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Suspended sediment modelling in the Nerepis River system.

By

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Abstract

Erosion from military training areas can contribute significant amounts of sediment loadings into nearby streams. The Soil Water Assessment Tool (SWAT) was selected as a modelling tool for its ability to simulate the hydrological and water quality conditions observed in the military landscapes of 5th Canadian Division Support Base (5 CDSB) in Gagetown, New Brunswick. The Nerepis River watershed, located in and around Gagetown was monitored from august to September 2021 to measure discharge and turbidity, as both variables are needed to calibrate the model. Once calibrated, the model will simulate runoff and sediment loadings for 1) current conditions; and 2) for conditions associated with mitigation strategies that could be implemented, such as increasing buffer strip widths in key locations.

Keywords: modeling, sediments, SWAT

Résumé

L'érosion causée par les zones d'entraînement militaire peut apporter des quantités considérables de sédiments dans les cours d'eau à proximité. (Soil Water Assessment Tool, ou SWAT) a été sélectionné comme outil de modélisation pour sa capacité à simuler les conditions hydrologiques et la qualité de l'eau observées dans les paysages militaires de la Base de soutien de la 5e Division du Canada (5 CDSB) à Gagetown, au Nouveau-Brunswick. Le bassin versant de la rivière Nerepis, qui prend sa source à Gagetown, a été instrumenté d'août à septembre 2021 pour mesurer le débit et la turbidité dans la rivière principale et ses affluents afin de calibrer le modèle. Une fois calibré, le modèle simulera le ruissellement et les charges sédimentaires pour 1) les conditions actuelles ; et 2) pour les conditions associées aux stratégies d'atténuation qui pourraient être mises en œuvre, comme l'augmentation de la largeur des bandes riveraines aux endroits qui présentent un risque majeur.

Mots-clés: modélisation, sédiments, SWAT

1. INTRODUCTION

The 5th Canadian Division Support Base Gagetown (5 CDSB Gagetown) was officially opened in 1958 as a training facility. Located near the city of Fredericton, New Brunswick, 5 CDSB is the second largest military base in Canada with nearly 1 500 km of roads, 900 km of off-road tracks, 740 buildings and accommodates operations for more than 6 500 military and civilian personnel (Government of Canada, 2022). The Range and Training Area (RTA) is located within Gagetown and covers most of the base. This area is used to conduct a variety of military operations, including tactical manoeuvres and live fire training exercises. Some of these training activities, such as the use of large military vehicles, can have disruptive impacts on the landscape including landscape erosion and watercourse sedimentation.

This study aims to simulate and understand the impact of military landscapes and training on hydrological and sediment conditions in the Nerepis River drainage basin, which is partly located on the RTA. The Soil Water Assessment Tool (SWAT) is used to simulate suspended sediment concentrations (SSC) and sediment loads at the Nerepis watershed. Field monitoring was initiated during the summer of 2021 at various locations in the Nerepis River to provide the data needed to calibrate and validate the model.

2. Materials and Methods

2.1 Study area

The study area is the watershed drained by the Nerepis river. It is a river of approximately 50 km long. The Nerepis River flows through the RTA and discharges into the Saint John River at Grand-Bay Westfield. Its drainage area covers 50 000 ha and includes highly disturbed areas (Figure 1).

The RTA intersects a region between the Southern New Brunswick Uplands and the Maritime Lowlands. Over the period from 2012 to 2021, the annual average precipitation was 1425 mm. The daily average temperature is 6.7 °C, which ranges from -8 °C in January to above 19 °C in July (https://climat.meteo.gc.ca/historical_data.html).

