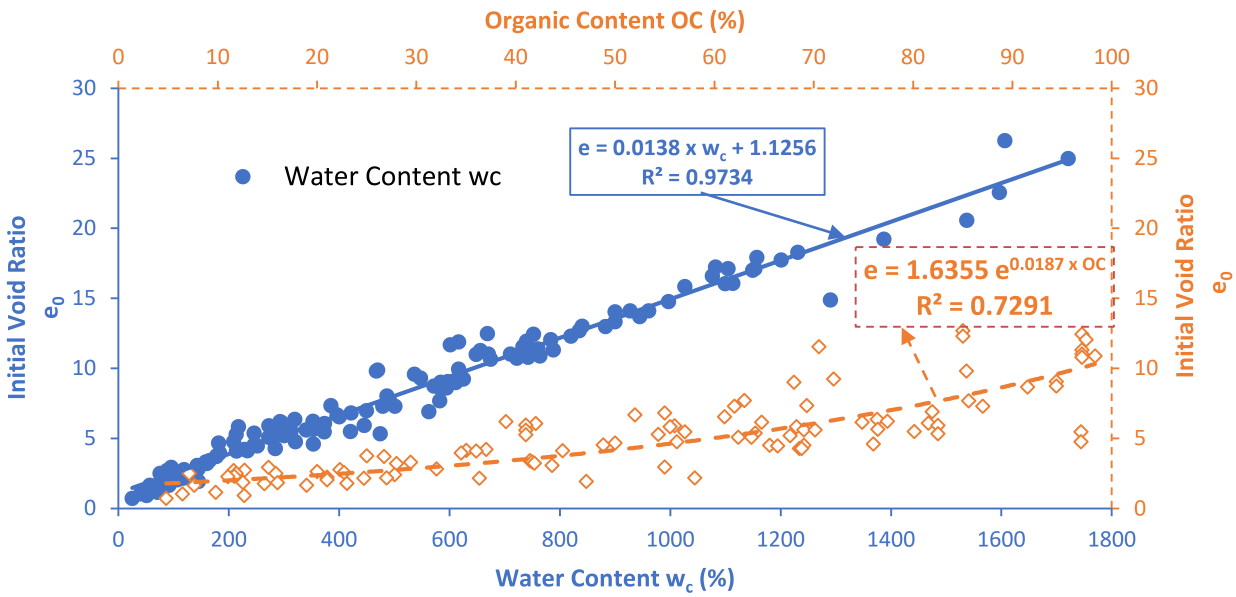


Figure 1. Effect of changing the water and the organic contents on the initial void ratio of organic soils.

