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An 11-yr (2007 – 2017) soil moisture and precipitation dataset from the Kenaston Network in the Brightwater Creek basin, Saskatchewan, Canada.

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Abstract. Soil moisture and precipitation have been monitored in a hydrometeorological network situated within the Brightwater Creek basin, east of Kenaston, Saskatchewan, since 2007. The majority of the prairie landscape is annually cropped with some sections in pasture. This agricultural region is ideal for remote sensing validation and calibration and, in conjunction with the flux tower situated within the network, hydrological model validation. Remote sensing validation collaborations have included ESA's Soil Moisture Ocean Salinity (SMOS) and NASA's Soil Moisture Active Passive (SMAP). The network was developed to capture soil moisture variation at two spatial scales, one high-resolution network installed over a 10 km^2 region and a second installed over 40 km^2. The networks are similar in design with three instrument depths for soil moisture and temperature, as well as precipitation measurement. The 2007 – 2017 dataset published in this paper has gone through a quality control review process, which involved both automated and manual processes. The dataset is limited to the summer months (May 1 – Sept 30) due to the uncertainties and complexities of measurement in frozen soils and the freeze/thaw period each year. Data is available at https://dx.doi.org/10.20383/101.0116.

1 Introduction

Soil moisture and precipitation are important elements of hydrological cycle. While it constitutes a small portion of the global water cycle, soil moisture has a significant influence on atmospheric and hydrologic processes. Soil moisture is highly variable across a landscape, being influenced by both atmospheric conditions (e.g. precipitation, evaporation), landscape variability (e.g. topography, soil characteristics), and vegetation. This creates difficulty when attempting to asses soil moisture at the typical scales of atmospheric circulation models (Crow et al 2012), however inclusion of soil moisture as a dynamic parameter within numerical modelling improves forecast skill for both hydrological and meteorological models (Koster et al. 2010; Koster et al. 2011; Drewitt et al. 2012; Wanders et al 2014). The difficulty of measurement has prompted researchers to develop remote sensing techniques to try and quantify soil moisture conditions at various scales. Any remote sensing technique requires calibration and validation, in this case achieved with *in situ* monitoring stations.

The Kenaston Network was designed to fulfil both the needs of land-atmospheric modelling and remote sensing validation programs. Very few existing monitoring networks have the ability to validate remote sensing products and hydrometeorological models over the Canadian prairies due to the unique combination of landscape and climatic conditions. Specifically for remote sensing of soil moisture, the individual stations were distributed at two spatial scales to accommodate validation of remote sensing products at various scales. The high resolution of the network sites allows for both intergrid and intragrid validation.

2 Network Description

The Kenaston Network, also called the Brightwater Creek Monitoring Network is located on the Canadian Prairies in central Saskatchewan, approximately 80 km south of Saskatoon. Stations within the network consist of a series of soil moisture and precipitation sites, set at two spatial scales, and a year-round eddy-covariance tower with a full complement of meteorological instrumentation. The monitoring sites are situated within the basin of Brightwater Creek, which drains northward into the South Saskatchewan River. Brightwater Creek has been monitored by a Water Survey of Canada flow gauge since 1965. The landscape is a typical agricultural region with annually cropped fields, mainly of cereals, oilseeds, and pulse crops, and pasture lands. The area is flat with slopes of less than 2% (Burns et al., 2016) which affects runoff in the region. Significant portions of the area are considering non-contributing, where in general water does not drain to streams or rivers but instead ponds in small wetlands and sloughs (Shook et al., 2013). Predominantly silt loam, the area ranges from sandy loam to clay in texture.

Data from the network have been used for several projects over the years including the European Space Agency's (ESA) Soil Moisture and Ocean Salinity (SMOS) mission, the National Aeronautics and Space Administration's (NASA) Soil Moisture Active Passive (SMAP) mission, the Drought Research Initiative (DRI), and the Changing Cold Regions Network (CCRN). A field campaign for the SMAP satellite was conducted in 2010 (CanEx-SM10), and previous publications that describe this network include Magagi et al. (2013) , Champagne et al. (2010; 2016), Rowlandson et al. (2015), and Burns et al. (2016).

