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Title: Data sets for the Upper Penticton Creek Watershed Experiment: a paired-catchment study to support investigations of watershed response to forest dynamics and climatic variability in an inland snow-dominated region

Running title: Upper Penticton Creek data note

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Acknowledgements

The UPC Watershed Experiment has been supported with funding from various sources, including the BC government, the Natural Sciences and Engineering Research Council (NSERC) of Canada, Weyerhaeuser Canada and Gorman Brothers Lumber. More than 55 researchers, technicians, students, consultants and operational foresters have contributed to the UPC database over the past four decades. Our project partners include the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development, Environment and Climate Change Canada, Weyerhaeuser Canada, Gorman Brothers Lumber, Tolko Industries, the University of British Columbia, Thompson Rivers University, Simon Fraser University, the Okanagan Nation Alliance and the Okanagan Basin Water Board. David Hutchinson and Stephanie Moore provided information on streamflow monitoring.

Data sets for the Upper Penticton Creek Watershed Experiment: A paired-catchment study to support investigations of watershed response to forest dynamics and climatic variability in an inland snow-dominated region

September 17, 2021

Abstract

The Upper Penticton Creek Watershed Experiment is one of a handful of forestry-focused paired-catchment experiments in the snow-dominated zone of western North America. The study involves an undisturbed control catchment and two treatment catchments. Streamflow has been monitored at weirs on all three streams since 1985. Following a pre-harvest monitoring period, the treatment catchments were subject to clearcut harvesting in multiple passes that cumulatively covered ~50% of the catchments. In addition to streamflow, available hydrometeorological data sets include weather observations, snowpack water equivalent, rainfall interception, soil water content, and water table levels in soil piezometers and bedrock wells. The data archive also includes digital elevation models, a Lidar-derived image of tree heights in 2016, and vector data associated with lakes and reservoirs, the stream network, clearcut boundaries, a soil map and the logging road network. Together, these data sets provide a basis for empirical analyses of hydrological response to forest dynamics and climatic variability, and for calibration and testing hydrological models using internal variables. They should also provide useful data sets for educational purposes.

1. Data set name

Upper Penticton Creek Watershed Experiment – Data Repository

2. Study site, geographic context and experimental design

The Upper Penticton Creek (UPC) Watershed Experiment was initiated in the early 1980s to address questions about the effects of forest harvesting on hydrology and water supply. The project remains active and, over time, has expanded in scope to include studies of hydrological processes at plot, hillslope and catchment scales, fluvial geomorphology, water quality and aquatic ecology and fish habitat (Winkler et al., 2021). Figure 1 shows locations of hydrometeorological monitoring sites.

The UPC Watershed Experiment is located in the southern interior of British Columbia (BC), Canada. UPC has a snow-dominated hydrologic regime, with an extended baseflow period from late autumn through the winter until the onset of spring snowmelt (Figure 2). Snowmelt occurs between April and June. Streamflow peaks in May or June, then declines through late summer and autumn, with occasional increases associated with rainstorms (Winkler, Spittlehouse & Boon, 2017; Gronsdahl, Moore, Rosenfeld, McCleary, & Winkler, 2019).

The UPC Watershed Experiment is one of a handful of forestry-focused paired-catchment experiments conducted in the snow-dominated zone of western North America. Others include Wagon Wheel Gap, Colorado (Bates & Henry, 1928; van Haveren, 1988), Fool Creek, Fraser Experimental Forest, Colorado (Troendle & King, 1985), Deadhorse Creek, Colorado (Troendle & King, 1987), Marmot Creek Research Basin, Alberta (Swanson, Golding, Rothwell, & Bernier, 1986; Harder, Pomeroy & Westbrook, 2015), Coon Creek, Wyoming (Troendle, Wilcox, Bevenger, & Porth, 2001), Horse Creek, Idaho (King & Tennyson, 1984; King, 1989), and Mica Creek, Idaho (Hubbart, Link, Gravelle, & Elliot, 2007). These studies cover a range of latitudes and climatic regimes, from continental (Marmot Creek and the Colorado studies) to maritime-interior transition (the Idaho studies). Within this context, UPC is the most northerly and, climatically, lies between the continental and maritime-interior transition regimes.