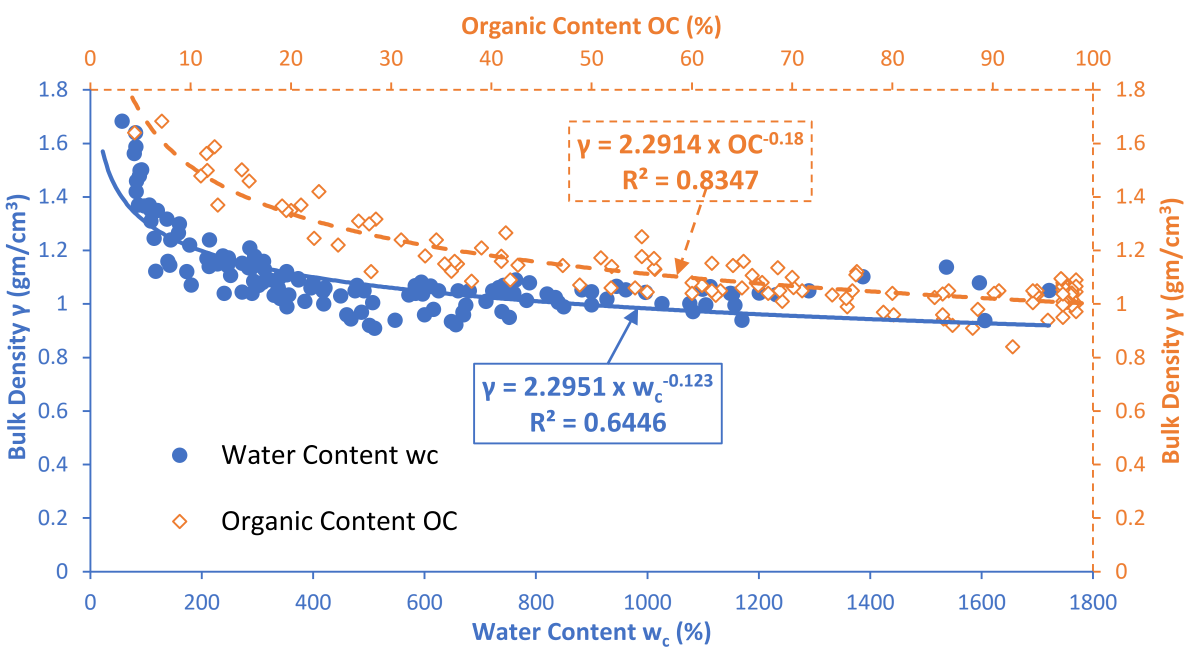


Figure 2. Change of bulk density due to change in water and organic contents of organic soils.

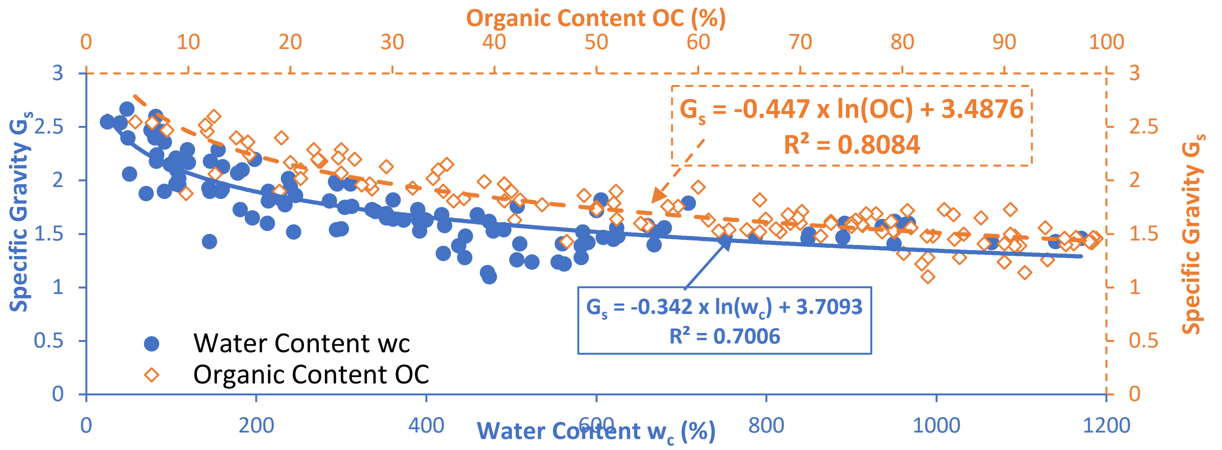


Figure 3. Specific gravity change due to water and organic contents' change of organic soils.

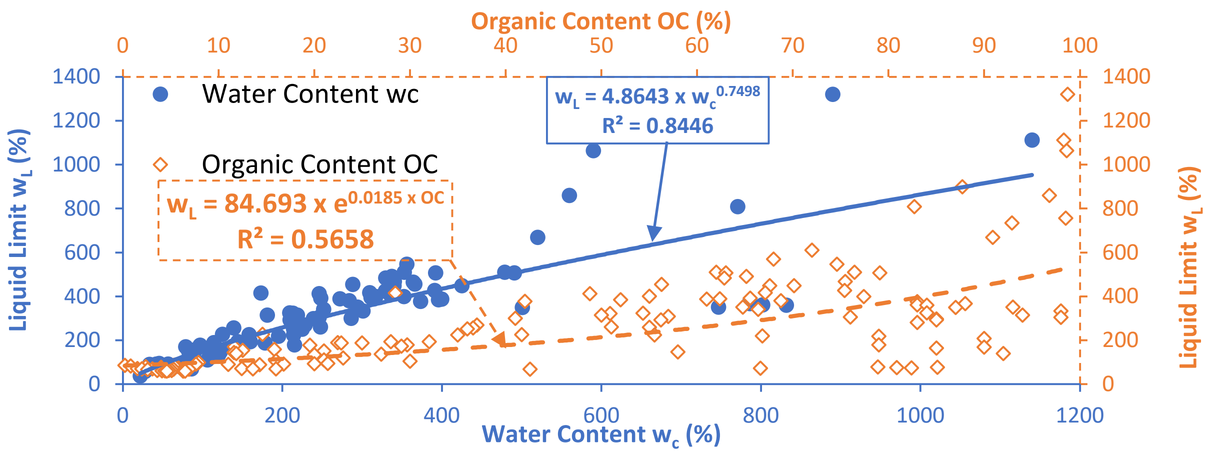


Figure 4. Effect of water and organic contents on the liquid limit of organic soils.