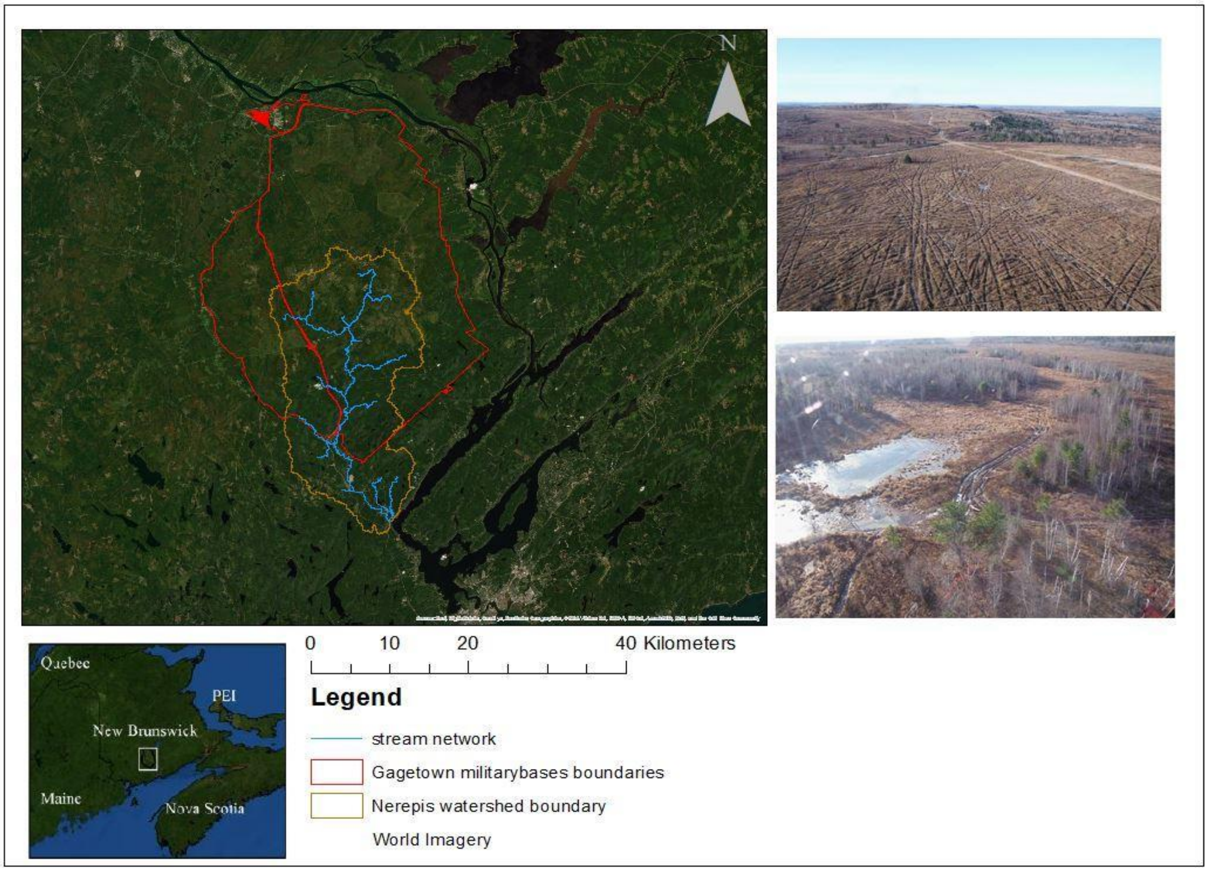

Figure 1.Atlantic Canada, Gagetown and the Nerepis watershed. To the right, an example of heavily trafficked training area within the Nerepis watershed.

2.2 SWAT description

The SWAT model is a watershed-scale model designed to simulate the impact of land practices and management on hydrology, sediments and the transport of pollutants in watersheds (Arnold et al., 1998; Neitsch et al., 2011). The efficiency of this model in studying long-term impacts has been proven (Neitsch et al. 2011; Arnold et al. 2012).

The SWAT model analyzes watersheds by discretizing them into sub-basins, which are then further subdivided into hydrological response units (HRUs) with homogeneous land use, soil properties, and slope (Yang et al., 2009). Erosion generated by precipitation and surface runoff is calculated using the Modified Universal Soil Loss Equation (MUSLE).

The water balances modelling with SWAT includes different processes (i.e., surface and subsurface runoff, percolation and base flow, and evapotranspiration and transmission losses). The physical processes involved in modelling the hydrological cycle and related to the loadings of sediments, nutrients and other pollutants and their movement through the channel network is presented in the SWAT tool user's manual (http://swatmodel.tamu.edu).

SWAT is coupled with a geographic information system (ArcSWAT 2012.10.5.1) and uses soil types, land use, topographic features and climate data (temperature, relative humidity, solar radiation, rainfall and wind) as inputs.