The objective of this note is to describe data sets that include both time series and spatial data. These should be useful support for empirical analyses of hydrological response to forest dynamics and climatic variability, as well as for testing process-based hydrologic models. We anticipate that these data sets will be valuable resources for developing educational materials.

3. Data sets

The data sets are available for download in a zenodo repository. Brief descriptions of the data and the methods used to acquire them are provided below. Stated accuracies for commercially available instruments are those provided by the manufacturers. More complete descriptions, along with photographs of the field sites and instrumentation, are available via a document in the repository named *upc_data_description.html*.

3.1 Spatial data sets

Three digital elevation models (DEMs) are available. One was obtained from the Government of Canada via https://geogratis.gc.ca/, and has a horizontal resolution of 25 m. In addition there are bare-earth and and vegetation height models, based on Lidar data acquired during flights conducted between Jul. 24 and Sep. 16, 2016. The point density was 9 m^{-2}, and the models were projected to BC Albers equal-area projection with 1-m resolution in both easting and northing. Horizontal and verticle accuracies are ± 0.3 m (two standard deviations) and ± 0.15 m, respectively.

Vector spatial data sets include points for locations of observational sites, line segments for roads and the stream network, and polygons for soil units, lakes, reservoirs, the catchment boundaries, and cutblock boundaries.

3.2 Streamflow

Streamflow is gauged by Water Survey of Canada (WSC). Station IDs are 08NM240, 08NM241, and 08NM242 for 240, 241, and 242 creeks, respectively, where 240 is the control and the others are treatment catchments. During the snowmelt freshet, streamflow is measured using broad-crested weirs; 90° v-notch weir inserts are installed after flows decline into summer. Tables 1 and 2 summarize instruments used for recording stage. Procedures for measuring stage and streamflow, fitting rating curves, and producing streamflow time series can be found via the following links:

- https://publications.gc.ca/collections/collection_2021/eccc/en37/En37-464-2016-eng.pdf
- https://publications.gc.ca/collections/collection_2021/eccc/en37/En37-274-2019-eng.pdf
- https://publications.gc.ca/collections/collection_2021/eccc/en37/En37-465-2019-eng.pdf
- https://publications.gc.ca/collections/collection_2021/eccc/en37/En37-525-1981-eng.pdf

Daily mean flows and annual extreme instantaneous flows are available via https://wateroffice.ec.gc.ca/search/historical_e.html or the **tidyhydat** package (Albers, 2017).

3.3 Weather

Daily weather observations began at three stations in late 1983 using Lambrecht 251 thermographs (accuracy ± 0.3 °C) in Stevenson screens for air temperature and Belfort 5-780 weighing gauges for total precipitation (accuracy and sensitivity at full scale of 0.5% and 0.1%, respectively). Daily maximum and minimum temperatures were extracted from the paper charts.

Since August 1991, seven weather stations have monitored hourly rainfall, air temperature, soil temperature, relative humidity, solar radiation, wind speed, snow depth, and snow temperature using instruments as described in Table 3. Data are recorded by Campbell Scientific CR10, CR10X or CR1000 data loggers.

3.4 Snowpack water equivalent and associated site characteristics

Snow surveys have been completed every two weeks from mid-March until the end of snowmelt in most years. From 1995 to 1997, snow was sampled at 64 stations, spaced in a 15-m by 15-m grid, at five locations. From 1998 to 2019, the number of stations at each location was reduced to 32, and stations at six new survey sites were located on a 10-m by 10-m grid. Since 1998, some snow courses have been removed, relocated, or added as project-specific objectives and forest cover have changed over time (Figure 1).