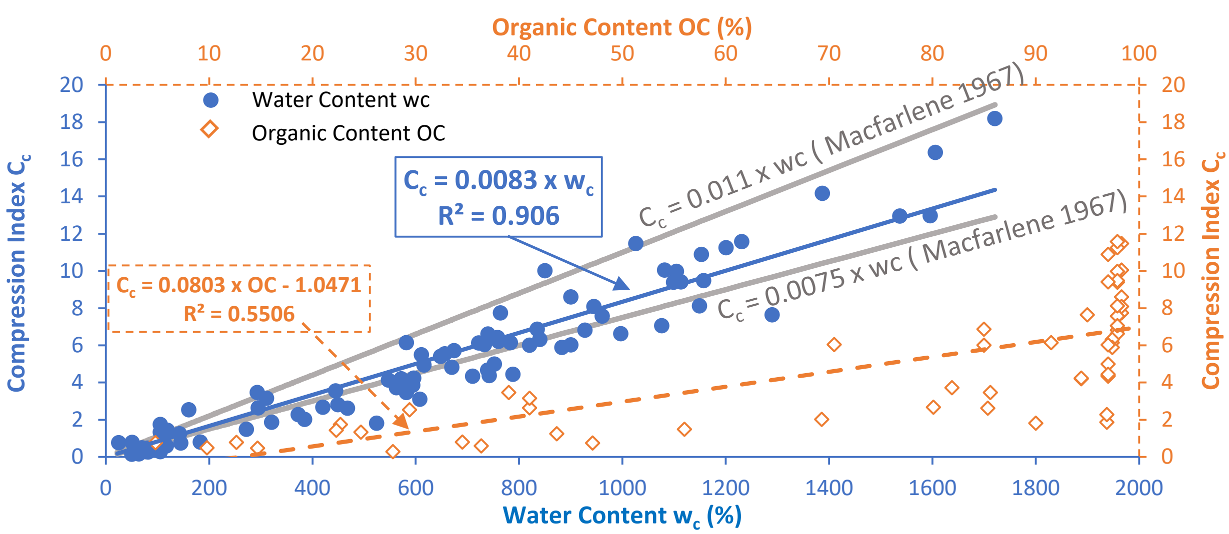


Figure 5. Effect of changing the water and organic contents on the compression index of organic soils.

The specific gravity of organic soils ranges between 1 and 2. It increases whenever the mineral component increases. Figure (3) illustrates the relationship between the specific gravity and the change of water and organic contents. The figure reveals that the specific gravity trend line tends to settle around 1.5 for water content higher than 500 % and organic content higher than 75 %. The same trend is observed for bulk density. The same reason for the bulk density trend with the water content and the organic content might be applicable for the specific gravity, which is the high mineral content at little water and organic contents. The two proposed equations are shown in Figure (3) reveal that the specific gravity is better correlated to the organic content than the water content due to the higher value of the least square error in case of the organic content.

### 2.4 Effect of water content $w_c$ and organic content OC on the liquid limit ($w_L$)

The liquid limit's determination of organic soils is questionable as it is not contributing to the classification of organic soils. Besides, the determination of the liquid limit of organic soils is difficult due to the presence of fibers while using either the Atterberg device or fall cone device (MacFarlane 1969; Hobbs 1986; Yamaguchi et al. 1987; Nakayama et al. 1990; Lan 1992). However, the available data in the literature for liquid limit enabled the derivation of the relation between the liquid limit and water and organic contents. Some of the available data show liquid limits values smaller than the natural water content, which makes no sense. Hence, these data have been excluded.

These relations might be used in the future if the research can prove that the liquid limit of organic soils has a specific contribution to the mechanical properties of organic soils, especially the undrained shear strength like the mineral soils.

