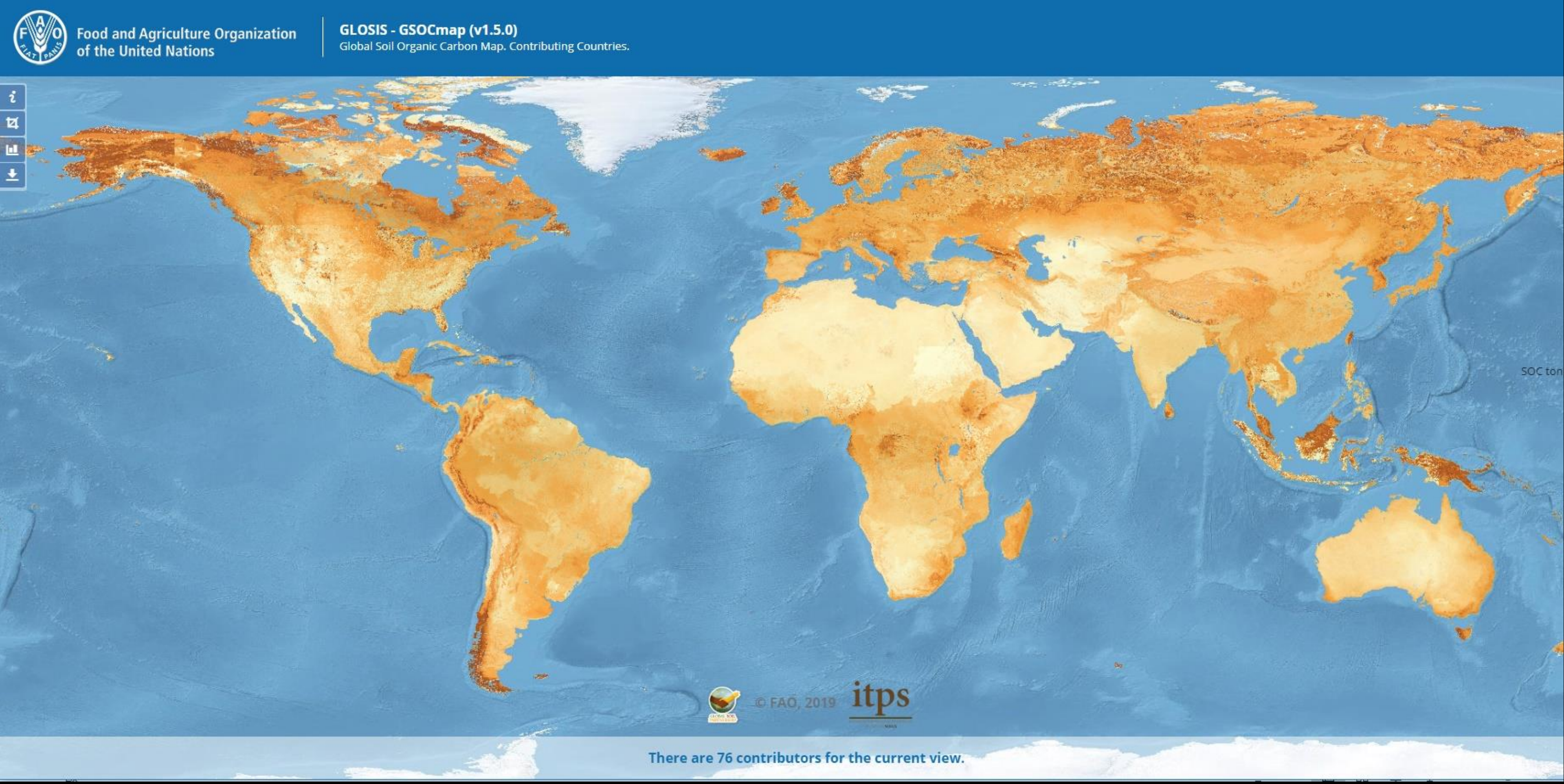
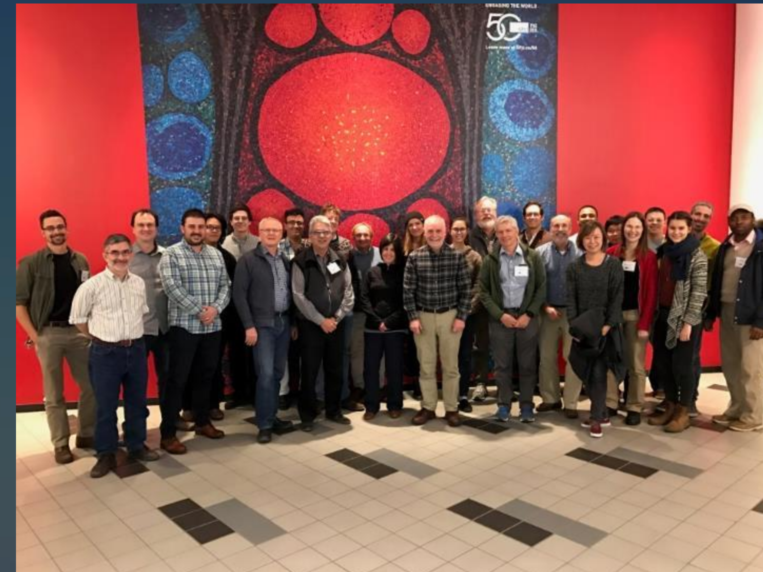


1. Introduction to Digital Soil Mapping

Canadian Digital Soil Mapping Workshop, 2022

About Us



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Why Soil Matters

*"The function of **supporting food** and agriculture worldwide is fundamental for the **preservation** and **advancement** of human life on the planet"* (FAO, 2017)

- Maintains natural and planted vegetation
- Supports plant and animal biodiversity
- Contributes to water quality and supply
- Foundation platform for buildings, roads, and infrastructure
- Regulation of earth systems

2015 International Year of Soils

International Decade of Soils 2015-2024

Soil Security as a “**Keystone**” to Existential Environmental Challenges

*“The **maintenance** and **improvement** of the world’s soil resource to produce food, fibre and freshwater, contribute to energy and climate sustainability, and maintain the biodiversity and the overall protection of the ecosystem”*

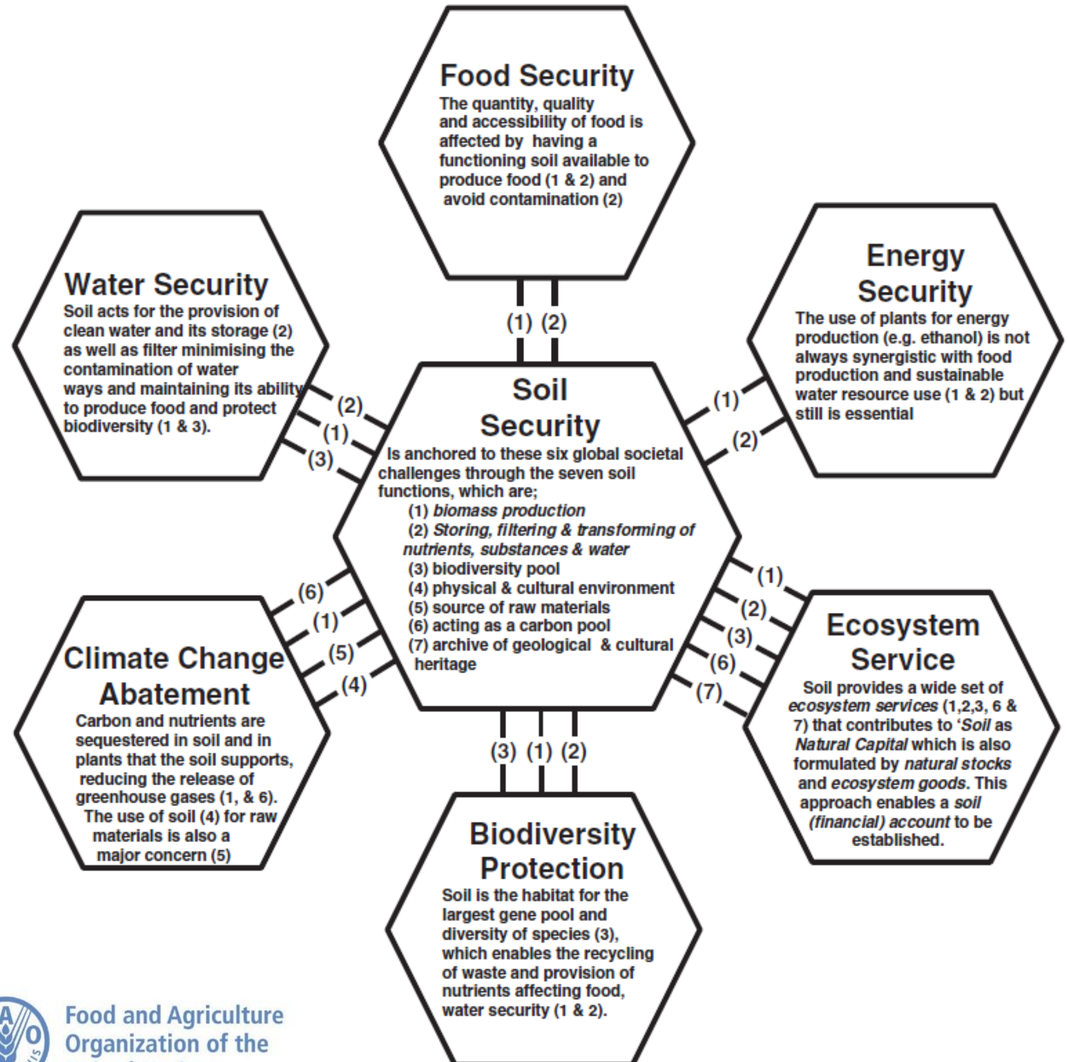
(Soil Carbon Initiative, 2011)

“Soil security is higher as the functions perform better”

(Bouma and McBratney, 2013)

EUROPEAN COMMISSION

Food and Agriculture Organization of the United Nations



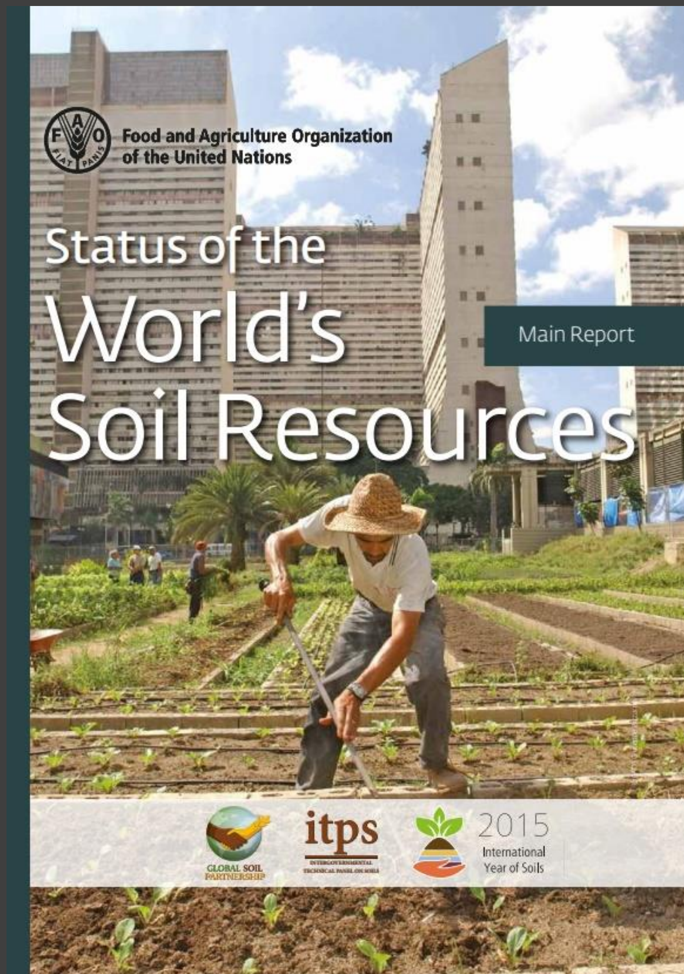
(McBratney et al., 2014; Commission of the European Community, 2006)

It’s all about the data…

“The main issue […] *of these* [policy] *reports has been the lack of access to authoritative assessments of soil conditions globally, that* [policy makers] *lack adequate **baseline datasets** including internal variability and systems for **monitoring change**”*

(Bouma and McBratney, 2013)

International Context



Pillar 1: Soil Management

Pillar 2: Awareness Raising

Pillar 3: Research

Pillar 4: Information & Data

Pillar 5: Harmonization

2015 International Year of Soils

International Decade of Soils 2015-2024

GLOBAL SOIL PARTNERSHIP

itps INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

Pillar 4: Information & Data

Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines

1. Answering critical questions at the global scale (e.g. is there enough arable land with suitable soil to feed the world?)
2. Providing the global context for more local decisions
3. Supplying fundamental soil data for understanding Earth-system processes to enable management of the major natural resource issues facing the world. These data need to be comparable with other fundamental data sets.

Canadians are starting to "get it" as well!