Snow depths and water equivalents are measured using a standard Federal snow tube, both recorded to the nearest 1 cm. Under snow conditions typical of UPC, standard Federal samplers overestimate SWE and density by 10% (Goodison et al., 1987). Recorded values have not been adjusted for this bias.

Tree measurements (e.g., species, height, diameter) and canopy photography have been acquired at all forested snow survey stations (Winkler et al., 2017). Canopy photos were taken under overcast skies using a Nikon 4500 camera with a FC-E8 fisheye lens converter. The camera was levelled with a bubble level on the lens cap and oriented so that the top of each image was north. Photography and analysis were completed by the same person. Threshold selection for binarizing the blue channel was automated using SideLook 1.1.01 (Nobis & Hunziker, 2005). Bitmap images were compared with the original photo, and contrast in the original image was adjusted in a few cases. Plant area index (needles, branches, and stems) and percent transmittance during snowmelt (April 1 to May 15) were determined using Gap Light Analyser 2.0 (Frazer, Canham & Lertzman, 1999).

3.5 *Canopy water balance*

Throughfall and stemflow were measured from May through October from 1997 to 2007 for three mature forest stands using five 6-m-long throughfall troughs connected to tipping buckets (0.05 ± 0.005 mm/tip) and 5 stem collars emptying into Jarek tipping buckets (33 ± 0.2 ml/tip), both monitored by data loggers (Spittlehouse, 1998). Data are presented as total depths for each precipitation event. A 25-year-old stand was monitored from 2004 to 2006 using storage gauges (± 5 ml) measured biweekly from May to October each year. The repository includes total gross precipitation, throughfall, stemflow and computed interception loss for each storm or bi-weekly monitoring period.

3.6 Soil characteristics

Dr. Graeme Hope, P.Ag. (Soil Scientist, BC Ministry of Forests, Lands, Natural Research Operations and Rural Development) conducted soil surveys and generated a map of soil units within the study catchments. A digital version of the map is included in the repository.

Soil pits were dug at seven sites that were monitored for the canopy water balance and soil moisture content. Porosity, particle density, bulk density and moisture contents associated with tensions of 5, 10, 33, 100, 300 and 1500 J/kg were determined for soil cores approximately 2 cm deep and 5 cm diameter that were taken from soil pits and analysed at SoilCon Labs, Richmond, BC, or BC Government Soil Analysis Lab, Victoria, BC. Sampling and analysis procedures followed those described in Carter and Gregorich (2008). Summary descriptions of properties of soil layers were determined for the soil pits, and a detailed soil profile is available from one pit described by Dr. Graeme Hope on Oct. 2, 2002.

3.7 Soil water content

Soil water content (m^3 water per m^3 soil) in the top 0.5 m of soil was measured manually on a biweekly basis from April to October using a Moisturepoint MP917 time domain reflectometer (Spittlehouse, 2000). Accuracy is $\pm$ 2% following calibration. Probes consisted of a pair of 3-mm-diameter stainless steel rods 30 mm apart, which were connected to the MP917 through 0.04 m of two-conductor cable, a shorting diode and 3 m of RG-6 coaxial cable.

The sites were a mature forest and regenerating stand (5 years old in 1997) monitored from 1997 to 2006, three mature forest-clearcut pairs monitored from 2003 to 2006, and a 25 year- old stand monitored from 2004 to 2006. At each site, measurements were made at 10 points along a transect, with sample points 5 to 20 m apart depending on site.

3.8 Water table observations

Groundwater levels within the soil layer in the 241 Creek watershed were monitored at 15 piezometers using Odyssey Capacitance Water Level Probes (Data Flow Systems Pty Ltd, Christchurch, New Zealand, vertical resolution of 0.8 mm). Recording intervals varied from 10 to 30 min, and were not synchronized among loggers. Piezometers were situated along downslope flow paths (Kuraś, 2006; Kuraś, Weiler & Alila, 2008; Voeckler, Allen & Alila, 2014).