The Kenaston Network is a community site, with involvement from Environment and Climate Change Canada (ECCC), the University of Guelph, the University of Saskatchewan, and Agriculture and Agri-Food Canada (AAFC), each of which is responsible for portions of the overall network. The AAFC stations are located within pasture sections and measure soil moisture down to 150 cm, along with standard meteorological sensors: data and site details can be found at [http://agriculture.canada.ca/SoilMonitoringStations/index-en.html]. This paper presents data from the soil moisture and precipitation stations managed by Environment and Climate Change Canada and the University of Guelph.

3 Soil moisture and precipitation site details

The soil moisture and precipitation sites are distributed at two spatial scales: 10 km^2 and 40 km^2 (Figure 1). The larger scale network has been modified over time and began in a 45 x 55 km area. Each site consists of a datalogger, power system, tipping bucket rain gauge (TBRG), and 3-4 Hydra Probes. These sites are usually set outside of the actively managed area of the field, in fence line strips, under powerlines, or at the very edge of the field. Figure 2 shows a typical setup. All sites have at least three probes, inserted horizontally at depths of 5, 20, and 50 cm below the surface that remain in place throughout the year. Additionally, site at the 10 km^{2-} scale also have a vertically placed probe, generally indicated as 0-5 cm, which moves into the field after seeding and is removed shortly before harvest. Figure 3 illustrates the general setup of the stations that include a vertically place probe, indicating the location of the four probes. Stations with only three probes have a similar setup, with all three probes inserted near the datalogger box.

Data is collected at 30 minute intervals, a single point measurement from each Hydra Probe and the sum over the interval for the TBRG. Provided from each probe for this dataset is real dielectric constant (real dielectric permittivity, ε_r), temperature, and soil moisture using the manufacturer’s loam calibration equation. Additional data has been collected at some sites within Kenaston, including soil conductivity, 2.5 cm soil temperature, crop types, heights, and photos, air temperature and relative humidity, point measurement snow depth, and snow surveys, which is not included in this dataset.

Sites are visited regularly throughout the field season to ensure TBRG cleanliness and check for site issues. Site with a vertically placed probe are visited more frequently than others due to the greater risk for disturbance and placement issues.

3.1 Soil Instrumentation

The instrument used throughout the network to measure soil parameters is the Stevens Hydra Probe II (Stevens Water Monitoring Systems (Inc, 2009: Burns 2016)). These are radiometric coaxial impedance dielectric reflectometer sensors, with four tines extending from a 4.2 cm diameter head, along which a radio frequency is applied and the reflected frequency measured (Stevens Water Monitoring Systems, Inc., 2018b). This reflected signal is related to the real dielectric constant (ε_r) of the soil which in turn is correlated to soil water content (e.g. Topp et al., 1980; Campbell, 1990; Seyfried et al., 2005). General ranges for ε_r are roughly 80 in water, 1 in air, and 2-5 in dry soil. A more detailed description of the instrument and the measurement principles can be found in publications from Stevens Water Monitoring Systems, Inc. (2018a, 2018b). These sensors are widely used in university and government research networks, including NOAA's Climate Reference Network (Bell et al., 2013), the USDA's Soil and Climate Analysis Network (Schaefer et al., 2007), and Agriculture and Agri-Food Canada's national monitoring networks (Adams et al., 2014).

Real dielectric constant (ε_r) is related to soil moisture through a calibration equation. The equations supplied from the manufacturer report a sensor accuracy of ±0.03 m^3m^{-3} (Stevens Water Monitoring Systems, Inc., 2018a or b), and a site specific calibration is recommended (e.g. Huang et al., 2004; Seyfried and Murdock, 2004; Rowlandson et al., 2013). The uncertainty in calibration method and ongoing work in this area presents a difficulty that has not been satisfactorily resolved, particularly for the measurements at deeper depths, as described in Burns et al. (2014). To ensure consistency for all of the data the manufacturer supplied loam calibration equation (Stevens Water Monitoring Systems, Inc., 2018b) is used to calculate soil moisture, with the understanding that this decreases the overall accuracy of the network. *In situ* calibration equations have been established for the majority of the near surface probes (5cm) and these equations are available upon request.