"To understand how agriculture can make a difference with good land management, we need to know what is happening where and when. ***A <u>coordinated process to collect and synthesize accurate place-based data</u>*** *can help. Entering the site-specific information into predictive models can provide the foresight necessary to* ***<u>prioritize and target actions</u>*** *toward those with the greatest ability to reduce or reverse soil degradation and protect water quality."*

Ms. Gabrielle Ferguson (Agronomist)

"We need ***<u>to increase the direct measurement of the state of our soils</u>*** *so that information can inform our management of those soils. Information will be critical to identify areas of concern and document solutions."*

Dr. David Burton (Soil Scientist)

"I think we need a ***<u>paradigm shift</u>****…"*

Sen. Rosmarie Moodie

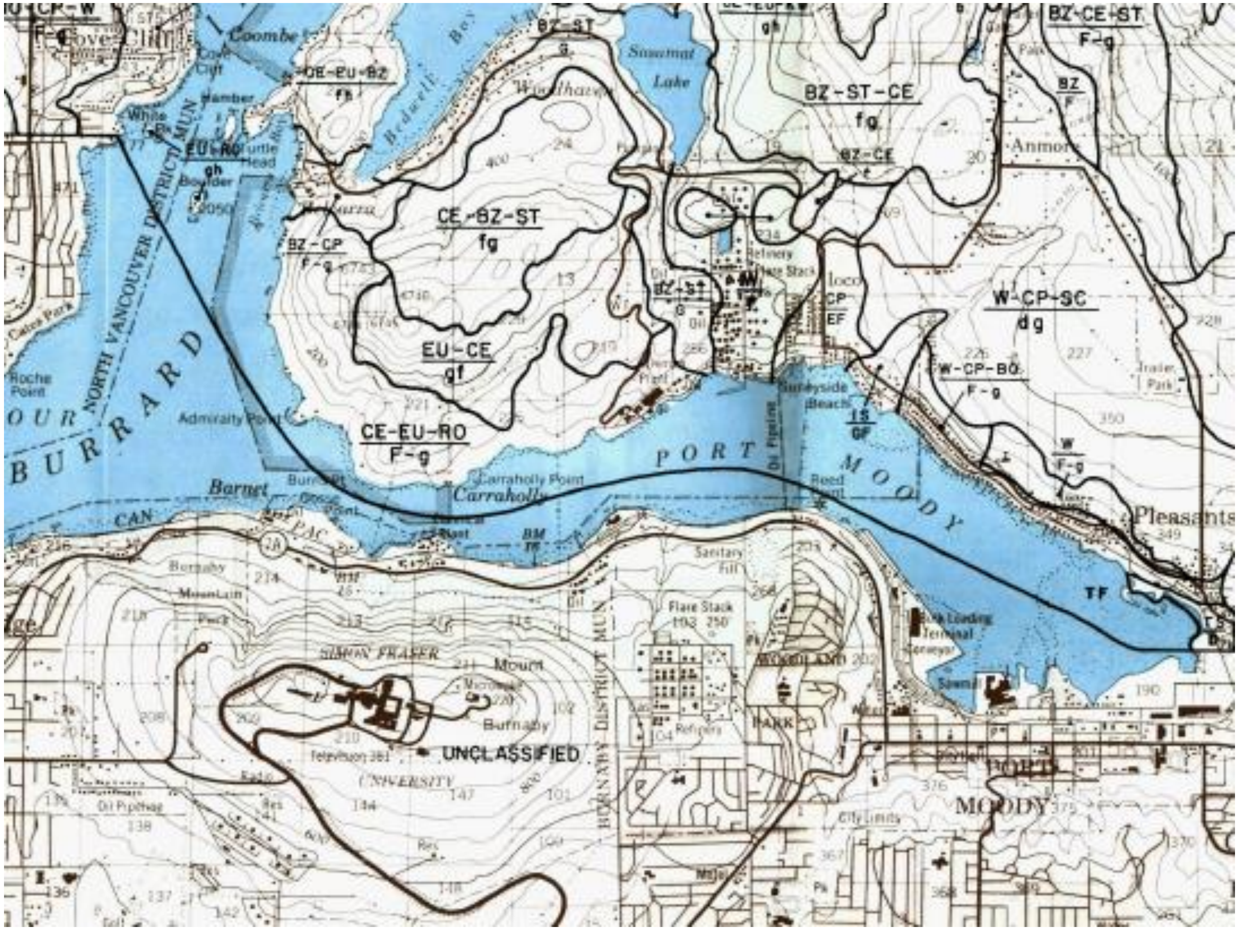
Standing Senate Committee on Agriculture and Forestry

Outline

1. **Theoretical Background: Paper to Pixels**

2. Generic Framework for Digital Soil Mapping

From Paper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W-CP-SC
dg
W-CP-BO
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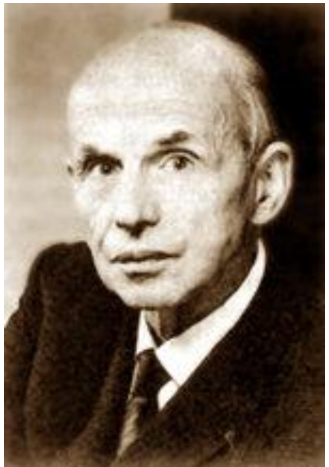
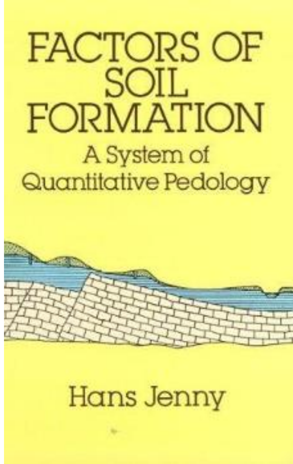
BZ-CE-ST
F-g
BURRARD
PORT MOODY
NORTH VANCOUVER DISTRICT MUN.
BURNABY DISTRICT MUN.
Sasamat Lake
UNCLASSIFIED
SIMON FRASER
UNIVERSITY
Mount Burnaby
Admiralty Point
Barnet
Carraholly Point
Pleasants
Anmore
Roche Point
Sanitary Fill
Flare Stack
Bulk Loading Terminal
Refinery
Sunnyside Beach
Reed Point
City Limits

Factors of Soil Formation (1941)

s = f(cl, o, r, p, t, …)

- Defines the soil’s environment
- Each factor is an independent variable.
- If we can precisely define the state of the soil system, we can predict its exact properties
  - Designed to assist soil mapping





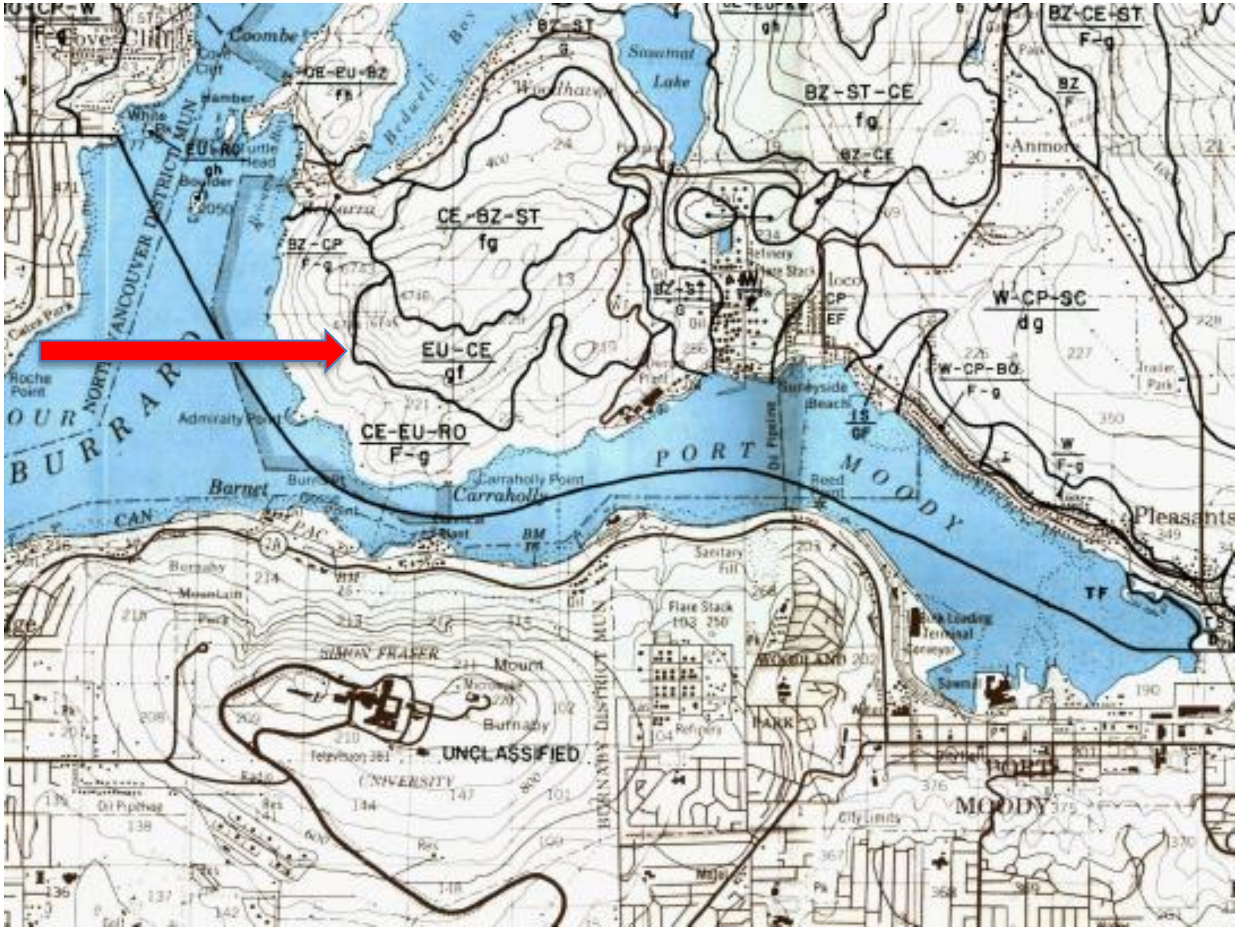
Factors of Soil Formation (1941)

s = f(cl, o, r, p, t, …)

*“The factors are not formers, or creators, or forces; they are **variables** that define the state of a soil system”* (Jenny, 1941)

These soil ***variables*** can also be represented as data layers in a geographic information system

Soil Map: Langley-Vancouver Map Area (1980)



EUNICE

DATE OF SURVEY: 69 SURVEYOR: HAL KELOWNA, B.C.M.A. & R.A.B.
SAMPLING PURPOSE: SEMI-DETAILED SURVEY

LOCATION		CLASSIFICATION	SLOPE	
LATITUDE(N):	49 15 43		%:	10.0
LONGITUDE(W):	122 31 55	TYPIC FOLISOL(1978)	TYPE:	SIMPLE
PRECISION (SEC):	05		CLASS:	STRONGLY SLOPING
ELEVATION (M):	200	STATUS: MODAL SOIL		

PARENT MATERIAL & LANDFORM

UPPER STRATIGRAPHIC UNIT
GENETIC MAT.: ORGANIC
SURFACE EXPRES.: VENEER

MIDDLE STRATIGRAPHIC UNIT
GENETIC MAT.: BEDROCK

BEDROCK
TYPE: INTRUSIVE ACID

DRAINAGE: RAPIDLY DRAINED
RUNOFF: SLOW

ADDITIONAL NOTES

SITE LOCATED 2400 METERS NORTH OF THE ADMINISTRATION BLDG, UBC RESEARCH FOREST.
THE LF IS FIBRIC, MAINLY CONIFEROUS LITTER; THE H IS HUMIC, YELLOW FUNGAL MYCELIA PRESENT AND SOME CHARCOAL.

PROFILE DESCRIPTION

HORIZON	THICKNESS DEPTH(CM)	HORIZON BOUNDARY	COLOUR 1	TEXTURE	STRUCTURE 1	CONSISTENCE	ROOTS 1
LF	11- 8	ABRUPT		ORGANIC			
H	8- 0	ABRUPT	5.0YR2.0/1.0 MATRIX MOIST	ORGANIC		FRIABLE	ABUNDANT
A E	0- 4	ABRUPT	5.0YR4.5/1.5 MATRIX MOIST	SANDY LOAM	VERY WEAK FINE SUBANGULAR BLOCKY	VERY FRIABLE	ABUNDANT
R	4-						

PHYSICAL & CHEMICAL DATA

HORIZON-DEPTH(CM.)		PH 1 SAMPLE STATE	PH 1 METHOD	PH 1 VALUE	PH 2 SAMPLE STATE	PH 2 METHOD	PH 2 VALUE	ORGANIC CARBON %	NITROGEN %
LF	11- 8	2	2	4.2	2	4	3.9	56.90	1.26
H	8- 0	2	2	3.6	2	4	3.1	55.39	1.48
A E	0- 4								
R	4-								

HORIZON-DEPTH(CM.)		EXCHANGEABLE CATIONS BUFF.(ME/100G) CA	MG	NA	K	C. E. C. DETERMINED	P1 PPM.	P2 PPM.	S PPM.	CU PPM.	ZN PPM.
LF	11- 8	15.07	3.56	.33	2.60	81.7	67.0	78.3	95.0	18.3	74.6
H	8- 0	11.23	2.44	.43	1.60	121.0	29.8	37.3	94.0	21.3	83.8
A E	0- 4										
R	4-										

EUNICE SOILS (EU)

Location and Extent: Eunice soils are common on the lower mountain slopes north of the Fraser River and on parts of the Sunshine Coast. About 170 ha of pure map units are classified as well as 7300 ha of soil complexes dominanted by Eunice soils. The complexes are mainly with Cannell, Hoover, Paton and Poignant soils and Rock Outcrop land type.

Topography and Elevation: Strongly to very steeply sloping or moderately rolling to hilly with slopes between 10 and 50 percent is the usual topography of Eunice soils. They usually occupy the tops and upper slopes of rocky ridges and knolls below 700 m above sea level.

Parent Material and Texture: Eunice soils have developed from 10 cm or more of coniferous organic material (litter) overlying bedrock. The upper 5 cm of organic material is partially decomposed to raw while the lower part is usually well-decomposed (humic). Less than 10 cm of sandy material sometimes lies between the organic material and the top of the bedrock.

Soil Moisture Characteristics: Eunice soils are well to rapidly drained. The organic material is rapidly pervious and has high water holding capacity. Substantial amounts of lateral seepage flows along the bedrock surface during prolonged heavy precipitation, especially where the bedrock is relatively massive.

General Soil Description: Eunice soils generally have a surface layer about 5 cm thick consisting of partially decomposed and undecomposed leaves, needles, twigs and moss. This is underlain by about 10 cm of black, matted, friable, well-decomposed (humic) organic material which, in turn, is abruptly underlain by massive to fractured, mainly granitic bedrock. Sometimes a thin (less than 10 cm), grayish, strongly leached, sandy layer lies between the organic material and bedrock. Soil reaction is extremely acid. Soil classification is *Typic Folisol*.