Nine of the shallow piezometers were installed in 2005 (Kuraś, Weiler & Alila, 2008); six were added in 2007 (Voeckler, Allen & Alila, 2014). Piezometers extend down to 0.70 to 1.3 m below the top of the A horizon, with a 0.01-m gap between the bottom of the piezometer and the sensor.

Piezometers were constructed from 32-mm-outside-diameter PVC pipe, with 6.35-mm-diameter holes drilled around the circumference up to a length of 30 cm from the bottom (Kuraś, 2006). This perforated portion of the pipe was covered with fine-meshed gauze to inhibit sediment influx. Piezometers were installed prior to spring snowmelt. After emplacing the piezometer pipe in a hand-augered hole, the space surrounding the tube was backfilled with fine gravel to a level 10-15 cm below the soil surface. A layer of bentonite clay added above the gravel sealed the hole from surface runoff.

Three groundwater wells were drilled into the bedrock of the 241 Creek watershed in July 2007. Wells W1 and W2 (46 m and 30 m deep, respectively) were drilled at an elevation of ~1805 m asl about 3 m apart. Well W3 (30 m deep) was drilled at ~1624 m asl, down-gradient from W1 and W2 (Voeckler et al., 2014). The wells were completed as open boreholes to their full depths, with shallow surface casings (~2.5 m for W1 and W2, and 6.4 m for W3). Groundwater levels were recorded in all three wells twice daily from July 2007 to September 2010.

Seametrics PT2X vented pressure transducer loggers (measuring daily and twice daily) were initially deployed in July 2007. The accuracies are $\pm$ 21 mm for the sensor in W1 and $\pm$ 3.5 mm for the other two. Due to instrument malfunction that was detected in August 2008, no data are available for W3 and the data from W1 and W2 for that initial period should be viewed with caution. Non-vented Onset HOBO U20-02 loggers (maximum error of $\pm$ 30 mm) were installed on November 3, 2008. Barometric pressure compensation in all wells was based on a HOBO logger placed inside the upper well casing at W1. All loggers were retrieved in August 2010.

Since October 2013, hourly groundwater levels for W2 have been included in the BC Observation Well record (Province of British Columbia, n.d.). In addition to water levels, pumping test results are available for W1 and W3 in the repository.

3.9 Vegetation

In addition to the LiDAR-derived vegetation height map and the forest stand data measured in conjunction with the snow courses (see section 3.4), vegetation surveys were conducted at the sites at which canopy water balance and soil moisture content were monitored. Forest stand characteristics include canopy closure, stem density, tree height, species, and diffuse and direct transmissivity (for

March 21 and June 21) and leaf-area index determined from hemispherical photographs (see section 3.4 for details). Below-canopy vegetation cover was measured along line transects at each monitoring site. Details are provided in the file named *upc_data_description.html* contained in the repository.

3.10 Additional data sets

Data sets including hourly streamflow and water quality variables will be added to future versions of the repository once they are finalized and/or manuscripts based on the data are completed.

4 Data availability statement

Data sets from Upper Penticton Creek are publicly available via the following doi:
https://doi.org/10.5281/zenodo.4456139.

5 Funding, contributors and data ownership

The table below summarizes the contributors of the data sets, the funding sources and ownership (BC gov = Government of British Columbia, WSC = Water Survey of Canada, SFU = Simon Fraser University).

Dataset	Contributors	Funding	Ownership
Streamflow	Water Survey of Canada	BC gov	WSC, BC gov
Weather	BC gov, D. Spittlehouse	BC gov	BC gov
Snowpack and associated data	BC gov, R. Winkler	BC gov	BC gov
Canopy water balance	BC gov, D. Spittlehouse	BC gov	BC gov
Soil water content	BC gov, D. Spittlehouse	BC gov	BC gov
Water table observations	BC gov, D. Allen, H. Voeckler, P. Kuras	BC gov	BC gov, SFU

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Table 1. Instruments for stage measurement by Water Survey of Canada

Instrument type	Make	Model	Accuracy
float-driven chart recorder	Stevens	A-71 or A-35	± 2 mm
pressure transducer	Tavis	DISI1200	0.1% full scale

Table 2. Effective date ranges for instrumentation used to measure stage at each station.