2.3 Data gathering

Although the SWAT model was previously implemented on the Nerepis River by a group of researchers from the Royal Military College (Burdett, 2014), and in spite of attempts to communicate with the researcher at R.M.C. in charge of this project, we were unsuccessful in establishing this partnership and thus, the data retrieval process needed to be repeated. This proved to be a much longer procedure than expected and partly explains, along with challenges associated with COVID, the fact that simulations will be completed in the early part of fiscal year 2022-2023.

DEM

A high-resolution (1m) digital elevation model (DEM) was acquired from the N.B. Department of Energy and Resource Development ArcGIS Server. The DEM was then used for the delineation of the watershed drainage area, as well as the modelling of the stream network. Subsequently drained area values are included as inputs to determine the size of the sub-basins within the watershed.

Once the delineation is done, a topographic report is generated by the software, which describes the distribution of the elevation in the catchment area and in the sub-basins.

The projected coordinate system of NAD 1983 CSRS New Brunswick Stereographic (Environmental Systems Research Institute, 2018) was used. The Nerepis watershed was delineated into 27 sub-basins.

Soil and Geological Characteristics

GIS soil data were also acquired from the GeoNB data catalogue (http://www.snb.ca/geonb1/e/DC/catalogue-E.asp). The GIS data provided spatial delineation for common New Brunswick soil series. These polygon features were converted into a 5 m raster format and projected into the DEM’s spatial reference. Limited soil data were provided along with this GIS. However, soil characteristics and parameters were taken from the AAFC soil survey database (Agriculture and Agri-Food Canada, 2012).

The soil input file defines the physical and chemical properties of all layers in the soils. The soil characteristics define the movement of water through the horizontal profile and have a major impact on the cycling of water within the HRU.

The Universal Soil Loss Equation (USLE_K) is used to model sediment mobilisation on slopes. The soils characteristics and the equations used are included in Appendix A.

There are 24 different soil types within the study area (Figure 2). The three first primary soil groups are: Interval, Mafic Volcanic and Gagetown and they are covering respectively 19 %, 11 % et 10 % of the study area.

The following soils : Serpentine Organic Tuadook Brittbrook represent from 6 to 4 % of soil types present on the drainage basin and the rest of the soil groups are evenly dispersed over the watershed area.

Land cover

The Land-use data were obtained from the North American Land Change Monitoring System (http://www.cec.org/north-american-land-change-monitoring-system/) and clipped by the watershed extent shapefile. This watershed is covered by approximately 45% mixed-forests (FRST), 33% forest Evergreen (FRSD), 5% of grassland (BROM) , and 3% barren features including roads, tracks and highly disturbed manoeuvre areas (BARR). Wetlands and water features are evident in this watershed but cover less than 2% of the drainage area.