Occasional measurement issues with the Hydra Probe were encountered, some of which may be specific to the Kenaston network. For example, during hot summer days when the surface soil becomes very dry, ε_r from the near surface probes (vertically placed 0-5 cm and horizontally placed 5 cm) will drop below ~2.6968, which produces a negative soil moisture value using the loam equation. These low ε_r values are possibly due to soil cracking, poor sensor contact with the soil, or are simply valid responses from the probe. During these dry periods repositioning the probe, which is the typical response to these types of issues in near-surface probes, is not typically possible simply due to the difficulty in inserting a probe into dry, hard-packed, fine grained soils. New cracks often form as the probe is taken out and re-inserted, resulting in the same issues. These probes are closely monitored and after the next sufficiently significant rain event, soil moisture typically increases and the probe begins responding as expected. Additionally, a diurnal oscillation of measured ε_r is observed, with greater amplitude during hot, dry conditions. This suggests a temperature effect on ε_r but is not investigated further here (Seyfried and Grant, 2007).

The Kenaston region is similar to other parts of Saskatchewan in the occurrence of saline soils, the results of which cause some issues with the deeper probes (horizontally placed probes at 20 and 50 cm) (Seyfried and Murdock, 2004). While a typical variation between successive timestamps outside periods of rainfall could be on the order of ±0.01 m^3m^{-3}, those probes measuring in saline conditions can vary as much as at ±0.10-0.20 m^3m^{-3}. This is corroborated by measurement of soil conductivity: increasing variability between consecutive timestamps coincides with an increase in conductivity, generally greater than 0.2 S m^{-1}. In some cases this only occurs for a season, while other sites show a consistent record of high conductivity and therefore large measurement variation in soil moisture.

3.2 Precipitation Instrumentation

All sites within the network are equipped with a tipping bucket rain gauge (TBRG) to capture precipitation. One of two varieties are used: the Onset RG3 or the Hydrological Services TB3. All sites began with an Onset TBRG but over the years they have been replaced within the 10 km^2 scale network to the configuration documented in Table 1. Currently all sites use a TBRG with a 0.2 mm scale but some earlier TBRG had a 0.1 mm scale. Common issues with the TBRG include blockage due to debris, mount damage from farm equipment, and the occurrence of single tips not related to network-wide rainfall events. Bird guards were installed on the TB3s where regular debris issues were common. Field calibrations of the TB3s have been regularly completed since installation. A known issue with TBRG-style precipitation gauges is the possibility of single tips due to the retention of water in the bucket or siphon (the latter only in the case of the TB3). Single tips within the dataset that are not temporally correlated to a rainfall event may not be indicative of rainfall within the 30 minute measurement period. These records have not been removed from the dataset due to the uncertainty in consistently determining validity without removing significant credible data.

4 Quality Control Process and Data

While the network is currently run year round, at maximum only May 1 – September 30 is included for each data year. The main challenges are difficulties in measurement and calibration occur during the winter and shoulder seasons when the ground is transitioning between a frozen and thawed state (e.g. Williamson et al.

2018). Additionally, TBRGs are not designed for solid precipitation measurement. Two phases of quality control/quality assurance (QAQC) are performed to warm season data: an automated check and then manual review. The automated phase checks for logger errors and common sensor errors, with the secondary manual review process including a review of field notes and checks of all sensors for known instrument errors and gaps in the automated process. The automatic review begins with the raw measurements and can be completed in near real time, while the secondary manual review is completed on an as needed basis, or seasonally.

4.1 Automated Review Details

The automated review process checks for the limits documented in Table 2 and removes data outside of these thresholds. These checks mainly screen for obvious sensor errors and provide consistency for the next phase of QAQC. Also applied during this process are flags that are using during the manual process to check for common errors (Table 3).

4.2 Manual Review Details

After the automated process, a manual review of the resultant data is conducted to do a final review of the data from each instrument and each site. Hydra Probes are typically reviewed against the site's TBRG, to ensure that jumps in soil moisture correlate with precipitation events. The TBRG are reviewed collectively, as at least for the dense set of sites precipitation events will be collected by all instruments. This repetition of equipment allows for a relatively high level of confidence in rainfall events and provides useful information to diagnose TBRG collection or measurement errors. Review of field notes and comparison of TBRG between nearby sites confirms TBRG cleanliness, (debris can delay or block rainfall passing into the buckets of the TBRG) and general agreement between sites. When disagreement between a single site and the majority is observed and confirmed by field visits, the data is removed.

Site visits can potentially cause erroneous data and the data from the day of each site visit is reviewed and edited for (1) extra TBRG tips due to cleaning; (2) erroneous data from the vertically placed 0-5 cm probe when it is moved into and out of the field; (3) other sensor issues that could result in incorrect data (physical damage, disturbance by field equipment or animals); (4) erroneous values from troubleshooting or maintenance checks. These checks are done in conjunction with review of field notes. Data from each sensor is also visually plotted and reviewed for general operation as sensor malfunction can often be caught in careful review of the sensor parameters. In this QAQC stage, the focus is on unexplained jumps or drops, gaps, and unusually high or low values that have not yet already been removed during the automated review. Any data diagnosed during this process as erroneous is removed from the final data set.

