Author responses to referee comments on "Fifty years of recorded hillslope runoff on seasonally-frozen ground: The Swift Current, Saskatchewan, Canada dataset" by Anna E. Coles et al.

13 May 2019

In this comment, we (the authors) respond to each of the comments made by the two referees – Chris Spence and Charles Maule – and detail the associated changes to the manuscript. Thank you to Drs Spence and Maule for their critical and constructive feedback.
Original referee comments are denoted by RC, author responses as AC, and manuscript changes as MC.

RC1: Spence

RC1.1 In this paper, the authors summarize a hydrological and chemistry dataset from a set of experimental hillslopes in Saskatchewan, Canada. It is a very nice dataset, which deserves to be catalogued and preserved. Its value is certainly enhanced by the long period of record. The data are easily accessible from Government of Canada open data websites. Upon reading the paper, I felt like there should be more description of the data, and more information on the methods used to collect it. As it is now, the paper does not provide enough information, particularly of the latter, for new users of the data to maximize its usage. My comments, both major and minor, are below.
AC1.1 Thank you for your comments. We couldn't agree more that this dataset deserves to be preserved and used for future studies. We agree in hindsight that there should have been more information on methods and descriptive statistics of the data. We respond to your individual comments pertaining to this and other aspects, below.
MC1.1 We have edited the revised manuscript to address all of your comments. Specific changes detailed below.

RC1.2 Page 1 Line 10: perhaps say "nutrient flux (or concentration or export)"
AC1.1 Agreed.
MC1.1 Edited to "nutrient concentrations"

RC1.3 Page 1 Line 13: Perhaps pick one of "edge of field" or "hillslope" and stick with it throughout the paper.
AC1.2 Agreed.
MC1.2 There was one occurrence of "edge-of-field" and one of "field" in the manuscript. Changed these to "hillslope" to be consistent with the rest of the manuscript.

RC1.4 Page 1: Line 20: The digital elevation data that are mentioned here should be introduced earlier in the abstract.
AC1.4 Agreed.
MC1.4 Added a line earlier in the abstract to say that digital elevation data are available for the three hillslopes at a 2 m resolution, and also at a 0.25 m resolution for one of the hillslopes (Hillslope 2)

RC1.5 There are very minor grammatical errors throughout, the kind that can perhaps be addressed by a copy editor at the end of the review period. However, these should be fixed during the next revision via a thorough proof read.
AC1.5 Apologies for missing these errors. We have made a thorough proofread.
MC1.5 We have made grammatical corrections throughout the manuscript.

RC1.6 Page 2 Line 2: I have never liked the phrase "to our knowledge" because they always reveal that the authors have not done their homework. For instance, the Experimental Lakes Area have been documenting runoff from several hillslopes since the 1970s. There are not many research hillslopes over frozen ground, but please do not perpetuate the idea that this is the only dataset that exists. Turkey Lakes, Trail Valley Creek, Wolf Creek, McMaster Basin; these are all places that have comparable data. Furthermore, aren't the Swift Current hillslopes in existence? I suggest rephrasing non-existent to rare or uncommon. What is distinct is the period of record. Long, very long.

AC1.6 I (Anna) really appreciate this comment, thank you. As well as the adjustments in this manuscript (next comment), I will be mindful of being much more thorough not using phrasing like this in the future.
MC1.6 We have modified the manuscript to remove “to our knowledge” and have edited “non-existent” to “uncommon”.

RC1.7 Page 2 Line 12: It has not been determined how applicable the results found at Swift Current are in other climates and landscapes. Perhaps temper the statement by saying “in this landscape or “in dry agroecosystems”.
AC1.7 Agreed
MC1.7 Edited to “in terms of land use change in dry agroecosystems”

RC1.8 Page 3 Line 2: It is unclear how the hillslopes were surveyed with the Leica instruments. Could the authors please provide information on the projection, datum and accuracy of the elevation data. Also, could you please describe the data. What are the mean elevation, slopes and relief, for instance?
AC 1.8 Agreed that this information is necessary
MC 1.8 Edited the manuscript to incorporate information on the survey equipment and the resultant data. We also reference the original dataset, where more information on the surveying and DEM generation is detailed.

