Organic Soil Calibration Algorithms for the Campbell Scientific handheld Hydrosense-I and II units

This document was compiled to share organic soil calibrations for the Hydrosense based on samples harvested in NWT, Canada and Alaska in 2016 by two ABoVE teams led by L. Bourgeau-Chavez and T. Loboda, respectively. This document updates previous versions with General calibration algorithms to use on organic soils.

The Campbell Scientific Hydrosense handheld soil moisture probes have built in calibration to a loam mineral soil. Organic soils of the Boreal-Arctic have characteristic low bulk density and the default loam calibration typically underestimates actual soil moisture condition. For that reason, we carefully harvested soil samples of 2.5 gallon size to use in a laboratory setting to develop gravimetric based calibration algorithms specific to the boreal and arctic organic soils (after Bourgeau-Chavez et al. 2010). A series of samples were collected in burned and non-burned tundra, boreal bog, fen, upland and lowland sites. The results of these calibrations are presented in this document.

Below are tables representing the organic soil layers calibration equations for different probes, probe lengths, ecosystem types, and soil horizon groups. The values given in tables 1 & 2 (A, B, C) are coefficients that should be used in the following equation where θ is the percent volumetric moisture content (% VMC) and τ is the probe period (ms for Hydrosense I and µs for Hydrosense II):

$\theta = A\,\tau^2 + B\,\tau + C$

The probes supplied by ABoVE are Hydrosense II. The 6 cm probe depth refers to the 12 cm probe length inserted at a 30 degree angle to measure the top 6 cm of soil. 10 cm probe depth refers to the 20 cm probe length inserted at 30 degree angle to measure the top 10 cm of soil. 12 cm and 20 cm depths are the 12 and 20 cm probe lengths inserted vertically from the surface down into the soil layers.

Be sure to select the equation for the correct probe (Hydrosense I or II) and probe length/depth that was used in the field, as they are not generally interchangeable. However, we did test the cross-validation of HydroSense II 20/10 cm algorithms and HydroSense I 12/6 cm algorithms and both of those worked well, i.e. one algorithm could be used for both depths. Unfortunately, we do not have a calibration specific to the 6 cm depth with the 12 cm probe length for the HydroSense II. This is an artifact of our specific soil sampling in 2016 and we will work to develop a 6 cm specific algorithm for the Hydrosense II this winter. For the time being, I would use the 12 cm probe length/12 cm probe depth algorithm for Hydrosense II for the 6 cm probe depth field measurements. DO NOT use the 10 cm probe depth for a 6 cm sample since it is based on the 20 cm probe length.

In table 1, the calibration coefficients are broken down by ecosystem type. The bog ecosystem type includes one upland black spruce station and one lowland black spruce station. The coefficients for fens and bogs were found based on soil collected in Northwest Territories, CA. The coefficients for tundra were found based on soil collected in Alaska.

Table 1: Calibration coefficients for generic fens, bogs, or tundra

Group	Probe	Probe (tine) length	Probe (soil) Depth	A	B	C	R^2	Standard Error
Fen	HydroSense I	20 cm	20 cm	-68.131	261.73	-156.582	0.92	5.6
Fen	HydroSense I	12 cm	12 cm	-379.494	898.785	-466.213	0.87	6.9
Fen	HydroSense I	12 cm	6 cm	-785.916	1665.498	-812.753	0.84	7.7
Fen	HydroSense II	20 cm	20 cm	2.77	26.148	-39.598	0.91	5.8
Fen	HydroSense II	12 cm	12 cm	-41.776	195.142	-156.988	0.87	6.8
Fen	HydroSense II	20 cm	10 cm	-10.438	84.966	-93.566	0.77	9.2
Bog	HydroSense I	20 cm	20 cm	-125.615	333.835	-176.817	0.85	4.1
Bog	HydroSense I	12 cm	12 cm	-464.086	990.342	-484.627	0.83	4.3
Bog	HydroSense I	12 cm	6 cm	-651.913	1315.138	-619.678	0.72	5.5
Bog	HydroSense II	20 cm	20 cm	-0.94	29.913	-34.663	0.84	4.2
Bog	HydroSense II	12 cm	12 cm	-46.225	180.604	-132.855	0.86	3.98
Bog	HydroSense II	20 cm	10 cm	-11.711	73.276	-71.367	0.76	5.2
Tundra	HydroSense I	20 cm	20 cm	-50.975	226.842	-143.071	0.97	3.3
Tundra	HydroSense I	12 cm	12 cm	-95.59	338.004	-203.612	0.94	4.2
Tundra	HydroSense I	12 cm	6 cm	-139.202	426.502	-243.01	0.95	3.8
Tundra	HydroSense II	20 cm	20 cm	5.716	12.91	-28.507	0.93	4.8
Tundra	HydroSense II	12 cm	12 cm	9.716	30.027	-40.261	0.93	4.7
Tundra	HydroSense II	20 cm	10 cm	7.332	5.021	-16.8	0.92	5.1