Commonly Associated Soils: Cannell, Hoover, Paton and Poignant soils and Rock Outcrop land type often are closely associated with Eunice soils either in soil complexes or in adjacent map units. Cannell soils differ from Eunice soils by consisting of 10 to 100 cm of mineral soil over bedrock, while Hoover, Paton and Poignant soils differ by being composed of more than 1 m of colluvial mineral soil over bedrock. Rock Outcrop land type differs from Eunice soils by having less than 10 cm of organic or mineral soil over bedrock, or has rock exposed at the land surface.

Vegetation: The natural vegetation is dominantly coniferous, mainly coast Douglas-fir, western hemlock, red alder and some western red cedar. Arbutus is also present in the coastal areas. Undergrowth is sparse and a moss layer usually covers the ground surface. Rooting is generally restricted to the depth of the organic material although some roots are established in fractures in the underlying bedrock.

General Land Use Comments: (1) Eunice soils are unsuited for agricultural use because of extreme shallowness to bedrock and steep topography. (2) Eunice soils are also very limited for urban and related uses. Although foundation conditions are good (bedrock), basements, underground utility installations and streets have to be constructed in rock. Insufficient soil exists for septic tank installation. (3) Forest growth is low to moderate being severely limited by shallow rooting depth and droughty conditions during the growing season. Limited plot data indicates potential productivity of Douglas-fir to range from about 3.5 to 7.5 m^3 of wood/ha/yr. During forest harvesting, extreme care is required to prevent removal or destruction of the organic layer. Should this happen, severe, long lasting site deterioration occurs.

CANNELL

DATE OF SURVEY: 63 SURVEYOR: GGR KELOWNA, B.C.M.A. & R.A.B.
SAMPLING PURPOSE: SEMI-DETAILED SURVEY

LOCATION

LATITUDE(N):
LONGITUDE(W):

CLASSIFICATION

ORTHIC HUMO-FERRIC PODZOL(1978)

STATUS: MODAL SOIL

PARENT MATERIAL & LANDFORM

UPPER STRATIGRAPHIC UNIT

GENETIC MAT.: COLLUVIAL
SURFACE EXPRES.: VENEER

DRAINAGE: WELL DRAINED
RUNOFF: MEDIUM

ADDITIONAL NOTES

CLASSIFICATION PHASE IS LITHIC.

PROFILE DESCRIPTION

HORIZON	THICKNESS DEPTH(CM)	HORIZON BOUNDARY	COLOUR 1	TEXTURE	STRUCTURE 1	FIELD PH
LH	5- 0					MEDIUM ACID
B F1	0- 15	GRADUAL	10.0YR5.0/4.0 MATRIX MOIST	LOAM	VERY WEAK MEDIUM SUBANGULAR BLOCKY	MEDIUM ACID
B F2	15- 33	ABRUPT	10.0YR5.0/3.0 MATRIX MOIST	LOAM	VERY WEAK MEDIUM SUBANGULAR BLOCKY	MEDIUM ACID
R	33-					

PHYSICAL & CHEMICAL DATA

HORIZON-DEPTH(CM.)		COARSE FRAGMENTS % VOL	GRAVEL %	COBBLE %	STONE %
LH	5- 0				
B F1	0- 15	60	10	30	20
B F2	15- 33	80	20	30	30
R	33-				

CANNELL SOILS (CE)

Location and Extent: Cannell soils are common in the mountainous parts of the report area. There are about 470 ha of pure map units and 24590 ha of soil complexes dominated by Cannell soils. The complexes are usually with Buntzen, Eunice, Lonzo Creek and Poignant soils and Rock Outcrop land type.

Topography and Elevation: Cannell soils are usually either strongly to very steeply sloping or moderately rolling to hilly with slope gradients between 20 and 60 percent. They mostly occupy the tops and upper slopes of ridges and knobs in the uneven landscape. Elevations range between 50 and 700 m above sea level.

Parent Material and Texture: The parent material of Cannell soils is a mixture of moderately coarse textured colluvium and glacial till. The deposits, up to 1 m deep but more commonly between 10 and 50 cm thick, overlie bedrock, usually granitic. In the eastern part of the report area, especially on Sumas and Vedder Mountains, variable amounts of silty eolian deposits either overlie or have been incorporated with the colluvium and glacial till. Surface and subsurface textures are mostly sandy loam or gravelly sandy loam, occasionally varying to gravelly loamy sand. Where the eolian deposits are present, loam textures are not uncommon. The soils are moderately to exceedingly stony.

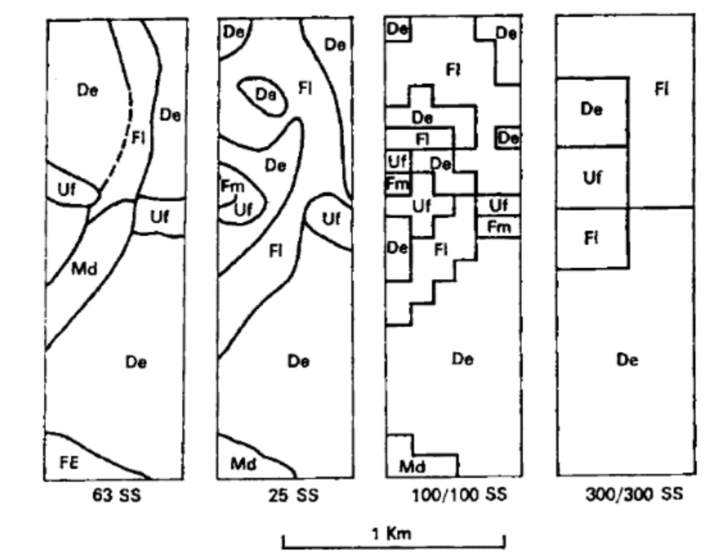
Soil Moisture Characteristics: Cannell soils are well to rapidly drained. They are rapidly pervious and have low to moderate water holding capacity. Where the underlying bedrock is relatively massive (i.e. unfractured), lateral seepage along its surface is common during periods of heavy rain (or during snowmelt).

General Soil Description: Cannell soils have up to 15 cm of mixed raw to well-decomposed coniferous forest litter and moss on the mineral soil surface. This is underlain by a loose, gray, leached, sandy layer usually less than 6 cm thick which, in turn, is underlain by 10 to 50 cm of friable, reddish-brown or dark reddish brown, gravelly or sandy material containing some hard, spherical concretions. This is usually abruptly underlain by bedrock or where the bedrock is deeper, a massive, friable to firm gravelly zone, grayish-brown in colour which separates the rock from the more reddish layer above. A thin, concentrated layer of roots often immediately overlies the rock. Soil reaction varies from extremely to very strongly acid throughout. Soil classification generally is *Orthic Humo-Ferric Podzol:lithic phase* although in the drier parts of the map area such as on the Sunshine Coast, the classification sometimes changes to *Orthic* or *Degraded Dystric Brunisol:lithic phase*.

Commonly Associated Soils: Cannell soils are closely associated with a variety of soils but most commonly are associated with Buntzen, Eunice, Lonzo Creek, Strachan, Hoover and Poignant soils and Rock Outcrop land type. Buntzen, Lonzo Creek and Strachan soils differ from Cannell soils by being developed from glacial till deposits more than 1 m deep. Hoover and Poignant soils, although colluvial in origin, are also more than 1 m deep. Eunice soils, on the other hand, are very shallow, having developed from 10 to 20 cm of organic forest litter over bedrock. The Rock Outcrop land type consists either of bedrock exposed at the surface or covered by less than 10 cm of mineral or organic soil material.

Vegetation: Most Cannell soil areas support second-growth forest, mainly Douglas-fir and western hemlock. The usually scanty understory includes various ericaceous shrubs with moss on the soil surface. Rooting depth is limited to 100 cm or less, depending on the depth to the underlying bedrock.

General Land Use Comments: (1) Cannell soils are generally not suited for agricultural cropping because of shallowness to bedrock, steep slopes and stoniness. (2) They are also poorly suited for urban and similar construction because of shallowness to bedrock and steep slopes. Although foundation conditions are good because they can be placed directly on bedrock, basements, underground utilities and other excavations are difficult to install. Septic tanks are unsuitable because of lack of soil depth for effluent disposal, and steep slopes. Roads are difficult and expensive to construct. (3) Forest production is moderate to low, limited by shallow rooting depth and low soil moisture levels. Limited plot data indicates productivity of coast Douglas-fir is about 5 to 8 m^3/ha/yr. Special care should be exercised during harvesting to prevent erosion or other removal of the limited soil depth present.



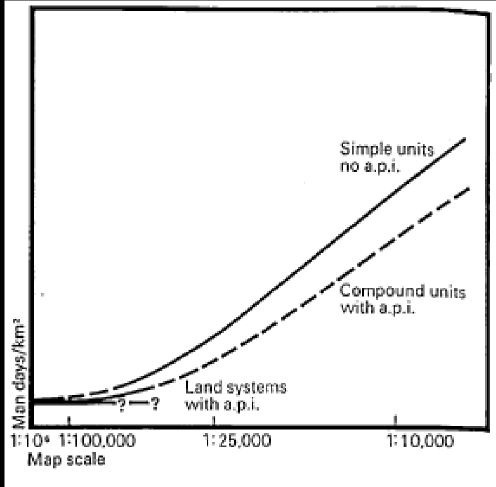


Figure 5 The total field effort of professional staff on 66 soil and land survey systems in Australia with and without airphoto interpretation (a.p.i.) [5].

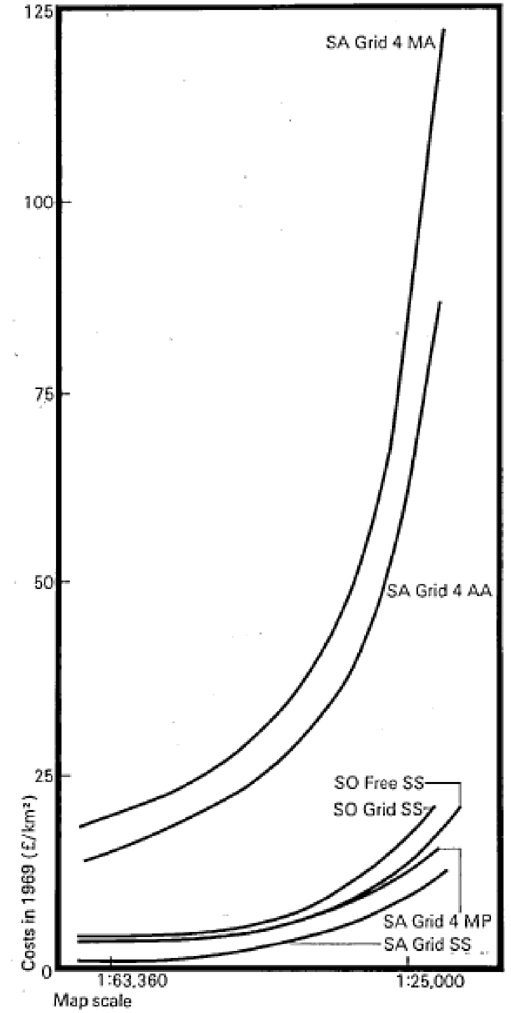


Figure 4 The direct costs of soil survey, averaged over three areas in the Vale of the White Horse, Berkshire [9], for free and grid survey, by graduate (SO) and unqualified (SA) staff, to general purpose legends (SS), and to single property legends of properties which may be assessed in the field (MP), or analysed in the laboratory by manual (MA) or automated (AA) procedures. Costs are for 1969.

- Increase in sampling density (grid) and detail results in increased cost and time required to complete a survey.
- General purpose maps are most cost and time effective
- Compound map units reduce the amount of time required to complete a survey

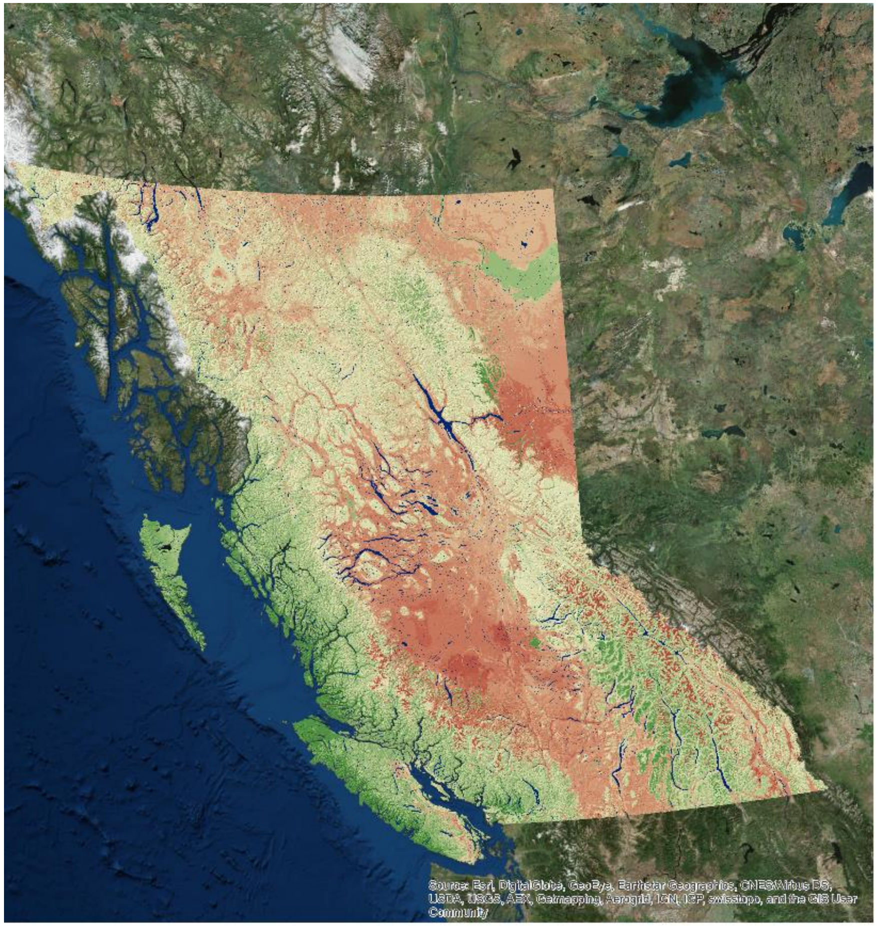
Beckett , 1971; Burrough et al., 1971

Conventional Soil Maps (CSM)

- Soil surveys have provided useful information about the distribution of soil types and their properties for over a 100 years.