RC1.9 Title of Section 3: Could I suggest rephrasing this? “Previous research”; “Prior research” Just some suggestions.
AC 1.9 Agree that modification of the existing title (“Work with the data to date”) would be an improvement, while still making sure that it is clear that it we are talking about research using this dataset.
MC 1.9 Edited to “Previous research with this dataset”

RC1.10 Page 3 Line 26: A lead in sentence would help here. “These data have proven valuable for the study of a variety of research relevant to the interactions among climate, hydrology, material export and agricultural practices.
AC 1.10Thank you, yes this would improve this paragraph.
MC 1.10 Edited to include a lead in sentence.

RC1.11 Page 3 Line 26: Perhaps “long term” is a phrase that is not required throughout the paper.
AC1.11 You are quite right, we were over-doing it with “long-term”
MC1.11Removed four “long-term”s, where they were not needed.

RC1.12 Page 3 Line 27: Please expand on what each of these studies found.
AC1.12 Agreed, this is good information to include.
MC1.12We have provided information on those studies’ key findings.

RC1.13 Page 4 Line 2: Perhaps rephrase to: “The data have also been used to . . ..”
AC1.13 Agreed
MC1.13Edited the manuscript to this.

RC1.14 Page 4 Line 5: The structure of this paragraph seems to jump all over. Categorize. Perhaps discuss 1) hydrological process studies; 2) effect of different ag practices; 3) material export a) erosion, b) nutrients, c) water quality; and 4) climate change.
AC1.14 Agreed that this paragraph is a little all over the place.
MC1.14 We have edited this paragraph to improve flow.

RC1.15 Page 4 Line 11: Please describe the data and provide numbers. Range, average annual runoff, standard deviations, peaks, annual yields, etc. would all be interesting for the reader.
AC1.15 Agreed.
MC1.15 Edited the manuscript to include runoff statistics describing the data (Table 3).

RC1.16 Page 4 Line 18: How were these heated? The authors should mention that the flumes are inside sheds. Maybe even provide pictures. This all helps people understand how the data were collected.

AC1.16 Agreed, thanks for this suggestion
MC1.16 Edited the manuscript to add information about the sheds and described how they are heated. We have added photos of the outside and inside of one of the sheds (at Hillslope 2).

RC1.17 Page 4 Line 18: "The only event to exceed flume capacity was generated by a heavy rainfall event on 14 June 1964." Please describe explicitly how this gap was filled. The paper needs to stand on its own, and not lean on citations to others that have described the methodologies used to collect the data. That is one of the major points of a data paper. Centralized information.
AC1.17 Thank you, we agree that the estimate data should be included here.
MC1.17 We have added in the estimated data for the total runoff and peak flow during this runoff event, but do not think it is so important to have the methodology for this one estimate included in this paper, therefore we still reference the paper where the data were originally estimated. We have also added information on the sample collection protocols and analysis techniques for the runoff and soil nutrient concentrations.

RC1.18 Page 4 Line 21: Please describe the nutrient export data and provide some plots illustrating the data.
AC1.18 Agreed that this information is lacking and that more figures illustrating the data (not just the runoff data) would be good. However, we have decided against providing additional figures illustrating the data, beyond those for the runoff data. That would be appropriate for a short data set, but the length of this dataset makes it difficult to be interpreted (as we have seen with the runoff figures, which we had to restrict to just one hillslope). More figures would be overkill for this data note, we think. Therefore, we only add more information in the form of statistics, to describe the nutrient export data.
MC1.18 Have added more information about the nutrient concentration data in the section "Runoff nutrient concentrations" and created Table 4 with summary statistics.

