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# Fifty years of recorded hillslope runoff on seasonally-frozen ground: The Swift Current, Saskatchewan, Canada dataset

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**Abstract.** Long records of hillslope runoff and nutrients are rare—on seasonally frozen ground they are almost non-existent. The Swift Current hillslopes at the Swift Current Research and Development Centre on the Canadian Prairies provide such a long-term hydrological record. Runoff, runoff nutrient concentration, snowpack, soil moisture, and soil nutrient concentration were monitored on the three 5 ha hillslopes over a 50-year period (1962 – 2011). Runoff from the hillslopes was generated episodically during snowmelt and occasional rainfall events. Edge-of-field runoff was measured with a 0.61 m H-flume. Daily runoff nutrient concentration data are available for nitrate (March 1971 – April 2011), ammonium (February 1996 – April 2011), and orthophosphate (March-April 1971; June 1991 – April 2011). Snowpack data (snowpack depth, density and water equivalent) were determined via manual snow surveys carried out several times each winter, between January and March, between 1965 and 2011 Gravimetric soil moisture content was measured in October and April each year between 1971 and 2011 at five depth intervals (0-15, 15-30, 30-60, 60-90, and 90-120 cm) at nine points on each hillslope. We summarize these hillslope data in two publically-available repositories: 1) 1962-2011 data on runoff, runoff nutrients, snowpack, soil moisture, soil nutrients, and crop and tillage practices at https://doi.org/10.23684/hhn5-rz52; and 2) digital elevation data at https://doi.org/10.20383/101.0117. Complete climate data recorded at a Environment and Climate Change Canada meteorological station located 390 m from the three hillslopes are publically-available at http://climate.weather.gc.ca/.

## 1 Introduction

Long-term datasets that chronicle hydrological processes within the context of long-term climate and land management change are rare. This is especially true for cold regions with seasonally-frozen ground and where remoteness and inclement weather limit continuous measurements. Long-

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term experimental datasets that do exist in such regions are diminishing quickly (Laudon et al., 2017). However, for hillslope-scale long-term experiments, such records are, to our knowledge, non-existent. Here we present a 50-year record for a set of three monitored agricultural hillslopes in southwest Saskatchewan, Canada that includes runoff, runoff nutrients, snowpack, soil moisture, soil nutrients, and associated meteorological data for a 50-year period, during which the hillslopes underwent controlled, comparative changes in agricultural practices.

The hillslope-scale dataset is at the spatial scale intermediate between more traditional long-term catchment-scale datasets (e.g. Water Survey of Canada (WSC) Historical Data, the United States Geological Survey (USGS) National Streamflow Information Program, or the UK National River Flow Archive) and point-scale datasets (e.g. TERENO-SOILCan network (Pütz et al., 2016) or the Reynold's Creek soil lysimeter network (Seyfried et al., 2001)). As such, hillslope-scale measurements of precipitation and runoff, together with internal measurements of soil moisture, snowpack, and soil nutrients offer an opportunity to understand mechanistically the links between climate trends in rainfall and snowmelt inputs and runoff outputs. Further, in terms of land use change, they offer an opportunity to understand how tillage, seeding, and crop rotational practices affect the hydrology of agricultural hillslopes, as well as nutrient delivery to downstream water bodies.

The collation of our long-term hillslope database has been motivated largely by the importance of water management and sustainability for dryland agriculture on seasonally-frozen, snowmelt-dominated terrain. This paper reports on an archive of downloadable data from an experimental, agriculturally-managed hillslope site at Swift Current, Saskatchewan. This dataset documents the characteristics more broadly of the semiarid portions of the northern Great Plains of North America. It serves as a resource for long-term analyses and model formulation, calibration, and testing of land management and climate change effects on agricultural hillslopes.

## 2 The Swift Current hillslopes

The three hillslopes are located at South Farm (50°15'53" N 107°43'53" W), an agricultural research site of Swift Current Research and Development Centre of Agriculture and Agri-food Canada, approximately 5 km southeast of Swift Current, Saskatchewan (Figure 1). The hillslopes adjoin each other and are rectangular in shape, with areas of 4.25 ha (Hillslope 1), 4.66 ha (Hillslope 2), and 4.86 ha (Hillslope 3). The hillslopes are approximately 150 m wide in the east-west direction and 300-320 m long in the north-south direction. They were artificially diked with raised grassed berms constructed in the 1950s by Agriculture and Agri-food Canada. Hydrological observations at the hillslopes began in 1962 to address the effects of agricultural land management practices on runoff water supply and quality, chemical transport, and soil erodibility.