Station	Start	End	Instrumentation	Time resolution	Real-time
08NM240	1/1/1983	7/6/2010	A-35 chart recorder with float	5 min	FALSE
08NM240	7/6/2010	3/23/2016	VEDAS II data logger with TAVIS DISI1210 transducer	15 min with 24 hour max/min instantaneous readings	FALSE
08NM240	3/23/2016	9/20/2018	FTS H2 GOES data logger with TAVIS DISI1210 transducer	5 min	TRUE
08NM240	9/20/2018	Present	FTS H2 GOES data logger with OTT PLS transducer	5 min	TRUE
08NM241	1/1/1983	10/14/2009	A-35 chart recorder with float	5 min	FALSE
08NM241	10/15/2009	8/30/2016	VEDAS II data logger with GOES with TAVIS DISI1210 transducer	15 min with 24 hour max/min instantaneous readings	TRUE
08NM241	8/30/2016	9/20/2018	FTS H2 GOES data logger with TAVIS DISI1210 transducer	5 min	TRUE
08NM241	9/20/2018	Present	FTS H2 GOES data logger with OTT PLS transducer	5 min	TRUE
08NM242	1/1/1985	5/18/2010	A-71 chart recorder with float	5 min	FALSE
08NM242	5/18/2010	3/23/2016	VEDAS II data logger with TAVIS DISI1210 transducer	15 min with 24 hour max/min instantaneous readings	FALSE
08NM242	3/23/2016	6/6/2019	FTS H2 GOES data logger with TAVIS DISI1210 transducer	5 min	TRUE
08NM242	6/6/2019	Present	FTS H2 GOES data logger with OTT PLS transducer	5 min	TRUE