RC1.19 Page 5: For each of the datasets, please describe the data and provide illustrations of them Section 4.3: "Snowpack characteristics were measured". . .. Please describe the equipment used during the snow surveys. Did this equipment ever change?
AC1.19 Yes, we agree that more data descriptions are necessary. However, as explained in the previous comment, we have decided against providing additional figures. We will provide more information on the data in the form of statistical summaries.
MC1.19 We have provided more description of the data in the "Snow depth, density and water equivalent", "Soil moisture" and "Soil nutrient concentrations" sections. We have written in information on the snow survey equipment used. We have created more Tables 5-7 with summary statistics.

RC1.20 Page 5 Line 7: "The measurements were taken at the same nine points on each hillslope at which snow traits were measured (Figure 1).
AC1.20 Agreed, this is a good clarification.
MC1.20 Edited the manuscript to that (but used "characteristics" instead of "traits").

RC1.21 Page 5 Line 9: "volumetric soil moisture"
AC1.21Yes
MC1.21 Edited to that.

RC1.22 Page 5 Line 10: What is the soil core method?
AC1.22 Strange use of words there, sorry for the confusion. We mean standard method of bulk density measurement.
MC1.22 Edited the manuscript to describe this.

RC1.23 Section 4.6: Because these are publically available data from an operational national climate network that were not collected by the authors, I do not think they should be included.
AC1.23 We disagree. We are not pretending that these are our collected data. We are merely showing the reader/user of the data the location of the best/most relevant meteorological data that would naturally be have to used in any analysis of the snowmelt- or rainfall-runoff data that we do present.
MC1.23 No changes made.

RC1.24 Page 5 Line 23: There is no description of the agricultural practices data, or it is too brief. This is an important detail, which should be highlighted more with some kind of time series plot.
AC1.24 Agreed. There should be more information on this.
MC1.24 Edited the manuscript to include more detailed description of the crop rotations, tillage management, and machinery used, including a new table (Table 1).

RC1.25 Acknowledgements: Willemijn Appels?
AC1.25 Absolutely, quite right, thank you.
MC1.25 Acknowledgement of Willemijn Appels' contribution.

Figure 2: I am not sure this is the best way to present this data. The short events are really hard to resolve, especially once it gets into a journal. Contours, if you wish to use this kind of plot? Maybe split the x-axis, because nothing ever happens between August and February.
AC 2.18 Thanks for this feedback. Both you and Referee 2 thought the same, and I agree this figure can be much improved.
MC 2.18 Created a new figure to better see the small runoff events: now have two additional figures, one zooming in on spring snowmelt events and another one zooming in on summer events, to better see those events.

RC2: Charles Maule

RC2.1 GENERAL COMMENTS This manuscript presents data for three agricultural fields that were monitored for snowpack characteristics (depth, SWE), pre- freezeup and postmelt soil moisture, daily runoff flows and nutrients, and climate from 1962 to 2011. The fields represent dryland farming in the semi-arid portion of the Canadian Prairies. The data set is unique in that it provides longterm continuous and fairly comprehensive climate, soil, and snowpack data that control snowmelt runoff. This dataset will prove very useful to researchers within snow hydrology and water quality, especially as it represents 50 years of documented data and management methods. With the exception of minor errors the manuscript is well written and structured. The data sets are also well organized and easily accessible.
AC2.1 Thank you for your time reviewing this manuscript. We address your specific comments below.
MC2.1 N/A

SPECIFIC COMMENTS

RC2.2 Should indicate whether or not the plots are still active after 2011. If data is still being collected should be a sentence about updating the data files.
AC2.2 The plots are not currently active, but might be in the future.
MC2.2 Added some lines to say that if regular monitoring of the hillslopes resumes, the data repository will be updated accordingly.

RC2.3 2,25: is any of the sediment data available? The plots were set up to investigate soil erodibility and reported upon by McConkey et al (1997) and Nicholaichuk and Read (1978) (4,1).
AC2.3 Sediment data is not included in this dataset.
MC2.3 Added a line to clarify this.