- Despite some of the short comings with conventional surveys, legacy soil maps still provide very useful information and insight into landscapes.

To Pixels



BC Soil Organic Carbon Map (250 m)

0 75 150 300 Kilometers

Soil Organic Carbon Stock (0 - 30 cm)

Tons/ha

High : 67.0727

Low : 0.334114

Digital Soil Maps (DSM)

- Demand for **up-to-date** and relevant digital soil information for land, resource, and environmental management
- Traditional soil surveys are **expensive** and **time-consuming**
- Take advantage of revolutionary advances in remote-sensing, computing, modeling, and GIS
- Provide a ***continuous*** coverage of soil information in raster format

GlobalSoilMap.net

POLICYFORUM

ENVIRONMENTAL SCIENCE

Digital Soil Map of the World

Increased demand and advanced techniques could lead to more refined mapping and management of soils.

Pedro A. Sanchez,[1*] Sonya Ahamed,[1] Florence Carré,[2] Alfred E. Hartemink,[3] Jonathan Hempel,[4] Jeroen Huising,[5] Philippe Lagacherie,[6] Alex B. McBratney,[7] Neil J. McKenzie,[8] Maria de Lourdes Mendonça-Santos,[9] Budiman Minasny,[7] Luca Montanarella,[2] Peter Okoth,[5] Cheryl A. Palm,[1] Jeffrey D. Sachs,[1] Keith D. Shepherd,[10] Tor-Gunnar Vågen,[10] Bernard Vanlauwe,[5] Markus G. Walsh,[1] Leigh A. Winowiecki,[1] Gan-Lin Zhang[11]

Soils are increasingly recognized as major contributors to ecosystem services such as food production and climate regulation (*1*, *2*), and demand for up-to-date and relevant soil information is soaring. But communicating such information among diverse audiences remains challenging because of inconsistent use of technical jargon, and outdated, imprecise methods. Also, spatial resolutions of soil maps for most parts of the world are too low to help with practical land management. While other earth sciences (e.g., climatology, geology) have become more quantitative and have taken advantage of the digital revolution, conventional soil mapping delineates space mostly according to qualitative criteria and renders maps using a series of polygons, which limits its resolution. These maps do not adequately express the complexity of soils across a landscape in an easily understandable way.

The Food and Agriculture Organization (FAO) of the United Nations (UN) and the UN Educational, Scientific and Cultural Organization (UNESCO) published the first world soil map in 1981, using a single soil classification terminology (*3*). The map has been utilized in many global studies on climate change, food production, and land degradation. But its low resolution (1:5 million scale) is not suitable for land management decisions at field or catchment scales. One of the most-cited soil degradation studies, the *Global Assessment of Human Induced Soil Degradation*, is based on expert judgment by a few individuals, has very low resolution (1:50 million scale), and lacks quantitative information on soil properties that indicate the degree of soil degradation (*4*). At present, 109 countries have conventional soil maps at a scale of 1:1 million or finer, but they cover only 31% of the Earth's ice-free land surface, leaving the remaining countries reliant on the FAO-UNESCO map (*5*). [See supporting online material (SOM) for more history.]

To address these many shortcomings, soil scientists should produce a fine-resolution, three-dimensional grid of the functional properties of soils relevant to users. We call for development of a freely accessible, Web-based digital soil map of the world that will make georeferenced soil information readily available for land-users, scientists, and policy-makers. A foundation for such an effort is being laid by the GlobalSoilMap.net (GSM) project. This effort originated in 2006 (*6*) in response to policy-makers' frustrations at being unable to get quantitative answers to questions such as: How much carbon is sequestered or emitted by soils in a particular region? What is its impact on biomass production and human health? How do such estimates change over time?

The GSM consortium's overall approach consists of three main components: digital soil mapping, soil management recommendations, and serving the end users—all of them backed by a robust cyberinfrastructure. [See fig. S1, expanded from (*7*).] Specific countries may add their own modifications.

Maps can provide soil inputs (e.g., texture, organic carbon, and soil-depth parameters) to models predicting land-cover changes in response to global climatic and human disturbances.

Digital Soil Mapping

Digital soil mapping began in the 1970s (*8*) and accelerated significantly in the 1980s because of advances in information and remote-sensing technologies, computing, statistics and modeling, spatial information and global positioning systems, measurement systems (such as infrared spectroscopy), and in more recent times, online access to information. Experimentation with these technologies is leading toward consensus (*7*, *9*–*12*), and operational systems are being implemented.

A digital soil map is essentially a spatial database of soil properties, based on a statistical sample of landscapes. Field sampling is used to determine spatial distribution of soil properties, which are mostly measured in the laboratory. These data are then used to predict soil properties in areas not sampled. Digital soil maps describe the uncertainties associated with such predictions and, when based on time-series data, provide information on dynamic soil properties. They also differ from conventional, polygon-based maps, in that they are pixel-based and can be more easily displayed at higher resolutions currently used by other earth and social sciences.

There are three main steps in digital soil mapping. Step 1, data input, starts with the production of base maps, assembling and calibrating spatially contiguous covariates from available data [e.g., the 90- × 90-m resolution digital terrain models from Shuttle Radar Topography Mission (SRTM v.3)]. Covariates, reflecting state factors of soil forma-

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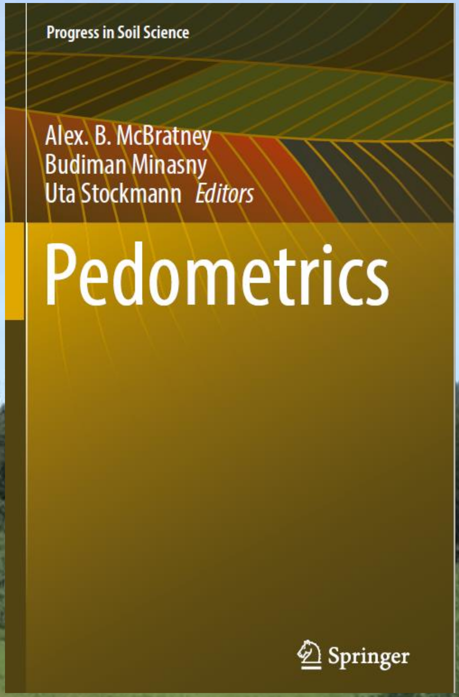
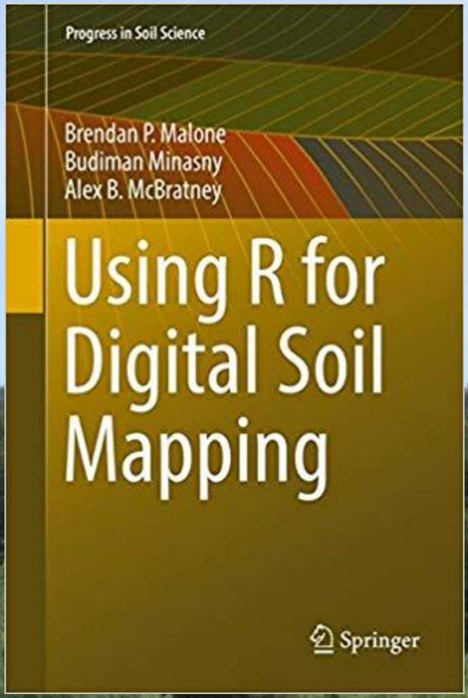
Digital Soil Maps (DSM)

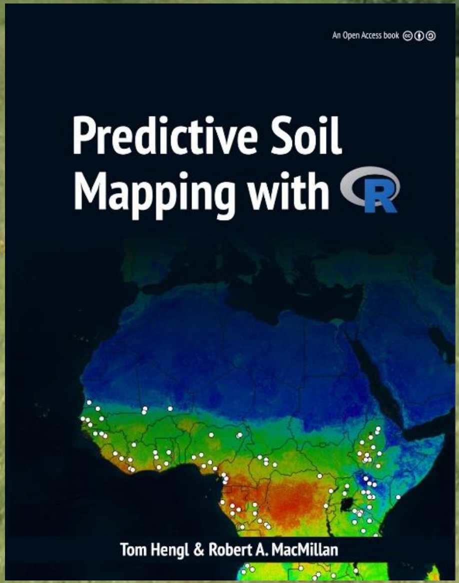
"…The creation and population of spatial soil information systems by numerical models inferring the spatial and temporal variations of soil types and soil properties from soil observation and knowledge from related environmental variables"

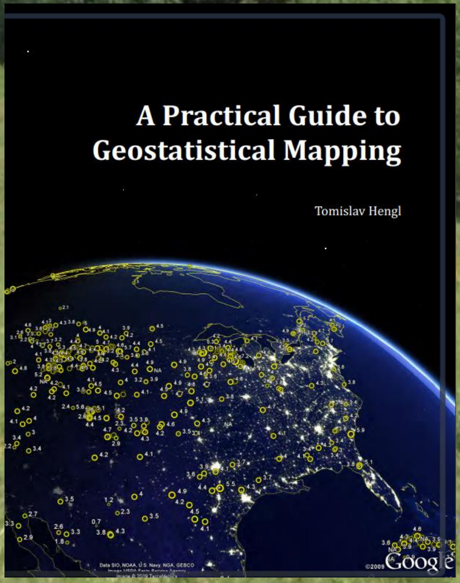
(Lagacherie, 2008. *Digital Soil Mapping with Limited Data*)

GlobalSoilMap.net









DIGGING INTO CANADIAN SOILS

An Introduction to Soil Science

Edited by Maja Krzic, Frances L. Walley, Amanda Diochon, Maxime C. Paré, and Richard E. Farrell

17.

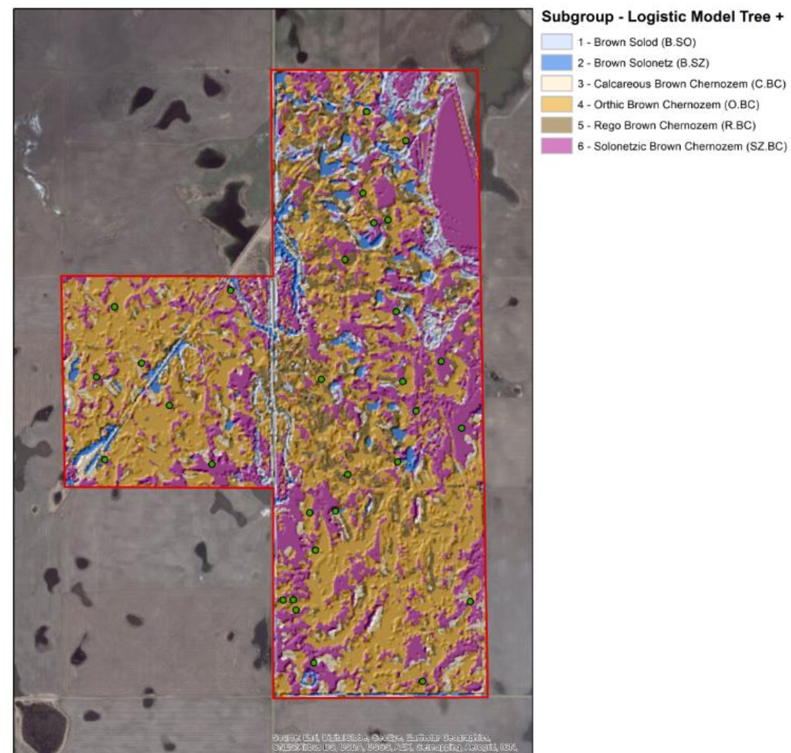
DIGITAL SOIL MAPPING

Brandon Heung, Daniel Saurette, and Chuck Bulmer

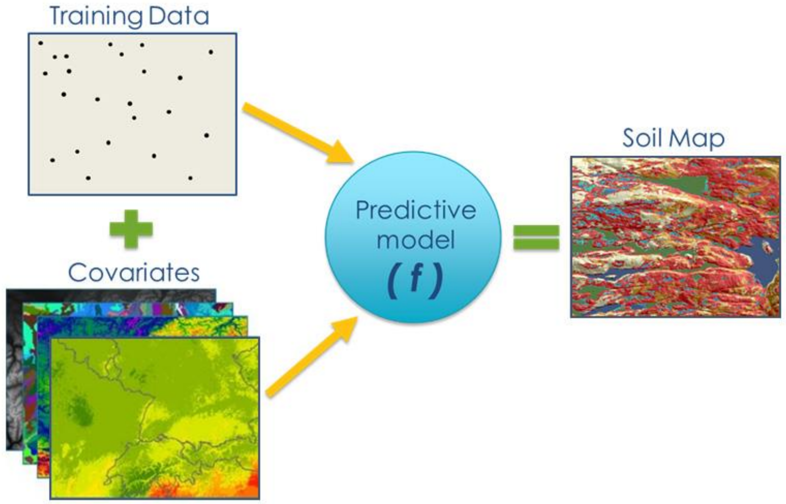
LEARNING OUTCOMES

Upon completion of this chapter, students will be able to:

1. Describe and rationalize a transition from conventional soil information to digital soil information
2. Link theories of pedogenesis to applications of digital soil mapping
3. Provide an overview of how digital soil information is used to generate soil maps