5 Data Availability

The data described here are available at the Federated Research Data Repository (FRDR) (https://dx.doi.org/10.20383/101.0116).

6 Summary

Data from 2007 – 2017, May 1 – Sept 30, from the Kenaston Network in the Brightwater Creek basin in central Saskatchewan, Canada, has been quality controlled and compiled in a standard format. The network consists of two scales of sites, each with 3 – 4 Hydra Probes and a tipping bucket rain gauge. Included in this dataset from each Hydra Probe is soil moisture, temperature, and real-dielectric constant (ε_r). Some issues with the Hydra Probe have been identified and documented, and the overall network coverage is good. It is anticipated that this dataset will continue to provide useful information for remote sensing validation and calibration as well as hydrometeorological modelling efforts.

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References

Adams, J. R., McNairn, H., Berg, A. A., and Champagne, C.: Evaluation of near-surface soil moisture data from an AAFC monitoring network in Manitoba, Canada: Implications for L-band satellite validation, J. Hydrol, doi:10.1016/j.jhydrol.2014.10.024, 2014.

Bell, J. E., Palecki, M. A., Baker, C. B., Collins, W. G., Lawrimore, J. H., Leeper, R. D., Hall, M. E., Kochendorfer, J., Meyers, T. P., Wilson, T., and Diamond, H. J.: U.S. Climate Reference Network soil moisture and temperature observations, J. Hydrometeorol., 14, 977–988, DOI:10.1175/JHM-D-12-0146.1, 2013.

Burns, T. T., Adams, J. R., and Berg, A. A.: Laboratory calibration procedures of the Hydra Probe soil moisture sensor: infiltration wet-up vs. dry-down, Vadose Zone J., doi: 10.2136/vzj2014.07.0081.

Burns, T. T., Berg, A. A., Cockburn, J., and Tetlock, E.: Regional scale spatial and temporal variability of soil moisture in a prairie region, Hydrol. Process., 30, 3639–3649. doi: 10.1002/hyp.10954, 2016.

Campbell, J.: Dielectric properties and influence of conductivity in soils at one and fifty megahertz, Soil Sci. Soc. Am. J., 54, 332–341, 1990.

Champagne, C., Berg, A., Belanger, J., McNairn, H., and De Jeu, R.: Evaluation of soil moisture derived from passive microwave remote sensing over agricultural sites in Canada using ground-based soil moisture monitoring networks, Int. J. Remote Sens., 31, 3669–3690, doi:10.1080/01431161.2010.483485, 2010.

Champagne, C., Rowlandson, T., Berg, A., Burns, T., L'Heureux, J., Tetlock, E., Adams, J. R., McNairn, H., Toth, B., and Itenfisu, D.: Satellite surface soil moisture from SMOS and Aquarius: Assessment for applications in agricultural landscapes, Int. J. Appl. Earth Obs., 45, 143-54, 2016.

Crow, W.T., Berg, A. A., Cosh, M. H., Loew, A., and Mohanty, B. P.: Upscaling sparse ground-based soil moisture observations for the validation of coarse-resolution satellite soil moisture products. Rev. Geophys., 50, RG2002, doi:10.1029/2011RG000372, 2012.

Drewitt, G., Berg, A.A., Merryfield, W.J., and Lee, W.S.: Effect of realistic soil moisture initialization on the Canadian CanCM3 season forecast model. Atmos. Ocean., 50 (4), 466–474, 2012.

Huang, Q., Akinremi, O., Sri Ranjan, R., and Bullock, P.: Laboratory an evaluation of five soil water sensors, Can. J. Soil Sci., 84, 431–438, 2004.

Koster, R. D., Mahanama, S. P. P., Livneh, B., Lettenmaier, D. P., and Reichle, R. H.: Skill in streamflow forecasts derived from large-scale estimates of soil moisture and snow, Nat.Geosci., 3, 613-616, 2010.