The groupings by bog and fen had high accuracies and met the needs of our ABoVE project, but we also have created calibration coefficients based on groupings by soil profiles. These groups only include data collected in Canada. The soil profile groupings are described in Table 2 and an example profile with definitions as well as a key to determine which category your soil samples fit into are provided at the end of this document. The coefficients by soil group are in Table 3, as well as generalized algorithms. See the figures on the last page that shows the laboratory measurements of probe period and gravimetrically determine volumetric moisture content with the various calibration algorithms plotted, and the general algorithm in black. Use the general algorithm for your probe model and length/depth if your sample doesn't fit one of the profiles well.

Table 2: Soil groupings by profile descriptions

Group	Burned or Unburned?	Profile Description of samples harvested
A	Unburned	Primarily upper/lower duff with <20 cm upper duff
B	Both	Soils with at least 6.5 cm of moss on top of upper/lower duff
C	Burned	<20 cm of organic soil
D	Burned	Primarily upper/lower duff with >20 cm upper duff
E	Burned	Primarily lower duff (<2 cm moss/upper duff)
F	Burned	Primarily upper/lower duff with <20 cm upper duff

Table 3: Calibration coefficients for different soil horizon groups and generalized algorithms

Group	Probe	Probe (tine) length	Probe (soil) Depth	A	B	C	R^2	Standard Error
All - General	HydroSense I	20 cm	20 cm	-30.28	179.03	-114.59	0.8996	5.449