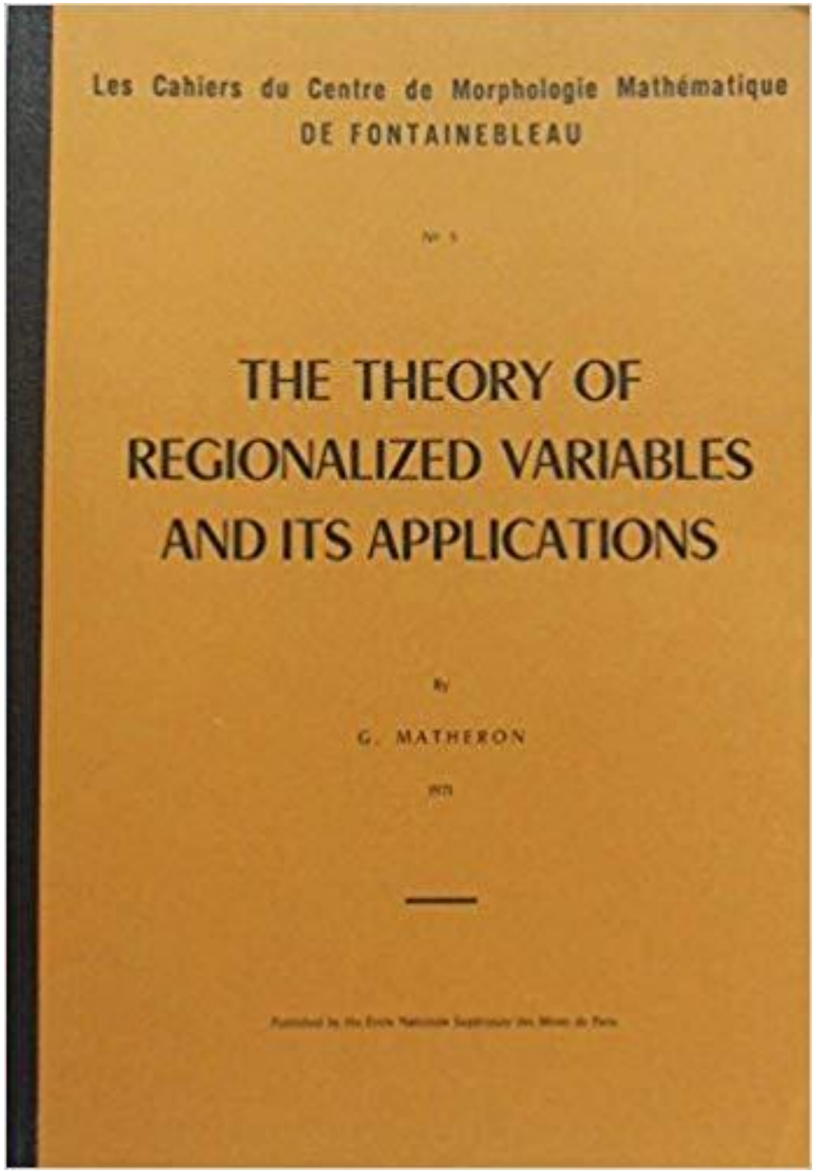
Digital Soil Mapping



The coupling of **Geographic Information Science** (GIS) and **Soil Science** to make predictions on soil classes and soil properties.

The development of DSM map layers (environmental covariates) and the collection, management, and analysis of soil data.

Relationships are made between environmental covariates and collected soil data using various models from which predictions can be made.



Universal Model of Soil Variation

$$Z(s) = Z^*(s) + \varepsilon(s) + \varepsilon$$

Z(s): Target soil variable (type or property)

Z*(s): Deterministic Component
Modelled using statistical soil-landscape model (e.g. regression or classification algorithm)

ε(s): Stochastic Component
Spatial structure that is modelled with a variogram (e.g. kriging)

ε: Spatially Uncorrelated Noise
Can't be modelled with the available data or models at a scale

Burrough and McDonnell, 1998

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On digital soil mapping

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[b] *EMBRAPA-Centro Nacional de Pesquisa de Solos, Rua Jardim Botânico 1024, 22.460-000, Rio de Janeiro, RJ, Brazil*

Received 19 November 2002; received in revised form 14 May 2003; accepted 5 June 2003

Abstract

We review various recent approaches to making digital soil maps based on geographic information systems (GIS) data layers, note some commonalities and propose a generic framework for the future. We discuss the various methods that have been, or could be, used for fitting quantitative relationships between soil properties or classes and their 'environment'. These include generalised linear models, classification and regression trees, neural networks, fuzzy systems and geostatistics. We also review the data layers that have been, or could be, used to describe the 'environment'. Terrain attributes derived from digital elevation models, and spectral reflectance bands from satellite imagery, have been the most commonly used, but there is a large potential for new data layers. The generic framework, which we call the scorpan-SSPFe (soil spatial prediction function with spatially autocorrelated errors) method, is particularly relevant for those places where soil resource information is limited. It is based on the seven predictive scorpan factors, a generalisation of Jenny's five factors, namely: (1) *s*: soil, other or previously measured attributes of the soil at a point; (2) *c*: climate, climatic properties of the environment at a point; (3) *o*: organisms, including land cover and natural vegetation; (4) *r*: topography, including terrain attributes and classes; (5) *p*: parent material, including lithology; (6) *a*: age, the time factor; (7) *n*: space, spatial or geographic position. Interactions (*) between these factors are also considered. The scorpan-SSPFe method essentially involves the following steps:

(i) Define soil attribute(s) of interest and decide resolution ρ and block size β.
(ii) Assemble data layers to represent Q.
(iii) Spatial decomposition or lagging of data layers.
(iv) Sampling of assembled data (Q) to obtain sampling sites.
(v) GPS field sampling and laboratory analysis to obtain soil class or property data.
(vi) Fit quantitative relationships (observing Ockham's razor) with autocorrelated errors.
(vii) Predict digital map.

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doi:10.1016/S0016-7061(03)00223-4

Introducing the *SCORPAN* Model

$$S_{c,a} = f(s, c, o, r, p, a, n) + \varepsilon$$

$S_{c,a}$: Soil classes or attributes

From Jenny's Equation:
c*:* Climate
o*:* Organisms, vegetation
r*:* Topography, landscape attributes
p*:* Parent material, lithology
a*:* Age or time factor

Additions:
s: soil, other properties of a soil at a point
n: space, spatial position – relative to sampling locations and environmental features
ε: spatially autocorrelated residuals

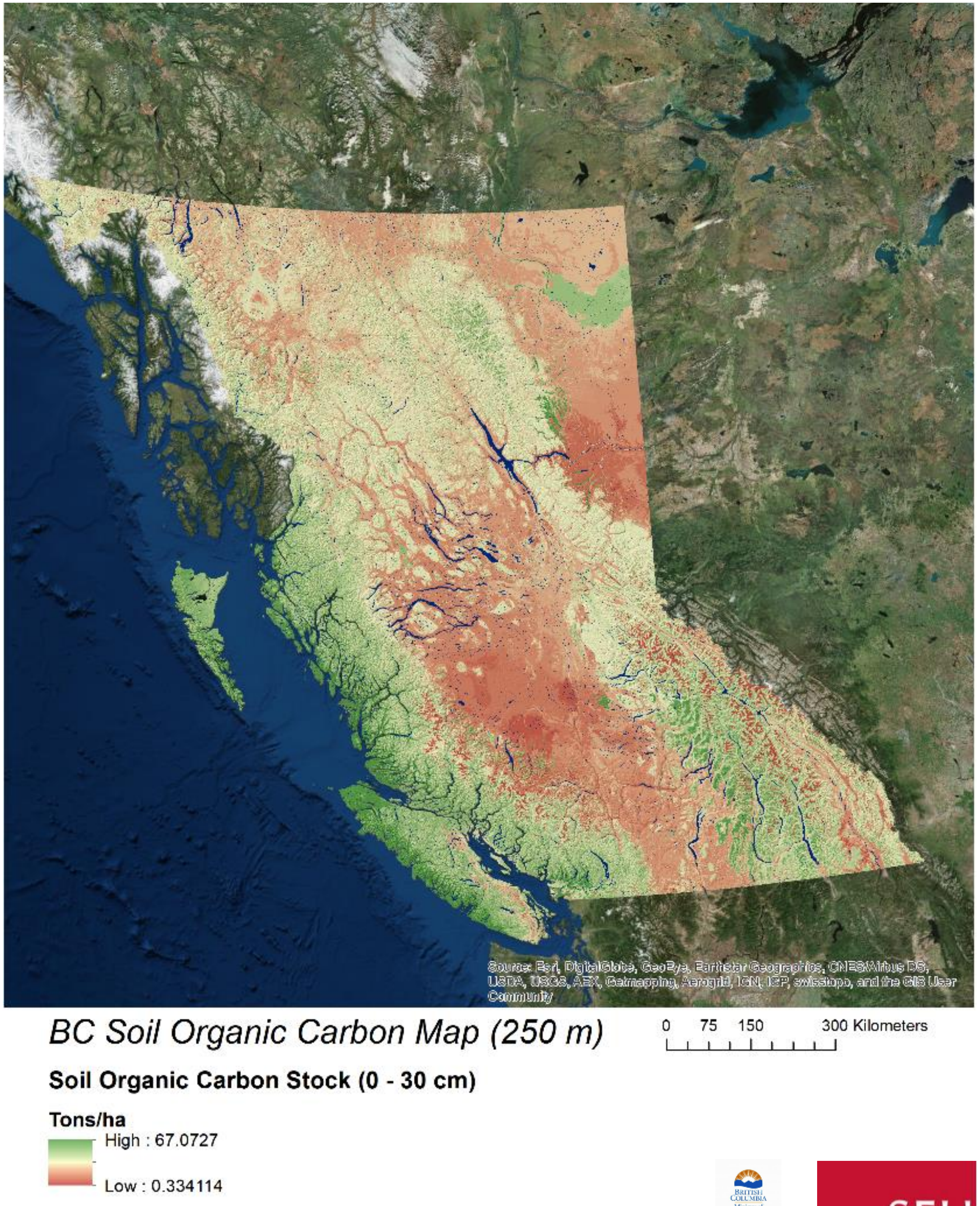
f(): Quantitative function *f* linking *S* to *scorpan* factors

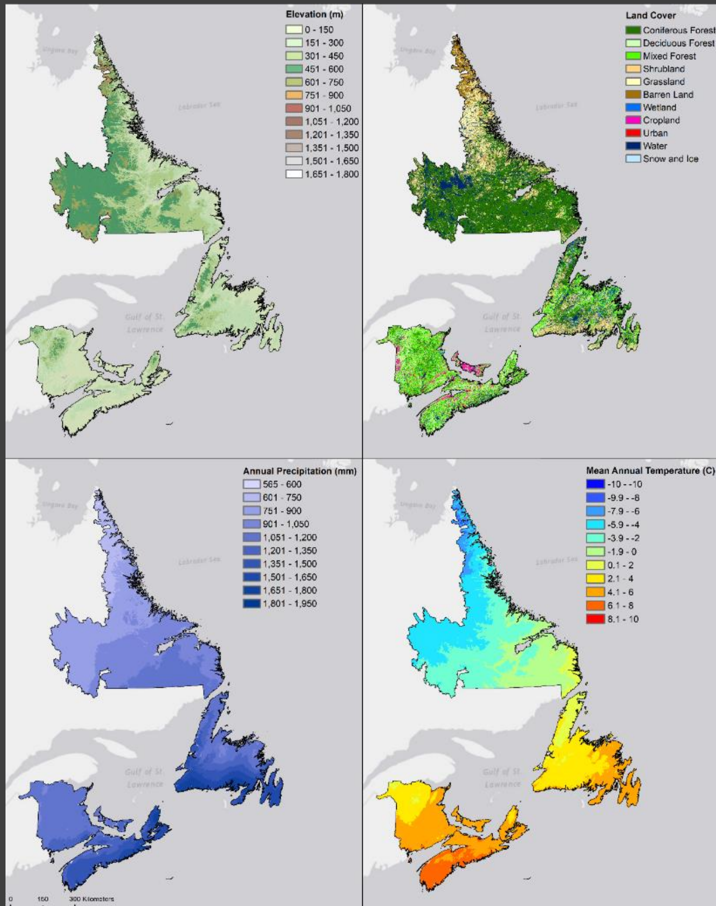
Pedometrics

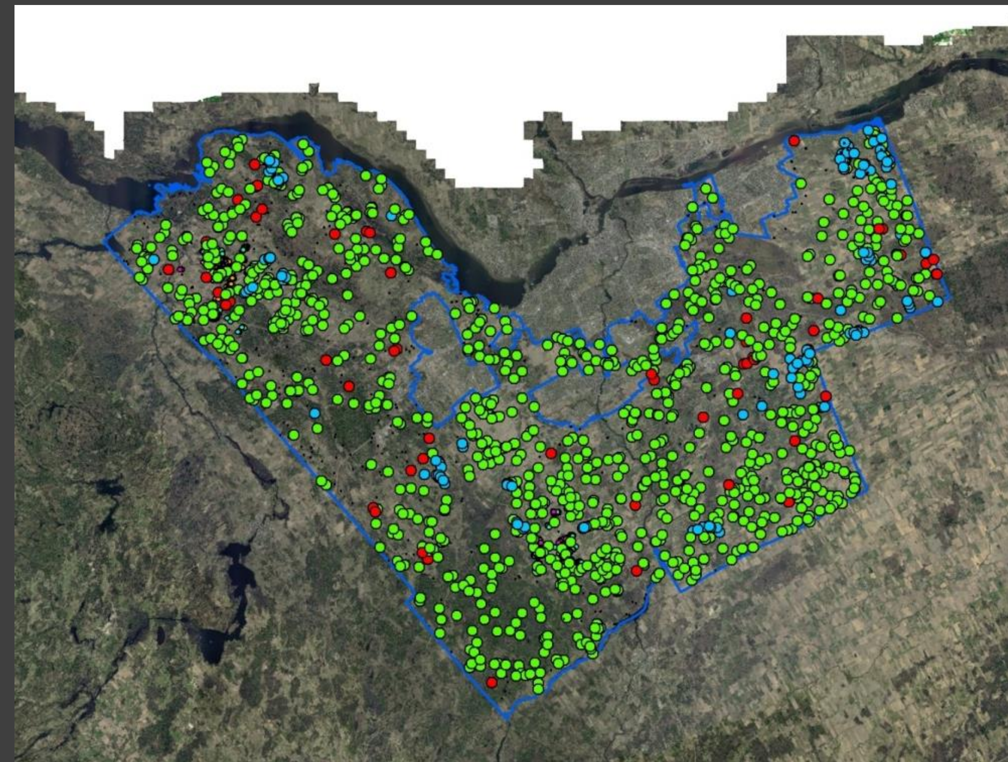
A branch of **soil science** that aims to develop **accurate** and **precise** **digital soil maps** that provide knowledge of soil variability over space using **statistical techniques** and **technological advances**.