Koster, R. D., Mahanama, S. P. P., Yamada, T. J., Balsamo, Gianpaolo, Berg, A. A., Boisserie, M., Dirmeyer, P. A., Doblas-Reyes, F. J., Drewitt, G., Gordon, C. T., Guo, Z., Jeong, Jee-Hoon, Lee, W. S., Li, Z., Luo, L., Malyshev, S., Merryfield, W. J., Seneviratne, S. I., Stanelle, T., van den Hurk, B. J. J. M., Vitart, F., and Wood, E. F.: The second phase of the Global Land-Atmosphere Coupling Experiment: Soil moisture contributions to subseasonal forecast skill, J. Hydrometerol, 12 (5), 805-822, 2011.

Magagi, R., Berg, A. A., Goïta, K., Bélair, S., Jackson, T. J., Toth, B., Walker, A., McNairn, H., O'Neill, P. E., Moghaddam, M., Gherboudj, I., Colliander, A., Cosh, M. H., Burgin, M., Fisher, J. B., Kim, S., Mladenova, I., Djamaï, N., Rousseau, L. B., Belanger, J., Shang, J., and Merzouki, A.: Canadian experiment for soil moisture in 2010 (CanEx-SM10): overview and preliminary results, IEEE T. Geosci. Remote., 51, 347–363, doi:10.1109/TGR.2012.2198920, 2013.

Rowlandson, T., Impera, S., Belanger, J., Berg, A. A., Toth, B., and Magagi, R.: Use of in situ soil moisture network for estimating regional-scale soil moisture during high soil moisture conditions, Can. Water Resour. J., 40, 343–351, doi:10.1080/ 07011784.2015.1061948, 2015.

Rowlandson, T. L., Berg, A. A., Bullock, P. R., Ojo, E. R., McNairn, H., Wiseman, G., and Cosh, M. H.: Evaluation of several calibration procedures for a portable soil moisture sensor, J. Hydrol., 498, 335-44, 2013.

Schaefer, G. L., Cosh, M. H., and Jackson, T. J., The USDA Natural Resources Conservation Service Soil Climate Analysis Network (SCAN), J. Atmos. Ocean. Technol., 24, 2073–2077, doi:10.1175/2007JTECHA930.1, 2007.

Seyfried, M. and Murdock, M.: Measurement of soil water content with a 50-MHz soil dielectric sensors, Soil Sci. Soc. Am. J., 68, 394–403, 2004.

Seyfried, M., Grant, K., Du, E., and Humes, K.: Dielectric loss and calibration of Hydra probe soil water sensor, Vadose Zone J., 4, 1070–1079, 2005.

Seyfried, M. and Grant, L.: Temperature Effects on Soil Dielectric Properties Measured at 50 MHz, Vadose Zone J., 6, 759-765, 2007.

Stevens Water Monitoring Systems, Inc., Users Manual, rev VI, Stevens Water Monitoring Systems, Portland, OR, 2018a.