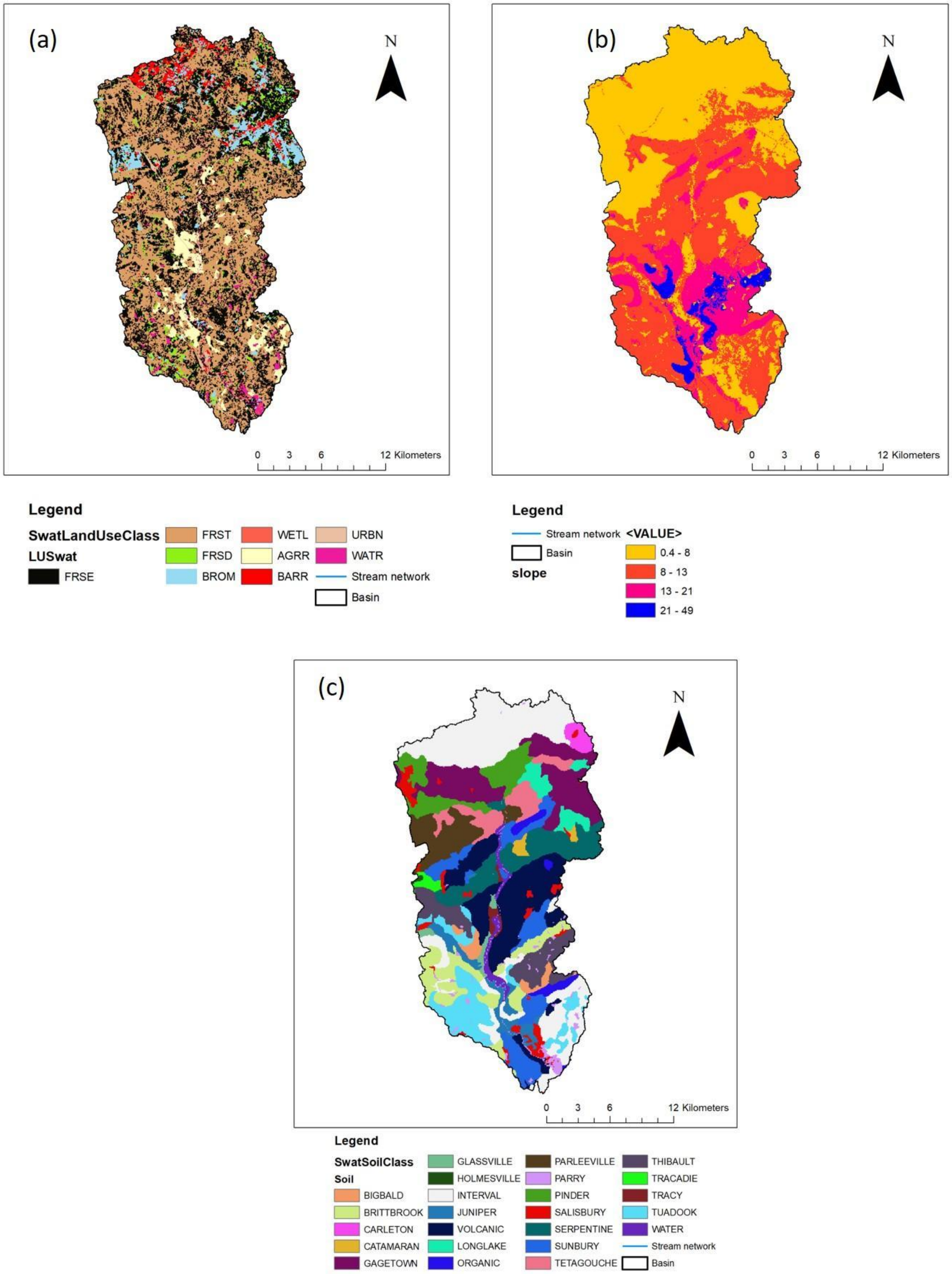

Figure 2. The Nerepis watershed (a) land use, (b) slope, (c) soil.

Meteorological data

Meteorological data required by SWAT are precipitation, temperature, wind speed, solar radiation and relative humidity. Among the weather stations located near Gagetown, the oak point station (45°30'25" N; 66°05'55"W) has the longest time series with data from 2012 to 2022. Climate data obtained from this station were combined with reanalysis data from ERA5 (https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5 -single-levels?tab=overview). Precipitation was also measured by DND at two rain gauges respectively located near Queens Brook (CT03) and River George (CT06) between 15 August and 19 October 2021.

SWAT incorporates the WXGEN weather generator model (Stockle *et al.*, 1992) to fill gaps in observed climate data or forecast climate trends.

The localisations of each data source are shown in figure 3.