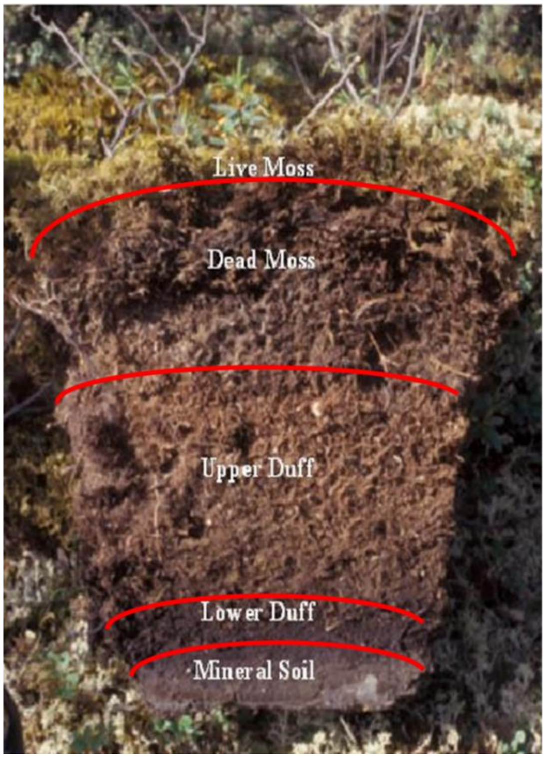
Group	Probe	Probe (tine) length	Probe (soil) Depth	A	B	C	R^2	Standard Error
All - General	HydroSense I	12 cm	12 cm	-303.36	737.36	-386	0.8341	7.004
All - General	HydroSense I	12 cm	6 cm	-585.09	1262.59	-620.44	0.7456	8.674
All - General	HydroSense II	20 cm	20 cm	7.693	1.641	-12.341	0.8873	5.773
All - General	HydroSense II	12 cm	12 cm	-24.28	134.55	-110.245	0.8294	7.102
All - General	HydroSense II	20 cm	10 cm	-5.307	58.327	-64.615	0.7621	8.388
A	HydroSense I	20 cm	20 cm	-15.123	129.602	-85.29	0.93	3.6
A	HydroSense I	12 cm	12 cm	-585.766	1268.285	-630.255	0.91	4.1
A	HydroSense I	12 cm	6 cm	-1269.42	2494.319	-1165.19	0.78	6.5
A	HydroSense II	20 cm	20 cm	5.528	5.544	-14.186	0.88	4.8
A	HydroSense II	12 cm	12 cm	-70.961	272.661	-207.311	0.94	3.4
A	HydroSense II	20 cm	10 cm	-8.692	65.258	-65.46	0.70	7.5
B	HydroSense I	20 cm	20 cm	-259.623	572.023	-282.318	0.86	3.3
B	HydroSense I	12 cm	12 cm	-1535.16	2836.281	-1277.27	0.81	3.8
B	HydroSense I	12 cm	6 cm	-774.769	1526.561	-711.361	0.75	4.4
B	HydroSense II	20 cm	20 cm	-20.273	105.372	-106.39	0.79	4.0
B	HydroSense II	12 cm	12 cm	-124.88	376.762	-253.225	0.76	4.3
B	HydroSense II	20 cm	10 cm	-23.5489	117.087	-111.133	0.74	4.5
C	HydroSense I	20 cm	20 cm	-201.132	496.551	-258.634	0.94	2.99
C	HydroSense I	12 cm	12 cm	-284.042	656.855	-334.118	0.91	3.8
C	HydroSense I	12 cm	6 cm	-456.828	978.665	-478.817	0.90	3.9
C	HydroSense II	20 cm	20 cm	-2.605	40.748	-46.835	0.94	3.1
C	HydroSense II	12 cm	12 cm	-23.79	117.833	-91.747	0.93	3.2
C	HydroSense II	20 cm	10 cm	-12.0269	79.901	-83.202	0.87	4.5
D	HydroSense I	20 cm	20 cm	-155.228	442.254	-248.58	0.96	3.5
D	HydroSense I	12 cm	12 cm	-409.776	944.245	-483.393	0.93	4.8
D	HydroSense I	12 cm	6 cm	-667.879	1447.79	-717.994	0.96	3.8
D	HydroSense II	20 cm	20 cm	-6.963	70.586	-88.985	0.97	2.95
D	HydroSense II	12 cm	12 cm	-53.906	229.615	-182.085	0.93	4.7
D	HydroSense II	20 cm	10 cm	-15.838	110.386	-125.094	0.94	4.6
E	HydroSense I	20 cm	20 cm	-44.22	214.336	-132.387	0.91	5.9
E	HydroSense I	12 cm	12 cm	-353.459	853.042	-446.178	0.84	7.97
E	HydroSense I	12 cm	6 cm	-869.977	1828.024	-889.499	0.82	8.3
E	HydroSense II	20 cm	20 cm	8.766	-0.569	-9.955	0.90	6.3
E	HydroSense II	12 cm	12 cm	-32.077	165.761	-134.694	0.84	7.9
E	HydroSense II	20 cm	10 cm	-11.183	90.804	-100.619	0.74	9.95
F	HydroSense I	20 cm	20 cm	-90.355	267.212	-144.948	0.90	3.3
F	HydroSense I	12 cm	12 cm	-1083.79	2079.915	-960.517	0.84	4.2
F	HydroSense I	12 cm	6 cm	-607.408	1277.302	-614	0.67	6.07
F	HydroSense II	20 cm	20 cm	0.982	22.651	-27.625	0.94	2.65
F	HydroSense II	12 cm	12 cm	-44.513	174.052	-126.51	0.66	6.2
F	HydroSense II	20 cm	10 cm	-5.717	47.469	-43.64	0.74	5.4

Note that additional samples were harvested in Alberta Canada and Sagwon, AK in summer 2017-18 for calibration to additional non-burned soil types. These will be processed this winter.