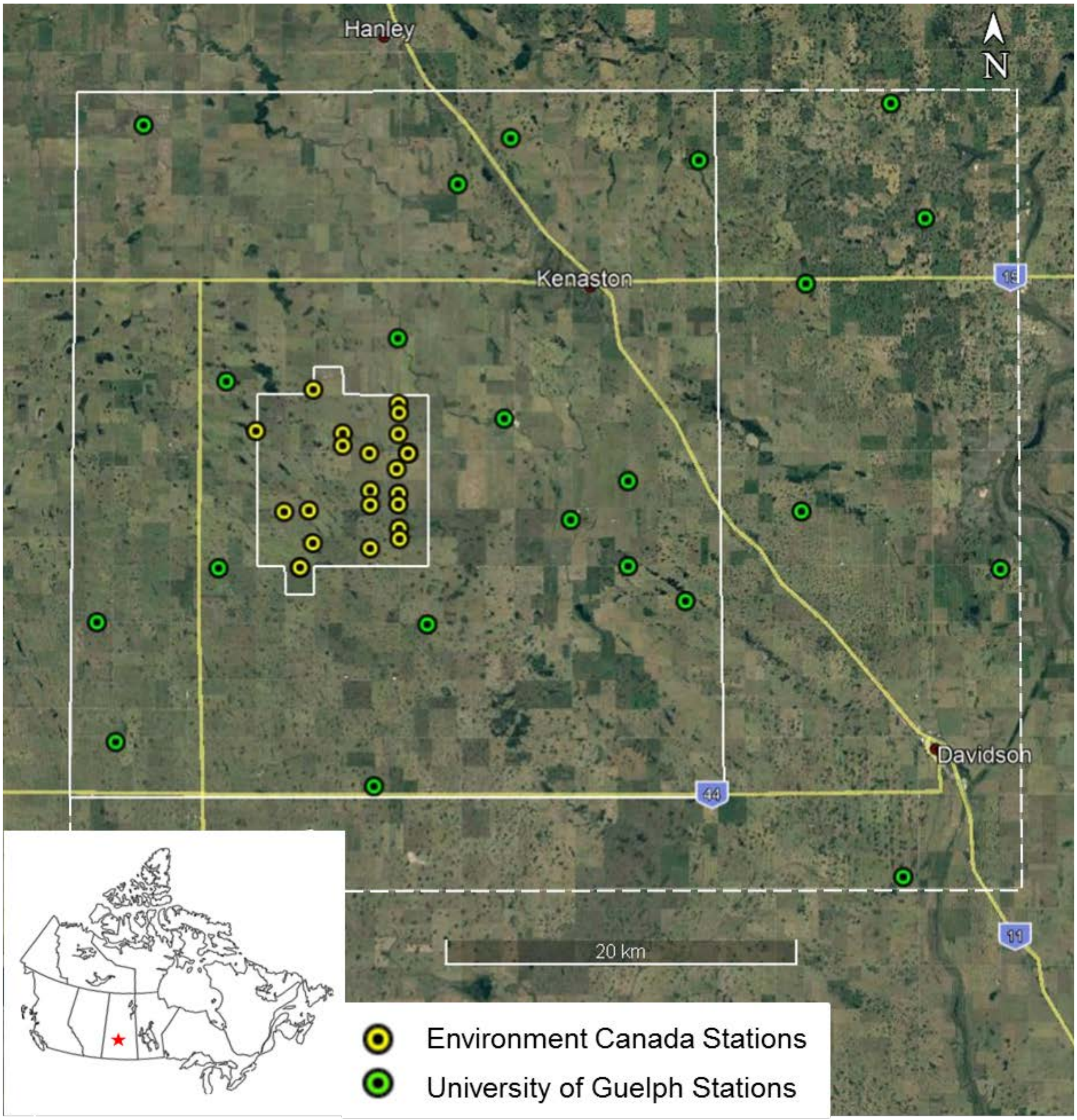
Stevens Water Monitoring Systems, Inc., Soil Data Guide, rev VI, Stevens Water Monitoring Systems, Portland, OR, 2018b.

Shook, K., Pomeroy, J. W., Spence, C., and Boychuk, L.: Storage dynamics simulations in prairie wetland hydrology models: evaluation and parameterization, Hydrol. Process., 27, 1875–1889, doi:10.1002/hyp.9867, 2013.

Topp, G., Davis, J., and Annan, A.: Electromagnetic determination of soil water content: measurements in coaxial transmission lines, Water Resour. Res., 16, 574–582, 1980.

Wanders, N., Karssenberg, D., de Roo, A., de Jong, S. M., and Bierkens, M. F. P.: The suitability of remotely sensed soil moisture for improving operational flood forecasting, Hydrol. Earth Syst. Sci., 18, 2343-2357, https://doi.org/10.5194/hess-18-2343-2014, 2014.

Williamson, M., Adams, J. R., Berg, A. A., Derksen, C., Toose, P., and Walker, A.: Plot-scale assessment of soil freeze/thaw detection and variability with impedance probes: implications for remote sensing validation networks, Hydrol. Res., 49(1), 1-6, 2018.



260 **Figure 1. Map of site locations, the white frames indicating the two scales of the sites. ECCC sites are within a 10 km^2 area and University of Guelph sites are within the current 40 km^2 area. The dashed line indicates the original larger scale; 45 x 55 km.**

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Figure 2. Typical site installation. (1) Horizontal 5 cm sensor; (2) horizontal 20 and 50 cm sensors and location of vertical 0-5 cm sensor during field season; (3) location of vertical 0-5 cm sensor during off season; (4) tipping bucket rain gauge; (5) loggerbox with datalogger; (6) solar panel.