Pedometricians

1. Model baselines
2. Monitor soil changes
3. Assess soil functions
4. Transform data into knowledge







Inputs

1. Environmental spatial data layers (i.e. covariates)
2. Georeferenced soil observations
3. Predictive model

Supervised Learning

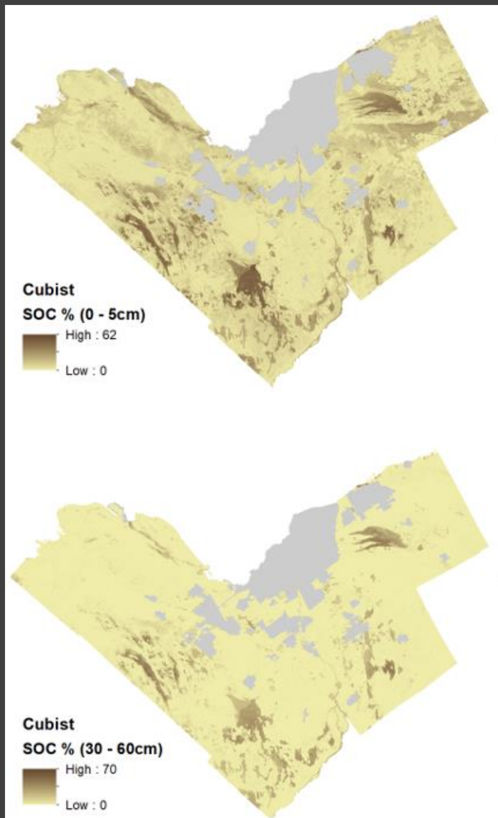
The process of inferring the relationship between a response variable and a set of predictor variables.

Response Variable: Soil attribute or soil class
Predictor Variable: GIS layers of the environment

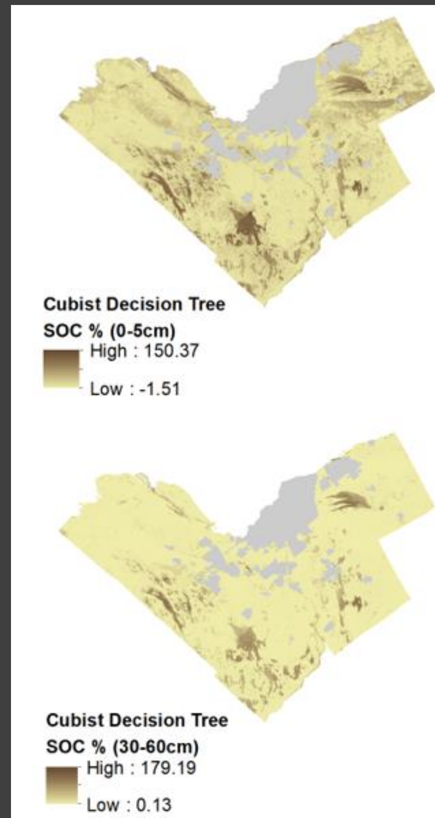
- **IF** the environmental conditions from which a soil sample is known, **THEN** the *soil-environmental* relationships may be inferred using a model.

- The model can be used to predict for un-sampled locations.

Soil Carbon Map



Uncertainty



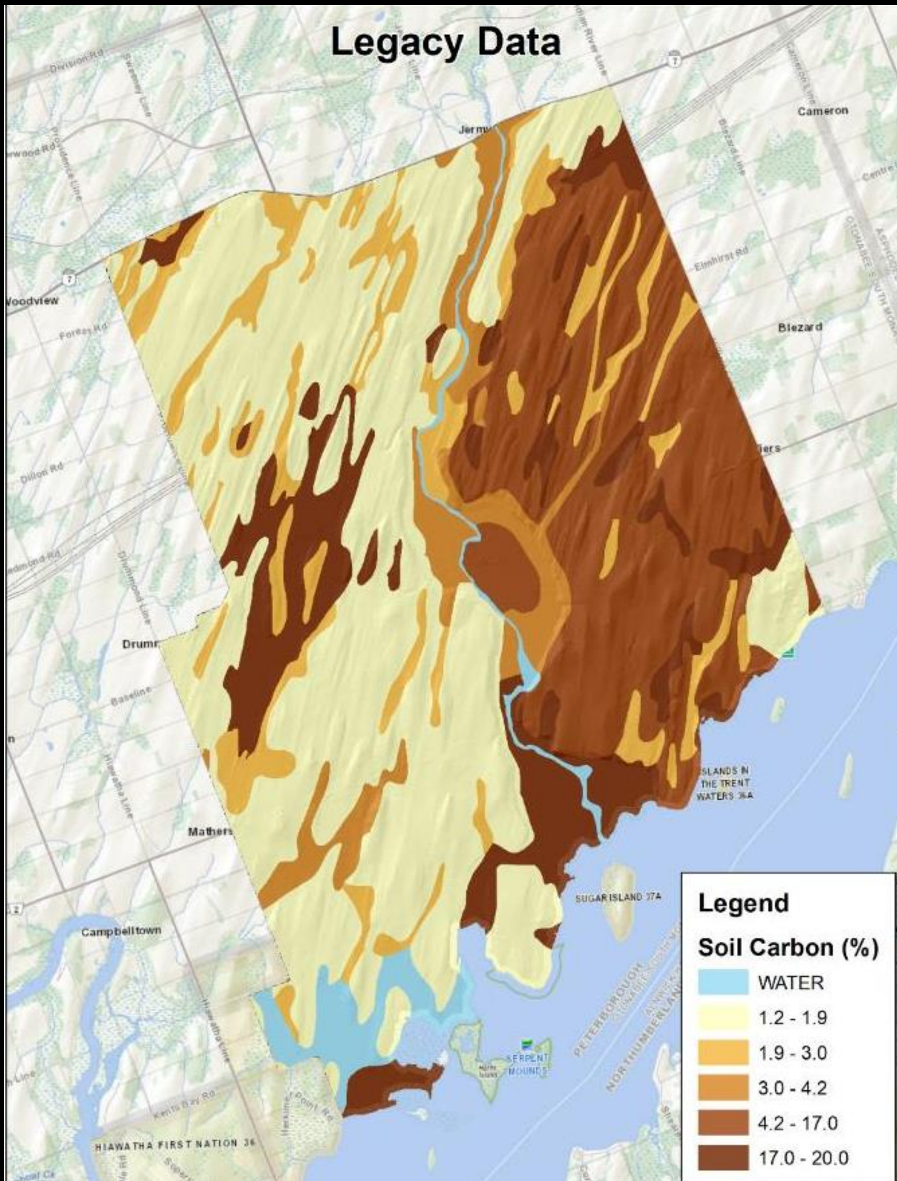
Accuracy Metrics

Soil Organic Carbon

0-5 cm Depth Increment: 65%
30-60 cm Depth Increment: 62%

Outputs

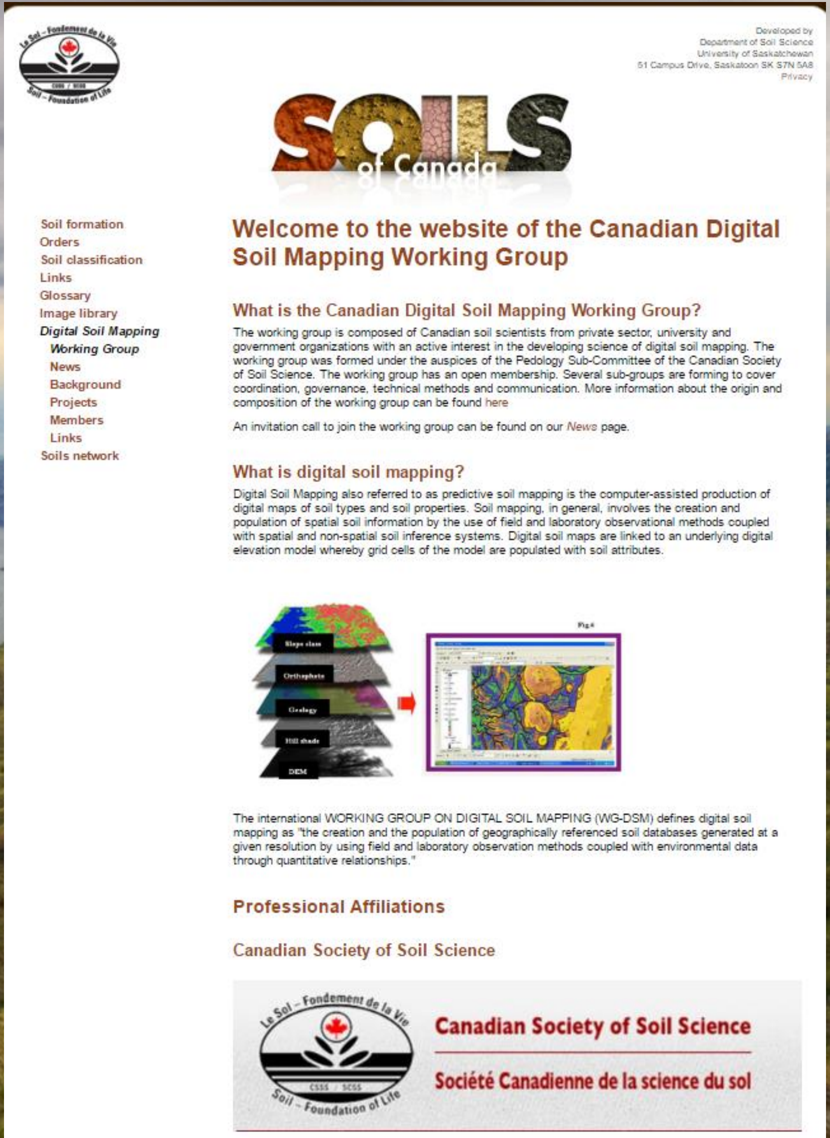
1. Predictive digital soil map
2. Uncertainty estimates
3. Accuracy metrics



Ontario
Ministry of Agriculture, Food and Rural Affairs

Canadian Digital Soil Mapping Working Group

- Formed under the CSSS Pedology Sub-Committee (2016)
- Tasked with developing DSM products and coordinating national-scale DSM research.
- Development of DSM in accordance to GlobalSoilMap.net specifications.
  - 12 key soil attributes
  - 6 depth intervals
- Development of soil carbon concentration and stock maps for submission to UN-FAO global carbon mapping project.



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Welcome to the website of the Canadian Digital Soil Mapping Working Group

What is the Canadian Digital Soil Mapping Working Group?

The working group is composed of Canadian soil scientists from private sector, university and government organizations with an active interest in the developing science of digital soil mapping. The working group was formed under the auspices of the Pedology Sub-Committee of the Canadian Society of Soil Science. The working group has an open membership. Several sub-groups are forming to cover coordination, governance, technical methods and communication. More information about the origin and composition of the working group can be found here

An invitation call to join the working group can be found on our *News* page.

What is digital soil mapping?

Digital Soil Mapping also referred to as predictive soil mapping is the computer-assisted production of digital maps of soil types and soil properties. Soil mapping, in general, involves the creation and population of spatial soil information by the use of field and laboratory observational methods coupled with spatial and non-spatial soil inference systems. Digital soil maps are linked to an underlying digital elevation model whereby grid cells of the model are populated with soil attributes.

The international WORKING GROUP ON DIGITAL SOIL MAPPING (WG-DSM) defines digital soil mapping as "the creation and the population of geographically referenced soil databases generated at a given resolution by using field and laboratory observation methods coupled with environmental data through quantitative relationships."

Professional Affiliations

Canadian Society of Soil Science

Canadian Society of Soil Science
Société Canadienne de la science du sol

Canadian Digital Soil Mapping Working Group

Canadian DSM Workshop (SFU, 2017)
25 Attendees from across Canada
- Students (Graduate & Undergraduates)
- University Faculty Members
- Government Agencies (Provincial & Federal)

Membership:

Coordination Committee (6 members)

Science & Technical Team (8 members)

Overall Working Group (40 members)

Key Contributors:

Agriculture & Agri-Food Canada

Canadian Forest Service, NRCAN

BC Ministry of Environment

BC Ministry of FLNRO

Quebec Ministry of Forests

Dalhousie University

McGill University

Simon Fraser University

University of Saskatchewan

CDSM WG

A Renaissance in Soil Survey?