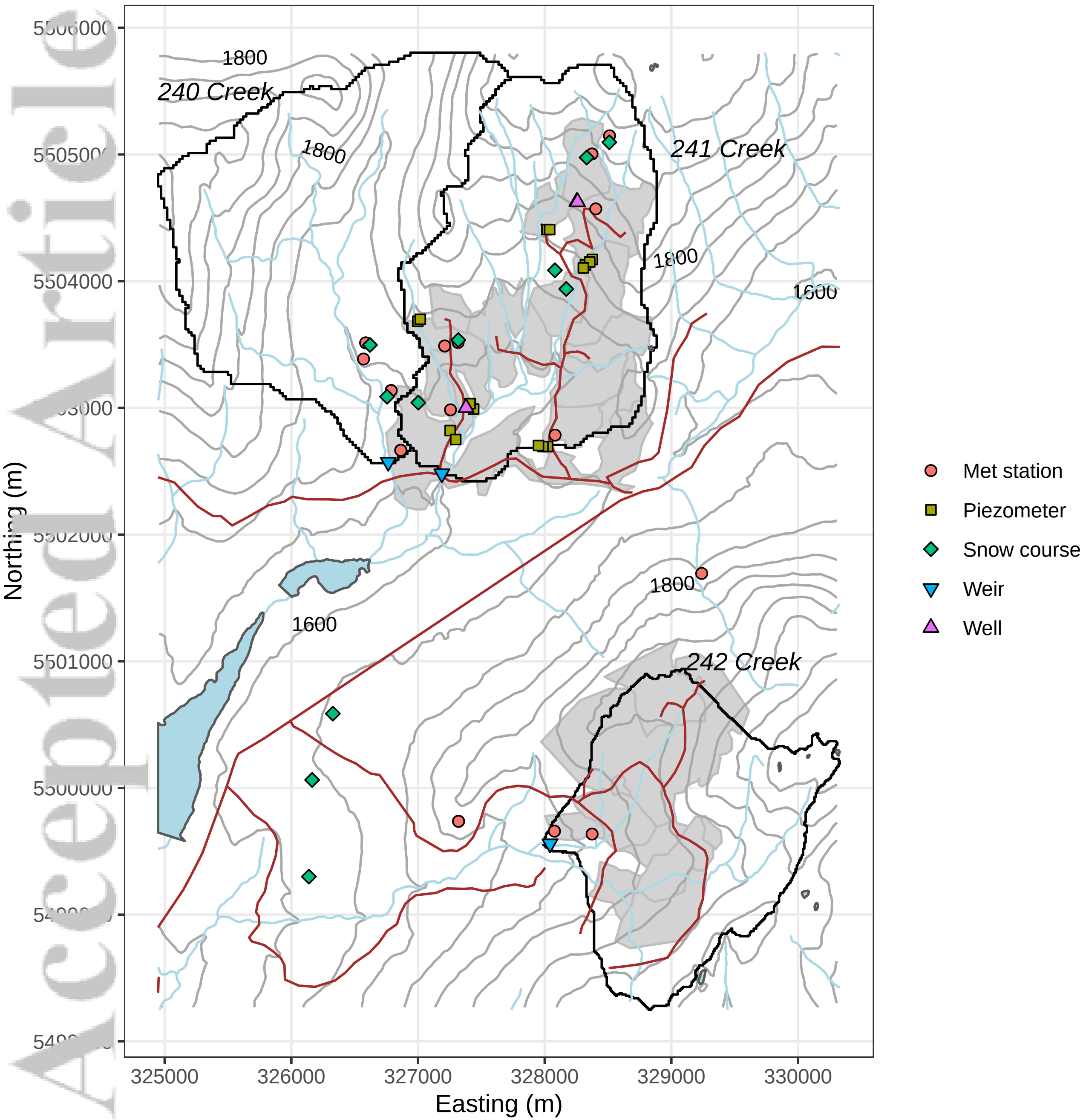
Table 3. Instrumentation employed at weather stations that provide hourly records.