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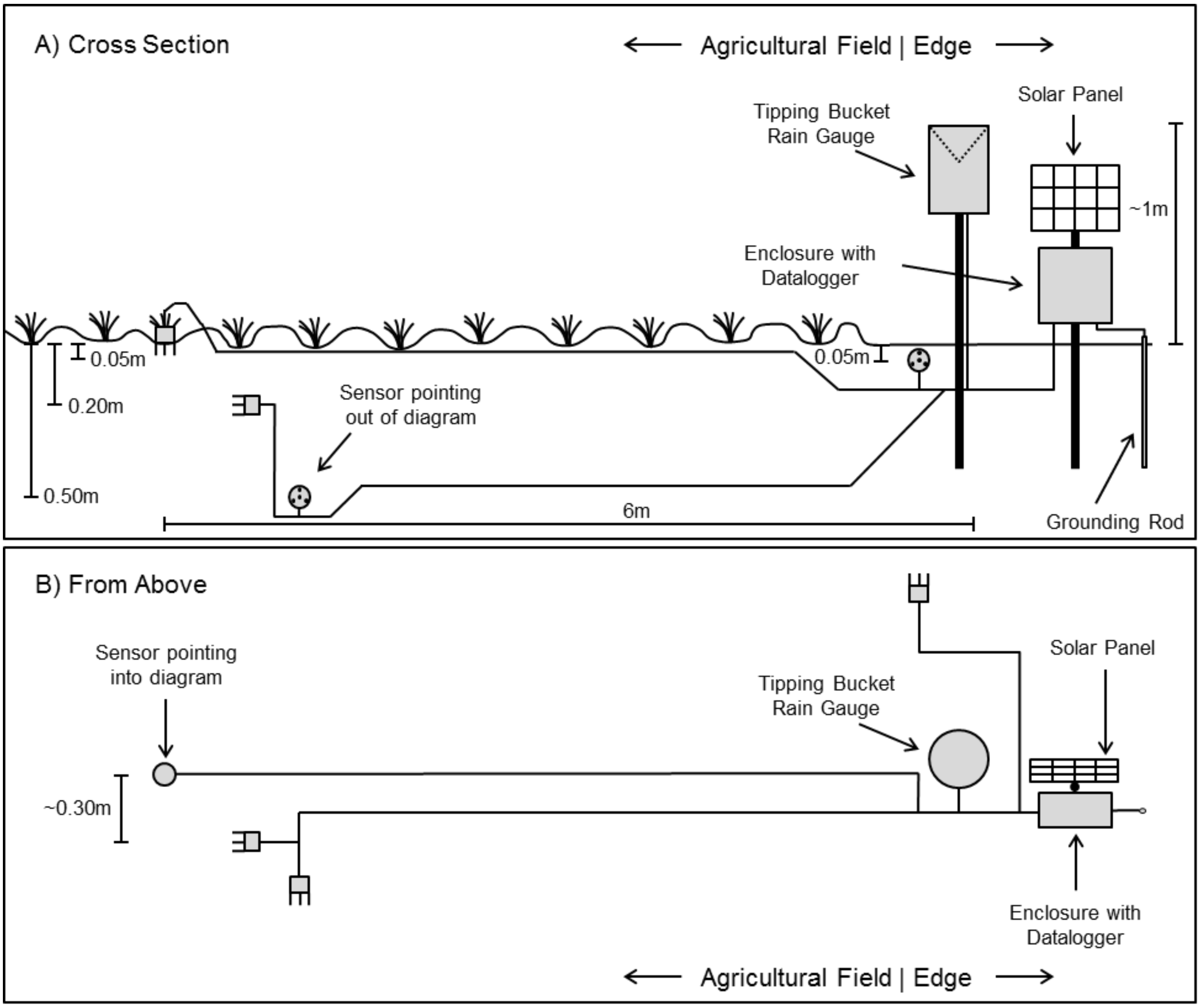

Figure 3. General configuration of each soil moisture station.

Table 1. Site metadata details including soil texture information.