The fields have undulating topography and slope towards the north-northwest with gradients of 1-4%. Digital elevation models (DEMs), obtained using a Leica Viva GS15 from 17-18 April 2012, are available for all three hillslopes at a 2 m horizontal resolution. Two additional DEMs, obtained using an Optech ILRIS-LR Terrestrial Laser Scanner in summer 2014, are available for Hillslope 2 at a 0.25 m horizontal resolution. These two finer DEMs of Hillslope 2 were obtained from surveys on 7 July 2014 and 24 September 2014, before and after a simulated seeding of the hillslope. They therefore capture the surface micro-topography of a tilled hillslope with random soil clod undulations, as well as a seeding-induced ridge-and-furrow features on the hillslope.

The soils are Orthic Brown Chernozems (Ayres et al., 1985), specifically Swinton silt loam in the upper four-fifths of the hillslopes, where the solum is developed within loess, and Haverhill loam in the lower fifth of the hillslope, where past erosion has resulted in the solum extending into the underlying loamy till (McConkey et al., 1997). The surficial 0-15 cm soil layer consists of 50.4% silt, 31.4% sand, and 18.2% clay, has a bulk density of 1.22 g $cm^{-3}$, and has a saturated hydraulic conductivity of 14.2 mm $hr^{-1}$. Silt content decreases with depth, while clay content increases with depth. Mean soil depth, as measured with a dynamic cone penetrometer, is 2.65 m (Coles and McDonnell, 2018).

The hillslopes have been under an annual rotation of wheat (*Triticum aestivum*) and fallow. This two-crop rotation is with the exception of: a period (1977-1980) of grass (*Psathyrostachys juncea* (Fisch.) Nevski) and a period (1982-1985) of annual wheat on Hillslopes 1 and 2; an annual rotation (1994-2010) of wheat and legume green manure (*Lathyrus sativus* L.) on Hillslope 1; and an annual rotation (2004-2011) of wheat and pulses (lentils and peas; *Lens culinaris* L. and *Pisum sativum* L., respectively) on Hillslope 2. The hillslopes have been under largely conventional tillage practice, with the exception of the period 1993-2011 when Hillslope 2 was switched to zero tillage practice. There was constant standing stubble or standing crop during the period 1993-2004 on Hillslope 2, when the wheat-fallow rotation coincided with the zero tillage period. Unlike the other two hillslopes, Hillslope 3 has had a consistent two-crop rotation and consistent tillage management since 1962.

From 1962 onwards, runoff, runoff nutrient concentration, snowpack characteristics, soil moisture, and soil nutrient concentration have been monitored on the hillslopes. Meteorological data from an Environment and Climate Change Canada meteorological station located 390 m to the south-southeast complement the hillslope dataset.

## 3 Work with the data to date

The long-term data from the hillslopes have so far been used to investigate the effects of tillage practices on runoff water quality (Cessna et al., 2013), and the effects of climate change on snowmelt timing (Cutforth et al., 1999) and runoff amounts (Coles et al., 2017). Other studies have used the dataset to determine the magnitude of soil erosion (McConkey et al., 1997) and nutrient transport (Nicholaichuk and Read, 1978) from agricultural hillslopes. More recent study has used these data to understand the relative importance of hydrological controls on snowmelt-runoff generation (Coles et al., 2018a). Other recent work on the Swift Current hillslopes undertaking single melt season intensive data collection has quantified the spatial patterns of hydrological variables and the generation of snowmelt-runoff connectivity over low-angled terrain (Appels et al., 2017; Coles and McDonnell, 2018).

## 4 Available data series

The available data are summarized in Table 1 and detailed below.

### 4.1 Runoff

Runoff from the hillslopes is non-continuous, and generated during snowmelt and occasionally during heavy rainfall events. Figure 2 shows the 50-year runoff record for one hillslope (Hillslope 2). Of the 50 years on record, 46 of those years saw measurable flow during spring snowmelt and 28 years saw measureable hillslope-scale runoff during non-melt rainfall-runoff events (on at least one of the hillslopes).

The raised grassed berms prevent runoff from being transferred between the hillslopes. Runoff from the hillslopes is routed through a 0.61 m H-flume (Bos, 1989) at the downstream outlet (north-northeast corner) of each hillslope. The flume state was measured between January 1962 and December 2011 using a Stevens (Portland, Oregon, USA) water level chart recorder in the stilling well of each flume. Since 1994, water level recorder shaft position encoder (Belfort Instrument Co., Baltimore, Maryland, USA) was the primary method to record water level. Daily cumulative runoff amounts (mm) were calculated from these water level measurements using a standard H-flume rating curve (Bos, 1989). The H-flumes were heated in cold weather to prevent icing. No runoff was measured during 1970. A heavy rainfall event on 14 June 1964 caused flow rates to exceed the flume capacity, and the runoff for that event was subsequently estimated by McConkey et al. (1997).