British Columbia:

- Agricultural systems for Lower Fraser Valley (S. Paul, S. Smukler)
- Provincial-scale mapping (B. Heung, M. Schmidt, C. Bulmer)
- Grasslands in Kamloops (J. Zhang, B. Heung, M. Schmidt, C. Bulmer)
- Forest stand-scale mapping in Kamloops (B. Kasraei, B. Heung, M. Schmidt, C. Bulmer)

Alberta:

- Agricultural soil carbon mapping (Food, Water, Wellness Foundation)
- Forest soil carbon mapping (Innotech Alberta)

Saskatchewan:

- Saskatchewan Soil Information System (J. Kiss, A. Bedard-Haughn, B. Heung)

Ontario:

- Supporting enhanced forest inventories in Northern Ontario (C. Blackford, K. Webster, B. Heung)
- Renewing soil surveys for Ottawa & Peterborough (D. Saurette, A. Gillespie, A. Biswas, B. Heung)

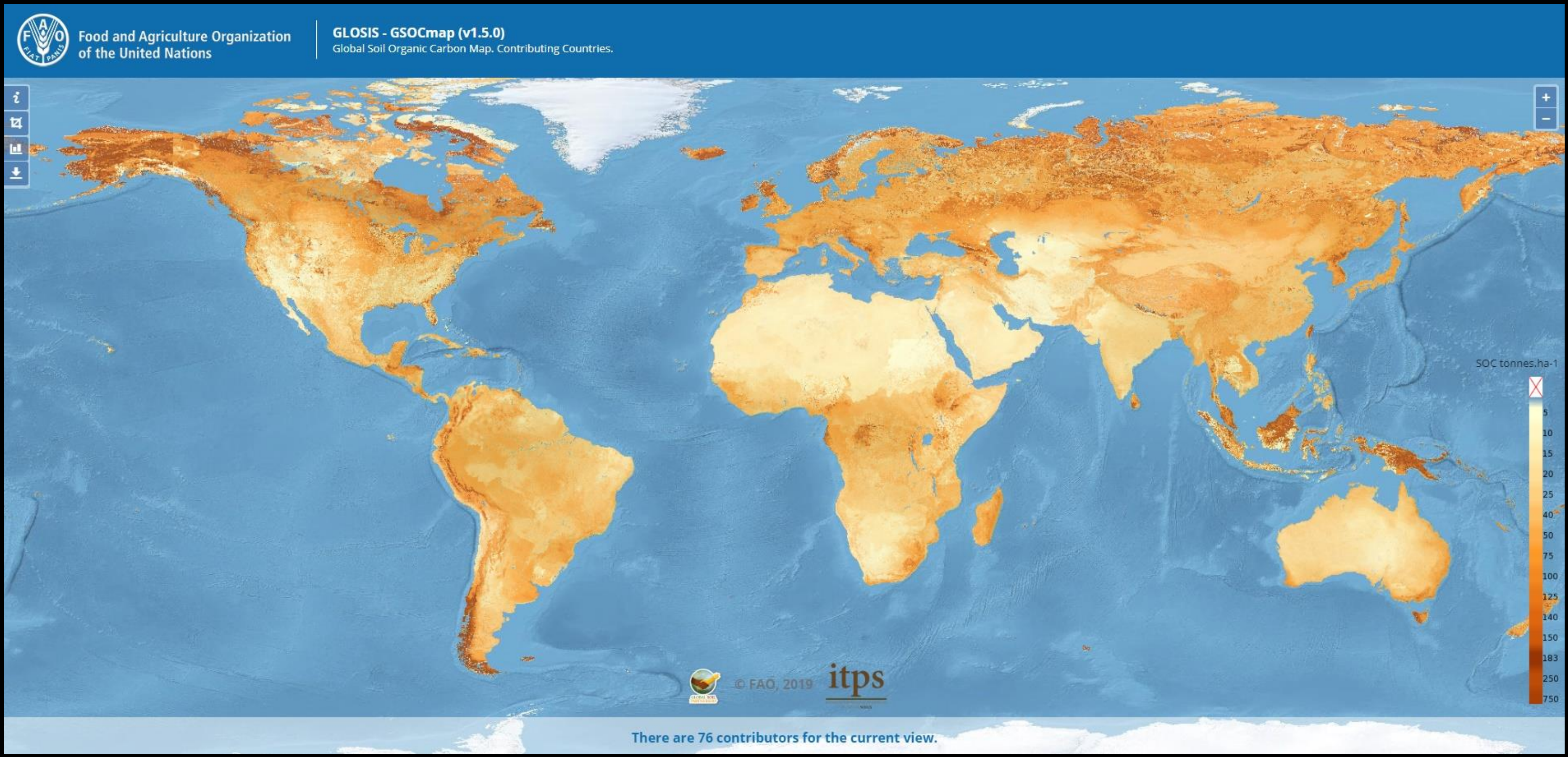
Quebec:

- Provincial-scale mapping (J.-D. Sylvain)
- Stand-scale SOC assessment for Valcartier Forest (J. Beguin, D. Paré)

Atlantic Canada:

- Soil health and biogeography assessment for Atlantic Provinces (L.-P. Comeau, S. Hann, B. Heung)

Co-Chairs: Brandon Heung (Dalhousie), Angela Bedard-Haughn (U. Sask.)
Core Researchers: **[BC]** – Chuck Bulmer (BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development), Margaret Schmidt (SFU), Sean Smukler (UBC), Scott Smith (Summerland, AAFC); **[A**– Nicholas Mansuy (Northern Forestry Centre, NRCan); **[MB]** – Glenn Lelyk (Winnipeg, AAFC); **[ON]** – Kara Webster (Great Lakes Forestry Centre, NRCan), Daniel Saurette (ON Ministry of Agriculture, Food and Rural Affairs & Guelph), Adam Gillespie (Guelph), Asim Biswas (Guelph), Bert Vandenbygaart and Xiaoyuan Geng (Ottawa, AAFC); **[QB]** – Jean-Daniel Sylvain (Ministère des Forêts, de la Faune et des Parcs de Quebec), Julien Beguin and David Paré (Laurentian Forestry Centre, NRCan); **[NB]** – Louis-Pierre Comeau and Sheldon Hann (Fredericton, AAFC).



Food and Agriculture Organization of the United Nations

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2 ZERO HUNGER

13 CLIMATE ACTION

15 LIFE ON LAND

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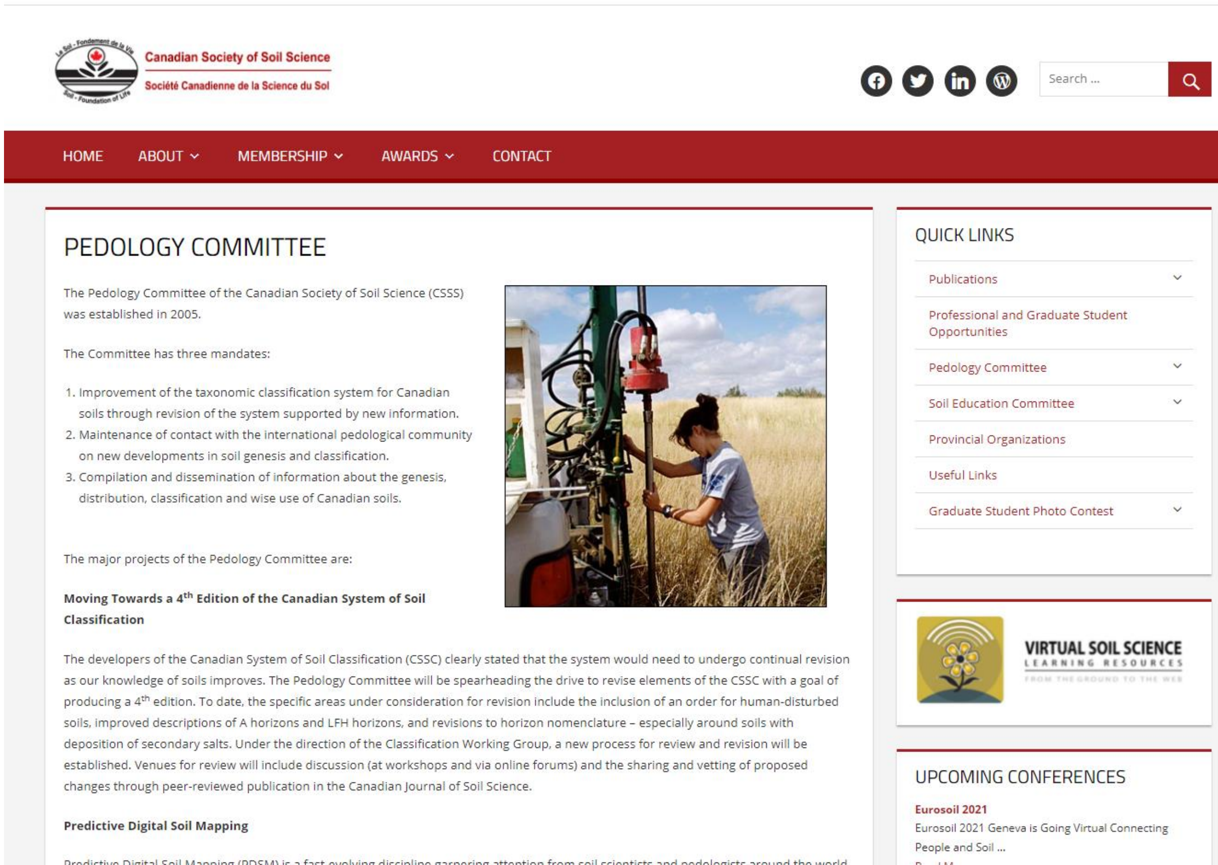


Canadian Society of Soil Science
Société Canadienne de la Science du Sol

Search ...

HOME ABOUT MEMBERSHIP AWARDS CONTACT

PEDOLOGY COMMITTEE

The Pedology Committee of the Canadian Society of Soil Science (CSSS) was established in 2005.

The Committee has three mandates:

1. Improvement of the taxonomic classification system for Canadian soils through revision of the system supported by new information.
2. Maintenance of contact with the international pedological community on new developments in soil genesis and classification.
3. Compilation and dissemination of information about the genesis, distribution, classification and wise use of Canadian soils.

The major projects of the Pedology Committee are:

Moving Towards a 4th Edition of the Canadian System of Soil Classification

The developers of the Canadian System of Soil Classification (CSSC) clearly stated that the system would need to undergo continual revision as our knowledge of soils improves. The Pedology Committee will be spearheading the drive to revise elements of the CSSC with a goal of producing a 4th edition. To date, the specific areas under consideration for revision include the inclusion of an order for human-disturbed soils, improved descriptions of A horizons and LFH horizons, and revisions to horizon nomenclature – especially around soils with deposition of secondary salts. Under the direction of the Classification Working Group, a new process for review and revision will be established. Venues for review will include discussion (at workshops and via online forums) and the sharing and vetting of proposed changes through peer-reviewed publication in the Canadian Journal of Soil Science.

Predictive Digital Soil Mapping

Predictive Digital Soil Mapping (PDSM) is a fast-evolving discipline garnering attention from soil scientists and pedologists around the world

QUICK LINKS

- Publications
- Professional and Graduate Student Opportunities
- Pedology Committee
- Soil Education Committee
- Provincial Organizations
- Useful Links
- Graduate Student Photo Contest

VIRTUAL SOIL SCIENCE
LEARNING RESOURCES

UPCOMING CONFERENCES

Eurosoil 2021
Eurosoil 2021 Geneva is Going Virtual Connecting People and Soil ...

Conclusions

- Advances in computing and technology with the availability remote sensing data and spatial information has greatly facilitated the development of DSMs.
- DSM techniques have greatly reduced the cost and time required for producing detailed and more accurate soil maps.

Outline

1. Theoretical Background: Paper to Pixels

2. Generic Framework for Digital Soil Mapping

Sequence of DSM Steps

Select Predictors (Covariates)

↓

Determine Sampling Locations

↓

Field Work, Analyze Samples, Database QA/QC

↓

Data Preparation

↓

Model Training & Validation

↓

Predictions

Selecting Predictors (Environmental Covariates)

Environmental Covariate:
A spatial layer representing one of the *scorpan* factors and having a direct or indirect relationship with the soil property or class being predicted.

Examples:

DEM	Satellite	Radiometric	Proximal Sensors	Land Use
Elevation	Individual bands	Uranium	Hyperspectral	National
Slope	Indices: NDVI, LST, etc.	Thorium	Multispectral	Provincial
Wetness Index	NDVI	Potassium	Electromagnetic:	Multi-year
TPI	LST	Total Count	EM31, EM38, DualEM	
Curvature		Ratios	Thermal	

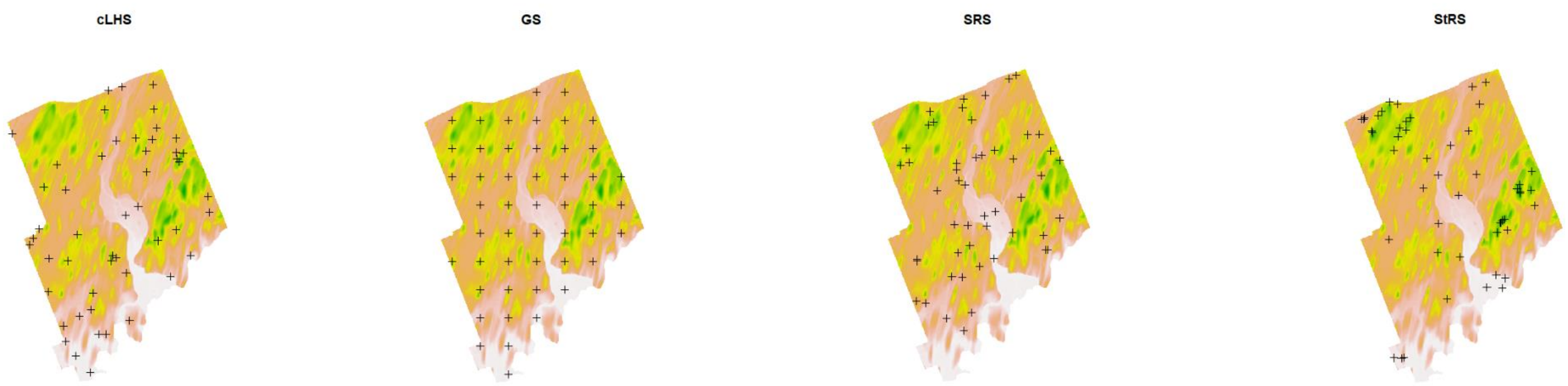
Determine Sampling Locations

Two Generic Approaches:

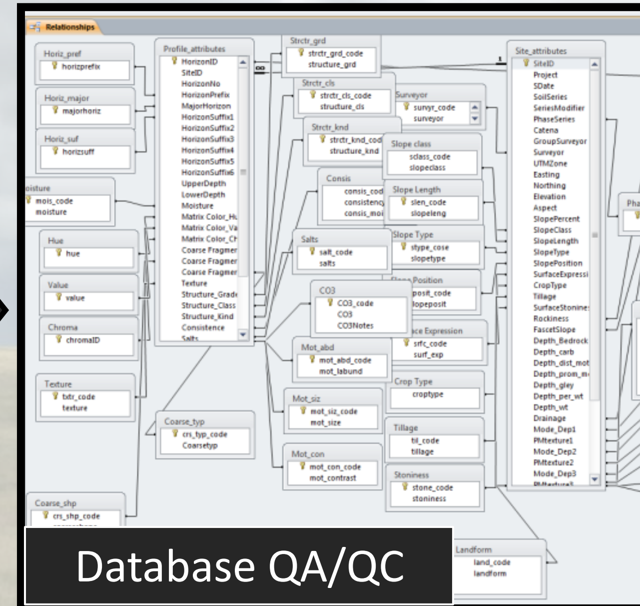
1. Sampling in geographic space
2. Sampling in feature (covariate) space