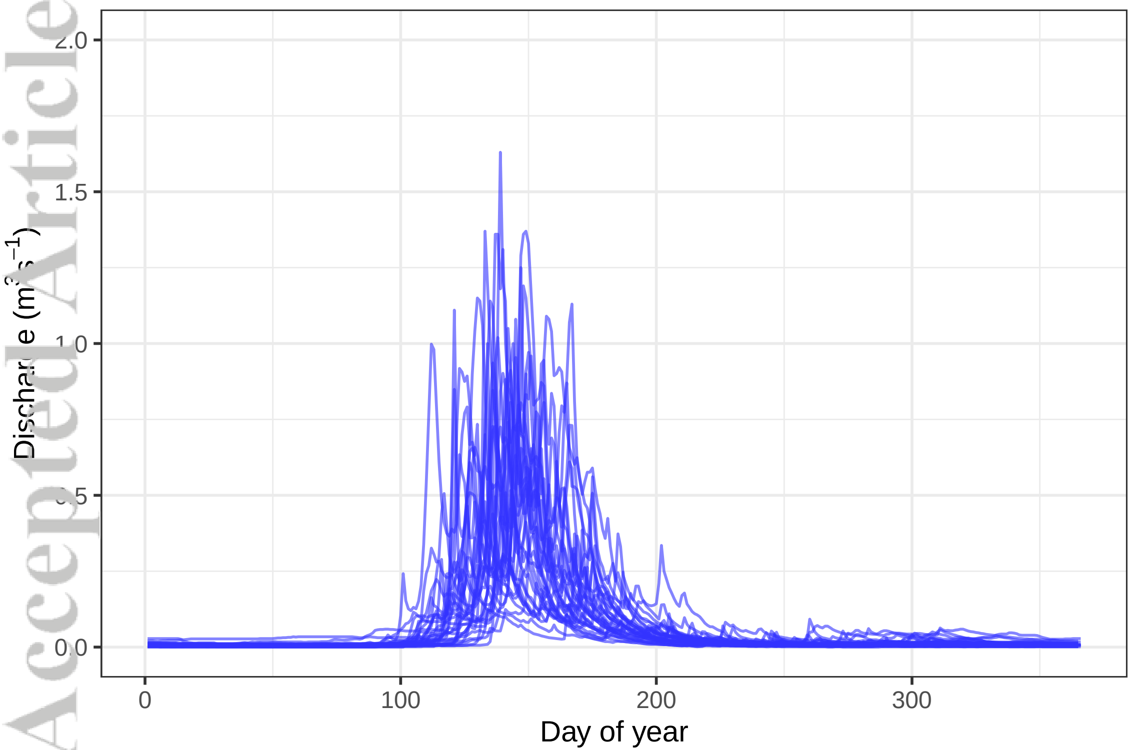
Variable	**Maker**	**Model**	**Accuracy**	**Quality Control**
Solar radiation - incident	LiCor Inc.	LI200 pyranometer	± 5%	Comparison with daily clear sky values
Solar radiation - reflected	Eppley	B&W pyranometer	± 3 το 5% (hourly)	Manual review of data
Solar radiation - reflected	LiCor Inc.	LI200 pyranometer	± 5%	Manual review of data
Air temperature	Vaisala	HMP35C, HMP45C	± 0.2 °C	Recalibrated every 5 years
Air humidity	Vaisala	HMP35C, HMP45C	± 2 % (0-90); ± 3 % (90-100)	Recalibrated every 5 years
Air temperature	Rotronic	HC-S3	± 0.2 °C	Recalibrated every 5 years
Air humidity	Rotronic	HC-S3	± 1.5 %	Recalibrated every 5 years
Rainfall	Sierra Misco	2401 tipping bucket	± 1.5% for 0 to 91 mm/hr	Calibration with burette
Precipitation	Four Seasons	Stand pipe gauge with Sensotec pressure transducer	± 0.2 mm	Manual measurement of depth of liquid
Snow depth	Campbell Scientific	UDG01, SR50, SR50A	± 1 cm or 0.4 %	Comparison between sites
Wind speed	MetOne	014A	± 0.11 m/s or 1.5 %; starting threshold 0.45 m/s	Serviced every 5 years
Wind speed	RM Young	Wind Monitor 01503-10	±0.3 m/s or 1 %; starting threshold 1 m/s	Serviced every 5 years
Wind direction	RM Young	Wind Monitor 01503-10	± 3°	Serviced every 5 years
Snow temperature	Omega thermocouple wire	Chromel-constantan	± 0.1°C	Manual review of data
Soil temperature	Omega thermocouple wire	Chromel-constantan	± 0.1°C	Manual review of data
Surface temperature	Apogee Instruments	SI-111	± 0.2 °C	Manual review of data
Net radiation	Kipp and Zonen	CNR1 allwave radiometer	± 10%	Manual review of data

Figure captions

Figure 1. Monitoring locations in the Upper Penticton Creek Experimental Watershed study. Grey shaded areas are clearcuts, and brown lines are logging roads. Contour interval = 50 m.

Figure 2. Daily streamflow hydrographs for each year of record for the control stream, 240 Creek, from 1983 to 2017. Each line represents an individual calendar year.


240 Creek
241 Creek
242 Creek
1800
1600
Met station
Piezometer
Snow course
Weir
Well
Easting (m)
Northing (m)
325000
326000
327000
328000
329000
330000
5504000
5501000


2.0
1.5
1.0
0.5
0.0
Discharge (m^{3}s^{-1})
0
100
200
300
Day of year