### 4.2 Runoff nutrient concentrations

Nutrient concentrations in the runoff were measured on a daily basis from runoff samples taken from the flume at the downstream outlet of each hillslope. Concentration data are available for nitrate (1971-2011), ammonium (1996-2011), and orthophosphate (1971; 1991-2011). Sample collection protocols and quantification methodologies are described in Cessna et al. (2013).

### 4.3 Snow depth, density, and water equivalent

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Snowpack data were determined for each hillslope by manual snow surveys each year between 1965 and 2011. Snow depth and density were measured, and snow water equivalent (SWE) was calculated, at nine points on each hillslope (as shown in Figure 1). Snow surveys were carried out several times each winter, between January and March. Hillslope-averaged snow depth, density, and SWE were calculated from the nine points for each survey.

### 4.4 Soil moisture

Gravimetric soil moisture content (water fraction by volume of soil) was measured twice each year between 1971 and 2011: in October, prior to freeze-up, and in April, following spring snowmelt. The measurements were taken at nine points on each hillslope (Figure 1), at five depth intervals per point: 0-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm. The soil moisture was measured from a subsample of the entire mixed interval and reported for the mid-point of the interval. These gravimetric soil moisture contents were converted to volumetric using average bulk density across the hillslopes derived from occasional measurements by the soil core method. These were: 1.26 g cm$^{-3}$ for 0-15 cm, 1.29 g cm$^{-3}$ for 15-30 cm, 1.39 g cm$^{-3}$ for 30-60 cm, 1.54 g cm$^{-3}$ for 60-90 cm, and 1.63 g cm$^{-3}$ for 90-120 cm. Hillslope-averaged soil moisture at each depth was calculated from the nine points.

### 4.5 Soil nutrient concentrations

A subsample from the same samples collected for soil moisture was air-dried and analyzed for $NO_3$-N and bicarbonate-extractable (Olsen) P (Hamm et al., 1970).

### 4.6 Meteorology

To complement the hillslope data, meteorological data are available from the Environment and Climate Change meteorological station (station name: Swift Current CDA; Climate ID: 4028060; WMO ID: 71446 and downloadable at http://climate.weather.gc.ca/), 390 m south of the southwest corner of Hillslope 1 and within 1 km of all three hillslopes. These data include daily (1962-present) and hourly (1995-present) precipitation (snowfall and rainfall), temperature, wind speed and direction, snow depth, and relative humidity.

## 5 Data availability

Data from the three Swift Current hillslopes are available at: https://doi.org/10.23684/hhn5-rz52. This depository includes the long-term runoff, runoff nutrient, snowpack, soil moisture, soil nutrient, and crop and tillage data. In addition to this, we have made available the digital elevation data for the site, which can be accessed at: https://doi.org/10.20383/101.0117 (Coles et al., 2018b). The Environment and Climate Change Canada meteorological data are available at: http://climate.weather.gc.ca/.

## 6 Summary

This paper has presented details of a long-term (1962-2013) dataset from three 5 ha research hillslopes at the Swift Current Research and Development Centre (of Agriculture and Agri-food Canada) in southern Saskatchewan on the northern Great Plains. The hillslopes are seasonally-frozen and under agricultural management. Runoff from the hillslopes is non-continuous and is dominated by spring snowmelt. The dataset includes runoff, runoff chemistry, snowpack, soil moisture, and soil chemistry. A nearby Environment and Climate Change standard meteorological station provides a dataset of precipitation, temperature and other climate conditions at a daily (1962 onwards) and hourly (1995 onwards) resolution. Data from the three hillslopes and the meteorological station are now available online. This rich dataset is a valuable source for hydrological response analysis and model formulation and calibration, within the context of long-term climate and land management change.

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**Figures and tables**

Table 1. Summary of data available and years recorded.

| **Data** | **Years** |
|---|---|
| Runoff | |
| - daily total | - 1962-1969; 1971-2011 |
| - daily peak flow | - 1962-1969; 1971-2011 |
| Runoff nutrient concentrations | |
| - nitrate ($NO_3$-N) | - 1971-2011 |
| - ammonium ($NH_4$-N) | - 1996-2011 |
| - orthophosphate ($PO_4^{3-}$) | - 1971; 1991-2011 |
| - sediment | - 1971-2011 (1971-1993 = occasional; 1994-2011 = almost continuous) |
| Snowpack | |
| - depth | - 1965-2011 (1-6 surveys per year) |
| - density | - 1965-2011 (1-6 surveys per year) |
| - snow water equivalent | - 1965-2011 (1-6 surveys per year) |
| Soil moisture content | |
| - 0-15, 15-30, 30-60, 60-90, 90-120 cm | - 1971-2011 (April and October) |
| Soil nutrient (N and P) concentrations: | |
| - 0-15 cm | - 1970-1992 (April and October) |
| - 0-15, 15-30, 30-60, 60-90, 90-120 cm | - 1993-2010 (April and October) |
| Meteorology: | - 1962-2011+ (ongoing) |
| - daily: maximum temperature, minimum temperature, rain, snow, precipitation, snow on ground | - 1994-2011+ (ongoing) |