Each approach has strengths and weaknesses. Some examples we will discuss:

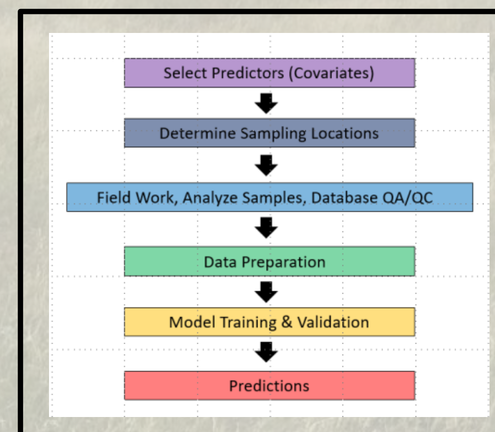
cLHS – Conditioned Latin Hypercube Sampling
GS – Grid Sampling
SRS – Simple Random Sampling
StRS – Stratefied Random Sampling



Field Work, Analyze Samples, Database QA/QC



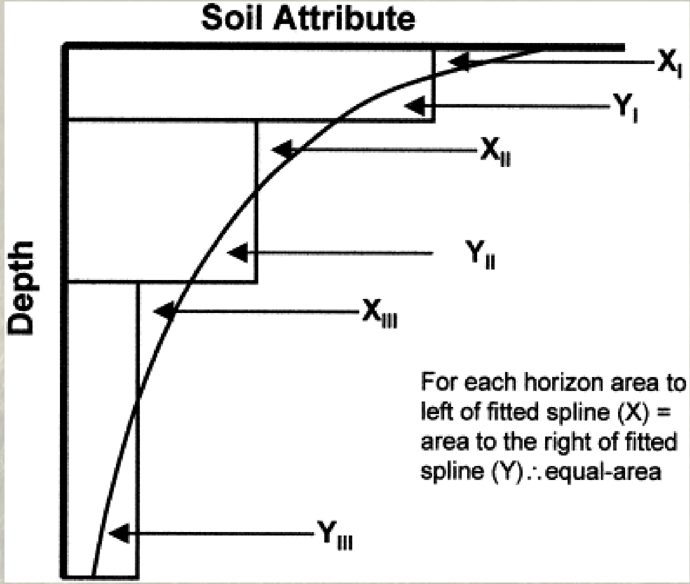
We compile a database with field observations and interpretations and analytical data from the lab. This database will form the foundation of model training and validation.

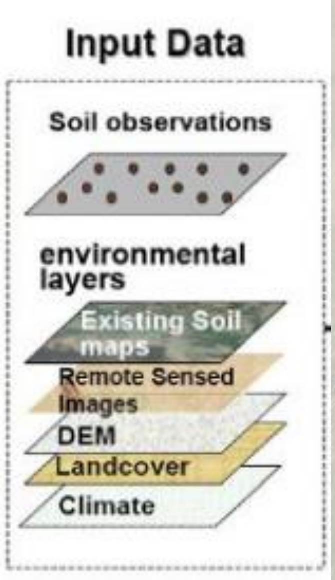


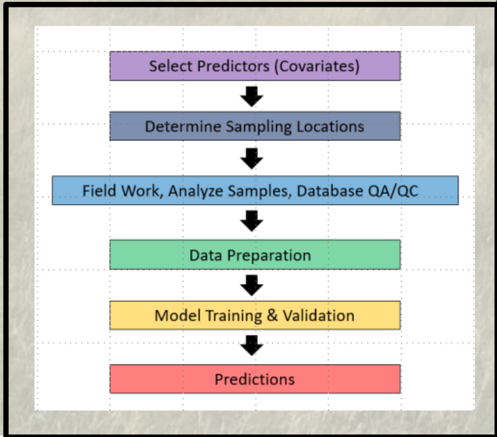
Prepare the Training Data

There are two primary steps to prepare training data:

1. Harmonizing profile data to standardized depths – soil profiles as described in the field have horizons of varying thicknesses. We must convert these discrete layers into a continuous curve to allow standardization of depth intervals for prediction (e.g., 0-5cm, 5-15cm, 15-30cm, 30-60cm, 60-100cm)
2. Extract the values of the environmental covariates at the sampling locations - the predictive models are built by “mining” the relationship between the environmental covariates and the soil property data at the sampling locations. This allows us to collect data at a finite number of sites and predict for the entire area for which we have covariates.







Model Training & Validation

- There are countless models that can be used, as we will see later in the exercises. Some models can only predict continuous data (e.g. soil carbon) while some can do both continuous and categorical (e.g. soil series).
- Popular DSM models are: Cubist, random forest, support vector machines, gradient boosting machines, k-nearest neighbor, etc. More than one model should be tested!!

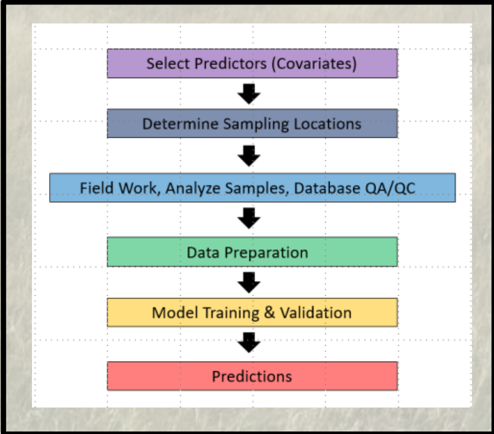
Training and Validation

- Validation with an independent, external dataset is the ideal situation
- In most cases, budget is a constraint and smaller sample sizes result in needing to use all the data for training and validation
- Cross-Validation Techniques are used in these cases

Model Evaluation – Goodness of Fit (GOOF):
Different stats are used for continuous and categorical models:

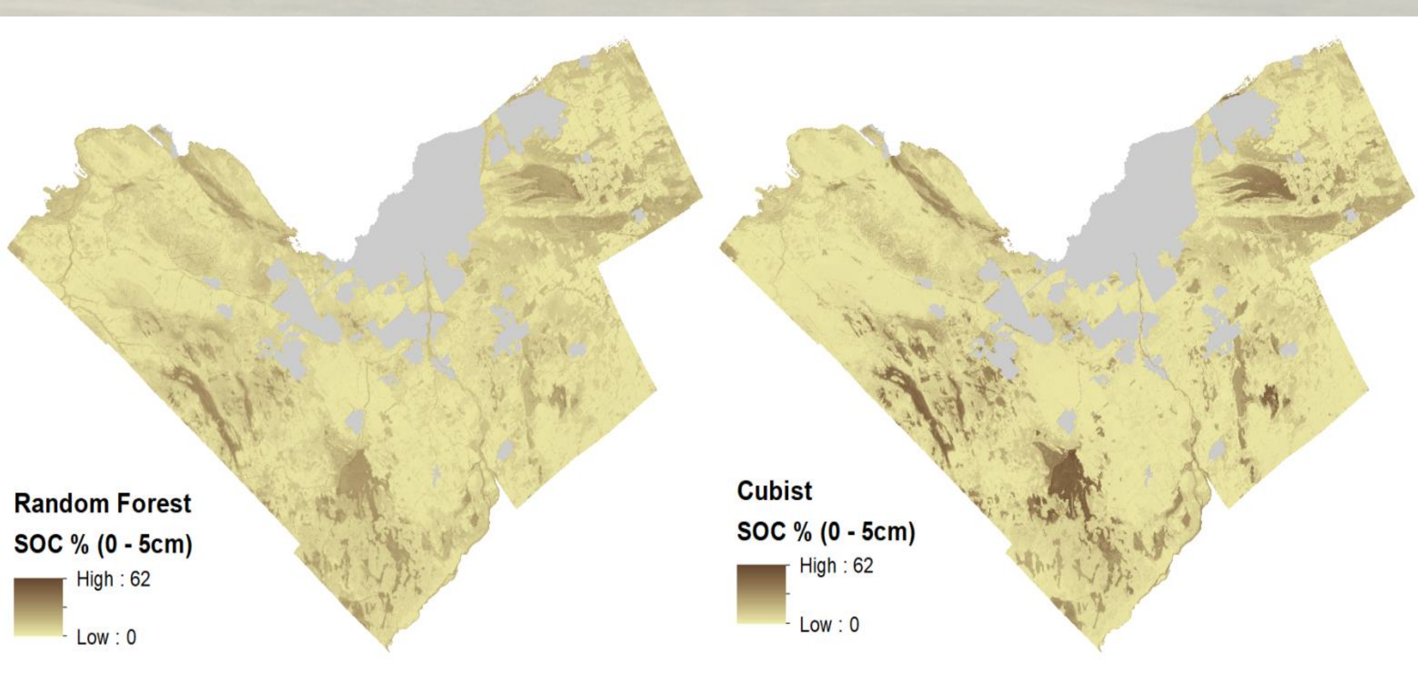
Continuous – R^2, Concordance, RMSE, bias

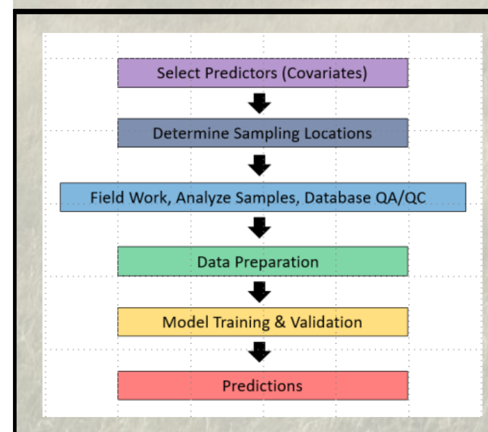
Categorical – Kappa, user's accuracy, producer's accuracy, overall accuracy



Predictions

Now that you have determined your best fit model, we can predict the response variable (e.g. organic carbon) against the environmental covariates and generate our final predictions/maps.





Summary of DSM Procedure

Select Predictors (Covariates)

↓

Determine Sampling Locations

↓

Field Work, Analyze Samples, Database QA/QC

↓

Data Preparation

↓

Model Training & Validation

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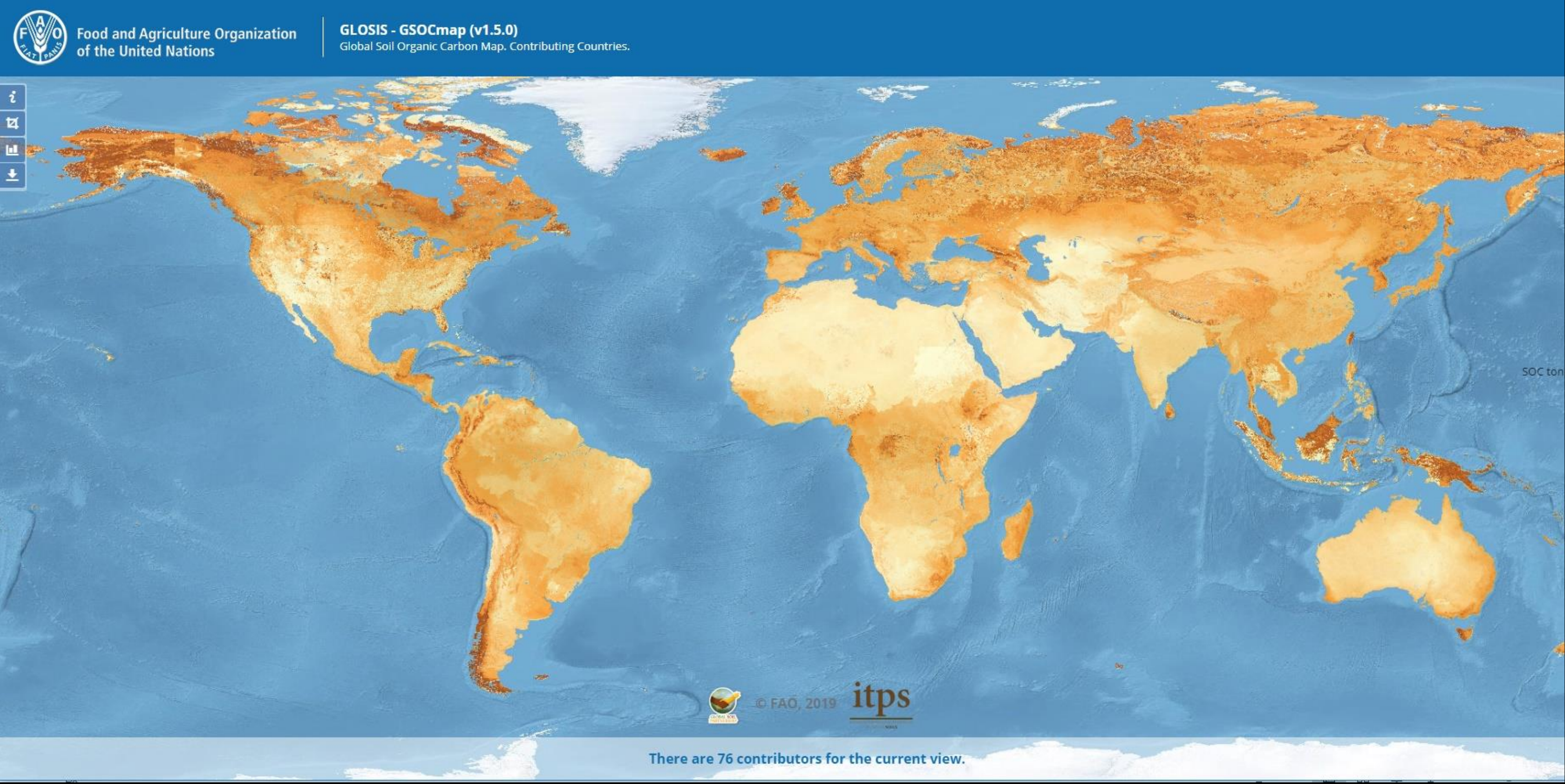
Predictions

Ontario



1. Introduction to Digital Soil Mapping

Canadian Digital Soil Mapping Workshop, 2022

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