Figure (4) depicts the increasing trend of liquid limit when the water and organic contents increase. The scattering around the trend line is remarkable whenever the water content is higher than 500 %, and the organic content is more significant than 30 %. The power equation proposed for the liquid limit determination as a function of the water content is preferred over the exponential relation of the organic content for small water content values (less than 500 %). It is worth mentioning that the number of data points available for higher water content (more than 500 %) is relatively small and displays a great scatter around the trend line, and this might have affected the regression analysis. However, for the sake of this study and to cover as much wide range as possible for the water content, these points have not been excluded from the analysis. Furthermore, the deduced least square error using the organic content is 0.5, which considered unacceptable for the geotechnical applications in practice. However, this small value is mainly due to the scattering at very high organic contents, which is mainly related to the Dutch peat.

## 3 CORRELATION OF COMPRESSION INDEX WITH WATER AND ORGANIC CONTENTS

One of the main characteristics of organic soils is their tendency to exhibit high compressibility, which makes these soils undesirable for many construction projects as this will lead to a significant settlement that affects the structural safety of any construction. The consolidation settlement of organic soils is either due to the dissipation of the excess pore water pressure, which called the primary consolidation or the particle rearrangement under a particular load, which called the secondary consolidation. The compression index $C_c$ represents the change of void ratio over the change of the applied loads within the compression segment of the e-log P' curve. Due to the initially high water content and void ratio of organic soils, values of the compression index are considered high compared to the clayey soils such that the $C_c$ for organic soils ranges between 0.5 to 18 whereas for clayey soils ranges between 0.3 to 0.8 (Lefebvre et al. 1984; Yamaguchi et al. 1985; Ajlouni 2000).

Obtaining an initial estimation of the compression index value would help in determining the consolidation settlement of organic soils. There are many previous trials in literature to correlate the compression index with the simply measured properties such as water content and void ratio (Macfarlane 1967; Kogure and Ohira 1977). The twp primary limitations of these correlations are that it accounts for organic soil in a specific area, and there is no mention of the effect of the organic content. In this section, the different data gathered from the literature that covers the whole range of the organic content have been used to get new correlations for $C_c$ as a function of water content and organic content, as shown in Figure (5).

The figure reveals that the $C_c$ increases when the water and organic contents increase. This could be attributed to the increase of the initial void ratio. The proposed relation between compression index $C_c$ and water content $w_c$, shown in Figure (5), has been compared graphically with the bounds proposed by Macfarlane (1967). The graph shows that there are many data points located outside the lower bound of Macfarlane (1967), but there are fewer data points located outside the upper bound. The scatter around the proposed trend line between compression index $C_c$, and water content $w_c$ is increasing whenever the water content increases. There are many points located below the lower boundary line proposed by Macfarlane (1969). This could be attributed to the different nature of the organic soils as Macfaralne (1969) mainly proposed these boundaries for the Canadian Muskeg, whereas, in this study, many soils have been used from various countries. The proposed equation using organic content has a small least squared error. Therefore, it is not advisable to use this equation in the engineering practice, and the compression index is better to be estimated using the proposed equation using the water content.

## 4 CONCLUSIONS

Organic soils are considered one of the problematic soils due to their high compressibility and small shear strength properties. That is why any engineering construction on these kinds of soils should abide by restricting precautions.

Organic soils are known for their high initial water content. Moreover, their organic content relies on the degree of decomposition that the soil has been subjected to. In this study, index properties such as void ratio, bulk density, specific gravity, and liquid limit, in addition to the compression index, have been correlated to the two main properties, which are the organic and water contents.

The proposed correlations showed that the void ratio, liquid limit, and the compression index are better estimated based on the water content, whereas, the unit weight and the specific gravity showed a better correlation with the organic content. Whenever the water content increases, more than 500 %, the bulk density tends to settle around one, and the specific gravity tends to settle around 1.5. Also, the scattered values of the liquid limit and the compression index around the proposed trend lines increase.

Furthermore, the study revealed that the lower bound proposed by Macfarlane (1967) for the determination of the compression index as a function of the water content is not applicable for the full range of the organic content. Besides, a high scatter of the compression index is noticed when the organic content is used for the correlations. Therefore, it is recommended for the initial tentative estimate of the compression to use the proposed equation of the water content instead.

## 5 ACKNOWLEDGMENTS

This work was supported by an NSERC CRD (Grant # 11R77115) to Drs. Dharma Wijewickreme and Sumi Siddiqua. The authors would like to thank TransCanada and ConeTec for providing funding, samples, and/or in-kind support for this research.

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