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| | |
|---|---|
| | - hourly: temperature, dew point, relative humidity, wind direction, wind speed |

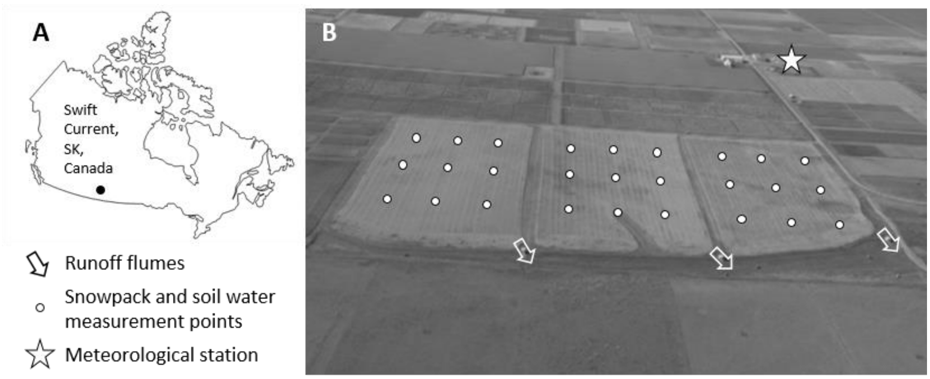


**Figure 1: A) Location of the Swift Current hillslopes in Canada. B) Aerial photograph (facing south) of the Swift Current hillslopes (from right to left: Hillslope 1, Hillslope 2, Hillslope 3), taken in a year when wheat was grown. The runoff flumes, measurement locations for snowpack and soil moisture, and the meteorological station are indicated. Figure modified, with permission, from Cessna et al. (2013) and Coles et al. (2017).**

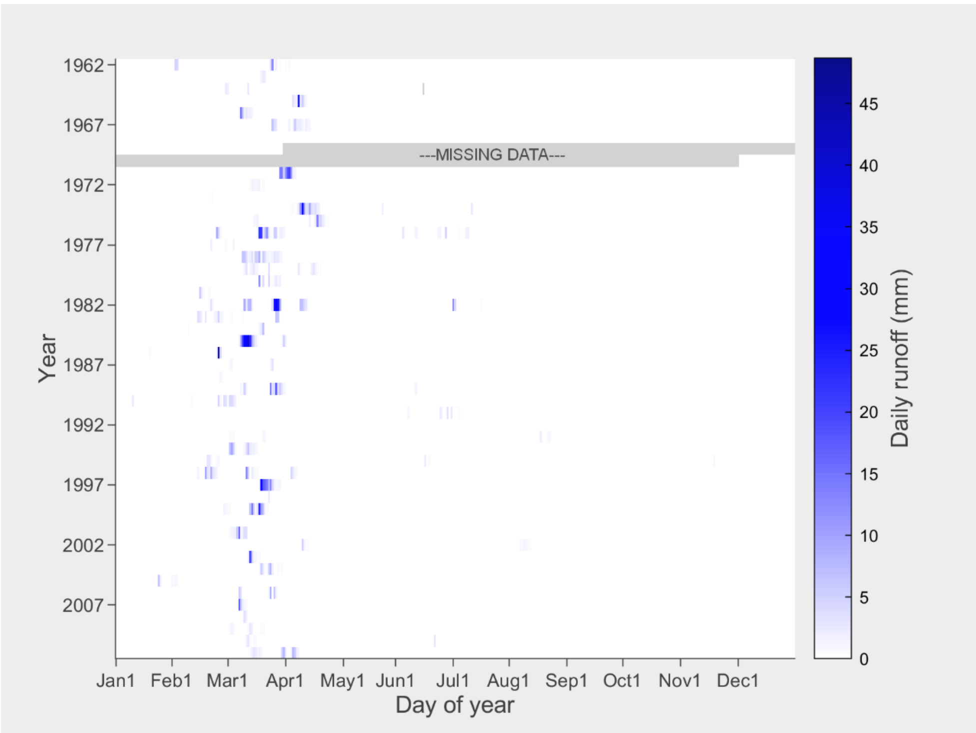


**Figure 2: Daily runoff (mm) for the 50-year period (January 1st 1962 to December 31st 2011) on Hillslope 2.**