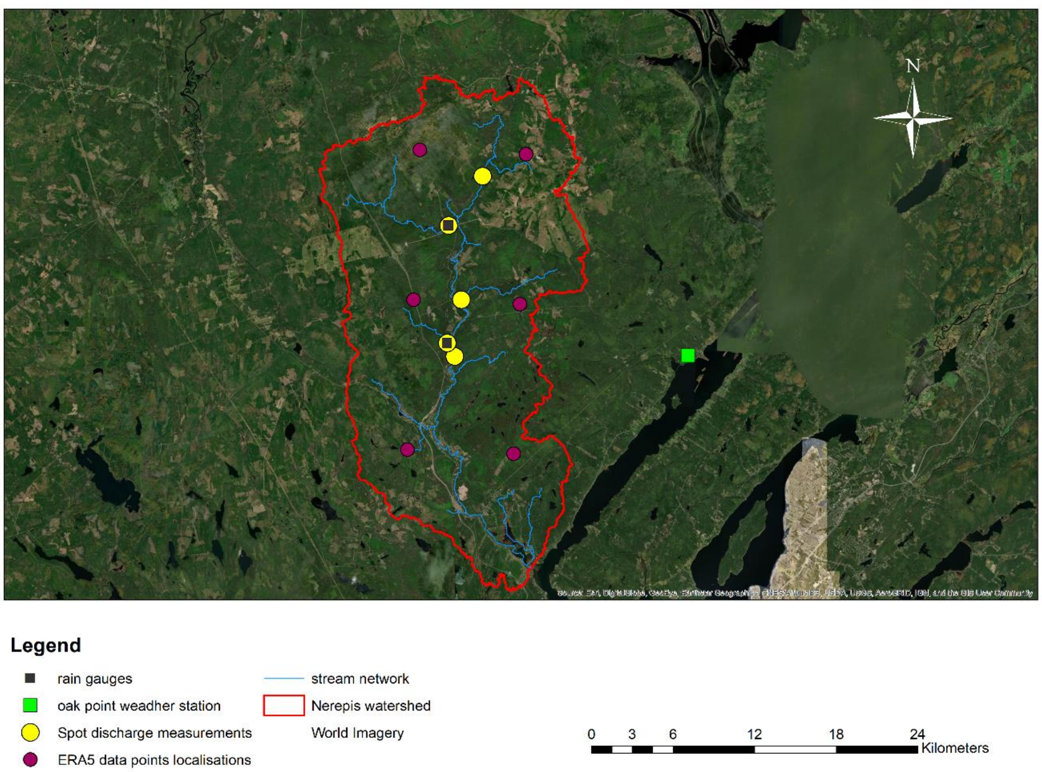

Figure 3. Location of meteorological and hydrometric stations.

Hydrometric data

In order to model suspended sediments and flows, probes were installed in various locations of the Nerepis river and its studied tributaries (figure 3). Water discharge was measured at four sites during field visits and discharge data from a gauging station (Nerepis River at Flowler's Bivouac) operated by Environment and Climate Change Canada (http://climate.weather.gc.ca) will also be used.

Turbidity meters were deployed at five stations in the Nerepis River system: Two on the river main stem (Nerepis River at Flowler's Bivouac; Nerepis River at Tok Chong Bridge) and three in the tributaries: River George, Queen and Sucker Brook. The YSI probes collect turbidity (NTU, to be converted into suspended sediment concentrations in mg/L).

The relation between the turbidity and SSC was determined by establishing a calibration curve with grab samples of river sediments with varying dilution to cover the range of measured turbidity. Each grab sample was subsequently filtered, dried and weighed to determine SSC. Calibration curves and derived SSC values were provided in Riahi and St-Hilaire (2022a).

2.4. Analysis and next steps

The distribution of HRU within the Nerepis watershed was set up using the "multiple HRUs per sub-basin" option with the same minimum areal coverage threshold of 5% for land use, soil and slope classes to be considered. Then, subdividing the sub-basin into homogeneous areas having unique soil, land use and management combinations resulted in a total of 202 HRUs for the Nerepis watershed. The largest sub-basin has an area of 1815 ha while the smallest sub-basin has an area of 0.3 ha. Some statistics regarding the area of those HRUs from the sub-watersheds are shown in Table 1.

Table 1. Statistics for areas of the HRUs.

Interval area [ha]	Sum area [ha]	Number of HRUs	Maximum (%)	Minimum(%)	Mean (%)	Standard deviation (%)
0-50	539.27	37	0.010	9.0	2.63	2.72
50-100	1861.93	25	2.718	5.31	3.84	0.69
100-500	29686.85	119	0.339	1.6	0.83	0.35
500-1500	17867.22	21	2.840	10.15	4.54	2.23

Now that the model set up is successfully completed as well as the HRU distribution fully defined, the next steps are : 1) Use the field observations (discharge and SSC data) to calibrate the model. 2) Agree with stakeholders on mitigation scenarios that will be simulated. 3) Proceed with the simulations of discharge, suspended sediment concentrations (SSC) and sediment loads at the Nerepis watershed.