Literature cited

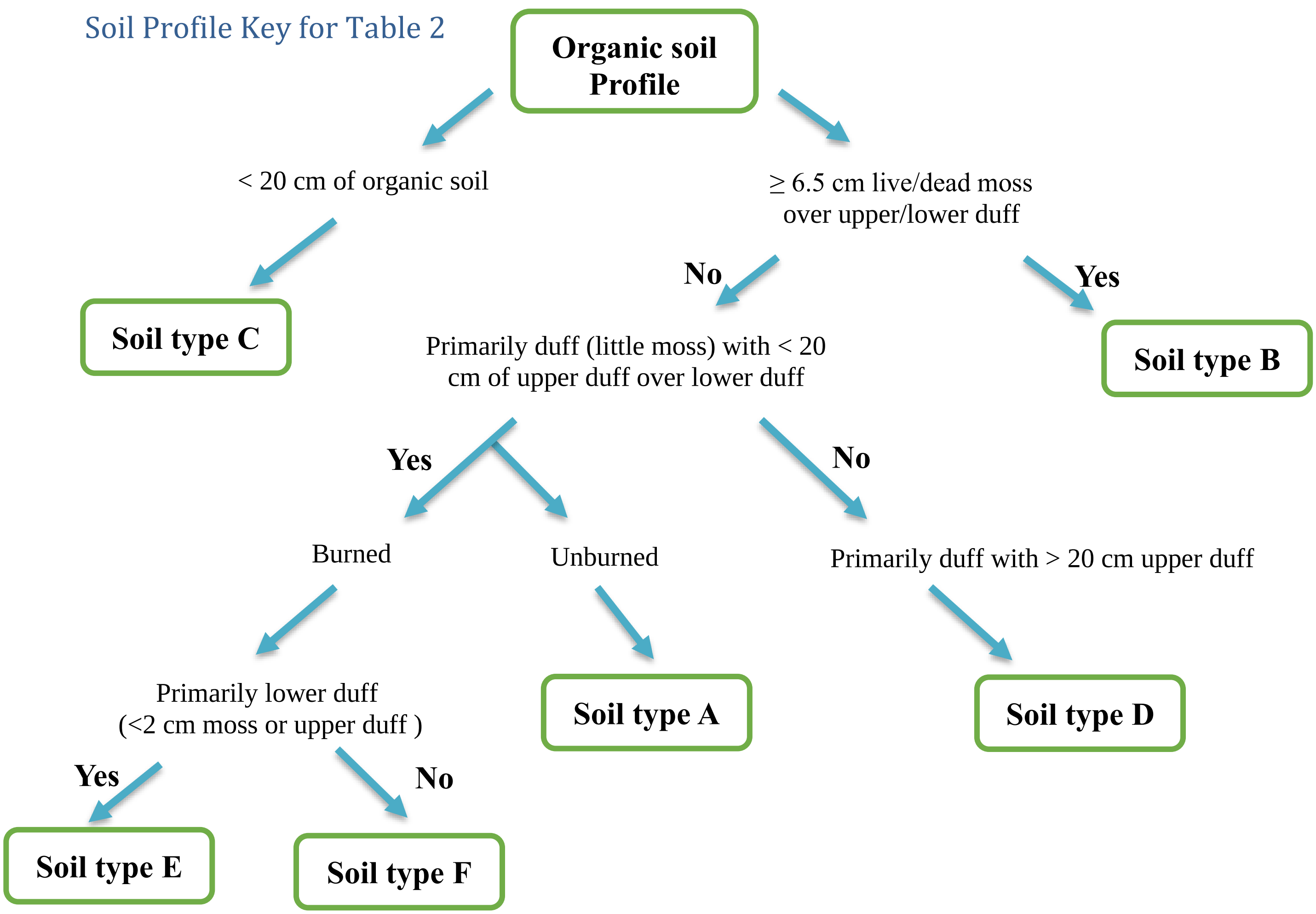
Bourgeau-Chavez, L.L., Garwood, G.C., Riordan, K., Koziol, B.W., and Slawski, J. 2010. Calibration algorithm development for selected water content reflectometers to burned and non-burned organic soils of Alaska. *International Journal of Wildland Fire*, Vol. 19:961-975.