Site ID	Coordinates		Instrumentation		Soil Texture			Data Record
	Latitude	Longitude	Hydra Probes	TBRG Type	Sand (%)	Silt (%)	Clay (%)	
2701000	51.2001	-106.0156	3	RG3	47.1	50.3	2.6	2007-2013
2701001	51.5836	-106.6364	3	RG3	33.4	63.7	2.9	2007-2017
2701002	51.5767	-106.3342	3	RG3	60.0	38.8	1.2	2007-2017
2701003	51.5651	-106.1799	3	RG3	54.7	43.0	2.3	2007-2013
2701004	51.5914	-106.0146	3	RG3	54.7	42.9	2.2	2007-2013
2701005	51.4529	-106.5672	3	RG3	35.7	60.8	3.5	2007-2017
2701006	51.5534	-106.3776	3	RG3	58.4	40.3	1.3	2007-2017
2701007	51.5021	-106.0927	3	RG3	61.7	37.0	1.3	2007-2013
2701008	51.5351	-105.9950	3	RG3	-	-	-	2007-2013
2701009	51.3300	-106.6724	3	RG3	31.0	52.0	17.0	2007-2015
2701011	51.3864	-106.0971	3	RG3	34.5	62.6	2.9	2007-2013
2701012	51.3564	-105.9351	3	RG3	23.8	72.4	3.8	2007-2013
2701013	51.2690	-106.6568	3	RG3	30.0	49.0	21.0	2007-2017
2701014	51.2468	-106.4460	3	RG3	25.0	54.0	21.0	2007-2017
2701015	51.3577	-106.5729	3	RG3	28.0	47.0	25.0	2007-2017
2701016	51.4020	-106.2385	3	RG3	39.8	52.2	8.0	2013-2017
2701017	51.4749	-106.4268	3	RG3	10.6	48.3	41.1	2013-2017
2701018	51.3292	-106.4025	3	RG3	10.5	63.7	25.9	2013-2017
2701019	51.3824	-106.2853	3	RG3	39.0	31.2	29.8	2013-2017
2701020	51.3588	-106.2386	3	RG3	33.6	60.6	5.8	2013-2017
2701021	51.3409	-106.1918	3	RG3	54.5	34.1	11.4	2013-2017
2701022	51.3817	-106.4159	4	TB3	26.2	60.5	13.3	2007-2017
2701023	51.3679	-106.4492	4	TB3	37.0	41.0	22.0	2007-2017
2701024	51.3706	-106.4960	4	TB3	34.0	50.0	16.0	2007-2017
2701025	51.4488	-106.4960	4	TB3	25.4	56.3	18.2	2007-2017
2701026	51.3727	-106.4253	4	TB3	28.6	57.3	14.1	2007-2017
2701027	51.3780	-106.4256	4	TB3	28.0	59.0	13.0	2007-2017
2701028	51.3872	-106.4994	4	TB3	42.0	41.0	17.0	2007-2017
2701029	51.3865	-106.5195	4	TB3	39.0	44.0	17.0	2007-2017
2701030	51.3958	-106.4262	4	TB3	31.0	46.0	23.0	2007-2017
2701031	51.3974	-106.4493	4	TB3	26.6	55.7	17.7	2007-2017
2701032	51.3904	-106.4262	4	TB3	15.7	52.0	32.3	2007-2017

2701033	51.3900	-106.4492	4	TB3	26.0	50.0	24.0	2007-2017
2701034	51.4164	-106.4184	4	TB3	29.0	49.0	22.0	2007-2017
2701035	51.4164	-106.4501	4	TB3	26.0	51.0	23.0	2007-2017
2701036	51.4084	-106.4277	4	TB3	33.0	46.0	21.0	2007-2011
2701037	51.4262	-106.4262	4	TB3	26.8	51.4	21.8	2007-2017
2701038	51.4265	-106.4718	4	TB3	13.8	57.0	29.2	2007-2017
2701039	51.4202	-106.4718	4	TB3	30.2	51.3	18.5	2007-2017
2701040	51.4277	-106.5428	4	TB3	31.8	46.1	22.1	2007-2017
2701041	51.4166	-106.4184	4	TB3	20.0	43.0	37.0	2007-2017
2701042	51.4370	-106.4258	4	TB3	12.7	70.1	17.2	2007-2017
2701043	51.3582	-106.5064	4	TB3	50.0	32.0	18.0	2007-2017
2701044	51.4416	-106.4262	4	TB3	24.6	59.5	15.9	2007-2017

[a] TBRG types: Onset RG3and Hydrological Services TB3.

Table 2. Limits applied in QC1 – data removed

Parameter	Limits
Temperature (°C)	$-60 < x < 60$
Real dielectric constant (ε_r, unit-less)	$0 < x < 90$
Soil moisture, loam calibration (VWC, (m^3m^{-3}))	$0 < x < 1.0$

275 **Table 3. QAQC flags for manual review**

Parameter	QAQC Checks
Temperature (°C)	$x < 0$
Real dielectric constant (ε_r, unit-less)	$x < 2.4$
Soil moisture, loam calibration (VWC, (m^3m^{-3}))	$0.02 < x < 0.6$
Conductivity (if available)	$x < 0.2$