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APPENDIX A. SOIL CHARACTERISTICS

Tableau 2: Physical and chemical characteristics of the first layer of each soil type present in the Nerepis watershed

Sol NAME	NLAYERS	HYDGRP	SOL_ZMX	SOL_Z1	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1 %	SILT1 %	SAND1 %	ROCK1 %	USLE_K1	SOL_PH1
BIG BALD	6	A	720	90	1.1	0.15	150	0.5	3	22	75	10	0.17	4.3
BRITT BROOK	6	B	1080	160	0.66	0.21	180	1.5	21	58	21	31	0.207	3.4
THIBAULT	5	B	1050	130	1	0.23	100	0.8	26	57	17	9	0.219	4.2
TRACADIE	6	C	1040	90	1.23	0.2	150	5	21	69	10	0	0.302	4.9
TRACY	5	C	1050	130	1.19	0.12	150	0.8	16	42	42	16	0.181	3.8
TUADOOK	5	C	1120	220	1.2	0.16	143	2	14	53	33	10	0.187	3.9
GLASSVILLE	4	B	1190	150	1.25	0.16	70	1.2	21	52	27	20	0.188	4.6
HOLMESVILLE	5	B	830	130	1.29	0.16	100	6.2	36	33	31	16	0.157	4.3
INTERVAL	3	B	1130	130	1.2	0.19	100	4	16	60	24	0	0.205	5.4
JUNIPER	5	B	1090	270	0.95	0.25	80	8	20	60	20	6	0.213	4.5
PARLEEVILLE	5	A	980	130	1.2	0.15	100	1.2	20	38	42	17	0.174	4.4
PARRY	6	C	1050	100	1.19	0.13	150	0.8	10	34	56	10	0.184	4.8
PINDER	5	A	1080	130	1.18	0.1	400	0.6	7	33	60	22	0.187	4.4
SALISBURY	5	C	700	150	1.2	0.16	100	0.7	13	37	50	11	0.182	4.4
SERPENTINE	6	C	1050	80	1.16	0.19	150	1.7	24	59	17	20	0.221	3.6
SUNBURY	6	A	1040	130	1.18	0.12	400	0.6	5	31	64	9	0.188	4.1
TETAGOUCHE	7	C	1060	110	1.19	0.15	100	1	13	34	53	10	0.18	3.8
CARLETON	5	B	1100	200	1.3	0.09	92	1.5	16	50	34	25	0.184	5.8
CATAMARAN	5	C	1120	120	1.2	0.14	143	2	12	43	45	10	0.182	3.9
GAGETOWN	4	A	1150	320	1.1	0.07	200	0.9	8	22	70	50	0.172	4.2
LOMOND	5	A	1060	150	1.2	0.07	300	1	8	40	52	40	0.188	4.1
ORGANIC	4	C	1600	700	0.16	0.2	50	27.2	0	0	0	0	0	6
LONG LAKE	5	B	1230	380	1.3	0.14	70	1.3	21	35	44	16	0.171	4.5

APPENDIX B. UNIVERSAL SOIL LOSS EQUATION

$$USLE_K = \frac{0.00021 \cdot M^{1.14} \cdot (12 - OM)}{100} + \frac{3.24 \cdot (c_{soilstr} - 2) + 2.5 \cdot (c_{perm} - 3)}{100}$$

$$M = (m_{silt} + m_{vfs}) \cdot (100 - m_c)$$

$$USKE_K = \left[0.2 + 0.3 \cdot \exp(-0.256 \cdot m_s \cdot (1 - \frac{m_{silt}}{100})\right] \cdot \left[\left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}\right] \cdot \left[1 - \frac{0.25 \cdot OM}{OM + \exp(3.72 - 2.95 \cdot OM)}\right] \cdot \left[1 - \frac{0.7 \cdot (1 - \frac{m_s}{100})}{\left(1 - \frac{m_s}{100}\right) + \exp(-5.51 + 22.9 \cdot (1 - \frac{m_s}{100})}\right]$$

$M = (m_{limon} + m_{STF})*(100 - m_{argile})$

m is the percentage of clay and silt

OM = percentage of organic matter (%)

$C_{soilstr}$ = The code for the soil structure

C_{perm} = Permeability class (1 = fast et 6 = slow)