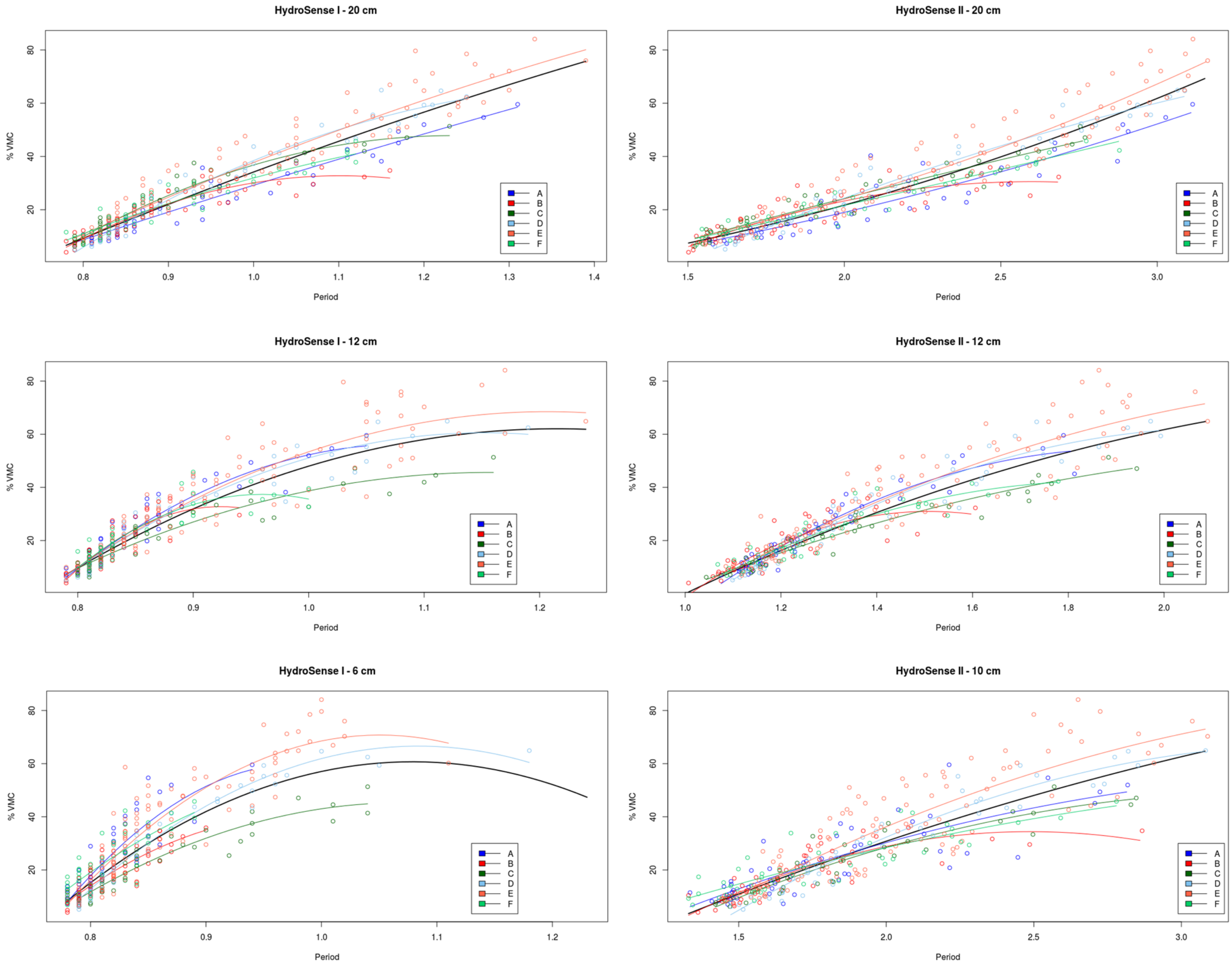
Soil Horizon Definitions



- **Live moss: living moss layer**
- **Dead Moss: undecomposed moss and other plant parts**
- **Upper Duff: fibric layer, partially decomposed moss/organic plant parts still visible**
- **Lower Duff: humic layer, decomposition more advanced, denser than fibric layer and plant parts are no longer visible**

Soil Profile Key for Table 2




HydroSense I - 20 cm
HydroSense II - 20 cm
HydroSense I - 12 cm
HydroSense II - 12 cm
HydroSense I - 6 cm
HydroSense II - 10 cm
% VMC
Period
A
B
C
D
E
F