TECHNICAL CORRECTIONS

RC2.4 1,12: specify what is meant by 'snowpack'?
AC2.4 Thanks, yes, we mean snowpack depth, density and water equivalent.
MC2.4 Edited the manuscript to say that.

RC2.5 1,17: a period is needed between '2011' and 'Gravimetric'.
AC2.5 Done
MC2.5 Done

RC2.6 1,18: are the data sets 'summaries' or the complete data sets?
AC2.6 Thanks for picking that up. Incorrect use of "summarize"! The data sets are complete, and are not summaries.
MC2.6 Edited to "We provide these data" instead of "We summarize these data"

RC2.7 4,10: as the runoff data set reports values as small as 0.01 mm/d with flag indicators of 'good observations', what minimum value is considered measurable flow?
AC2.7 Because the flumes are so small, the minimum measureable instantaneous flow through the flume is 0.07 L. Assuming a reliable reading would need 30 seconds at that flow rate, this translates to a minimum measureable daily flow of 0.000049 mm/day (Hillslope 1), 0.000045 (Hillslope 2) and 0.000043 mm/day (Hillslope 3).
MC2.7 Edited the manuscript to include this information.

RC2.8 4,11: does the "on at least one of the hillslopes" apply to the spring snowmelt as well?
AC2.8 Yes
MC2.8 Edited to clarify that.

RC2.9 3,9-11: reference for the two sentences covering these lines.
AC2.9 Added the reference
MC2.9 Added the reference

RC2.10 4,18: "No runoff was measured during 1970" could be read as no measurable runoff occurred. From the data set it appears that 'The H flumes were not operational (or not measured?) from March 1969 through to end of November 1970 thus no data is reported.' Is this the only instance that the flume was not operational/not measured?
AC2.10 No runoff was measured because the H flumes were not operational, therefore during that period we neither know if runoff occurred nor, if it did, how much runoff there was. That was the only instance of the flumes being non-operational.
MC2.10 Edited the text to clarify that.

RC2.11 4,19: should clarify in the text that the value is reported as NA in the dataset and estimated values can be found in McConkey et al (1997).
AC2.11 Good point, we clarify that.
MC2.11 Edited to clarify that.

RC2.12 4,22: to maintain consistency with data units should use the terms 'nitrate-N', 'ammoniacal-N', and 'phosphate-P'.
AC2.12 Thanks, this is a good point
MC2.12 Edited all references to nutrients in the text to 'nitrate-N', 'ammoniacal-N', and 'phosphate-P'

RC2.13 4,23: Cessna et al (2013) refers to a herbicide paper that has no analysis description of nutrients.
AC2.13 This should be a different paper, sorry for that mistake and thanks for catching it.
MC2.13 We have added the methodology for this, and also the correct reference to the analytical methodology manuscript.

RC2.14 5,6: as fall sample dates also occur in September and November perhaps just state samples taken in fall prior to freezeup and 'in spring following snowmelt' (as samples were also taken in May).
AC2.14 Right, this needs changing.
MC2.14 Edited to "in fall prior to freeze-up (sometime in September-November), and in spring following snowmelt (sometime in April-May).

RC2.15 5,18: as hourly data does not include precipitation or snow depth perhaps reword this sentence so it is clear.
AC2.15 Thank you.

MC2.15 Edited to “These data include daily (1962-present) precipitation (snowfall and rainfall), temperature, wind speed and direction, and snow depth, and hourly (1995-present) temperature, wind speed and direction, and relative humidity.”

RC2.16 6,7: ‘snowpack’ characteristics?
AC2.16 As above, we mean snowpack depth, density and water equivalent
MC2.16 Edited to clarify that here too.

RC2.17 Table 1: hourly meteorology data? To what set of data does the ‘1994-2011+ (ongoing)’ refer to?
AC2.17 Thanks for picking up on that
MC2.17 Edited the daily and hourly data to match the relevant data, as per two comments ago. Also moved the 1994-2011+(ongoing) (corrected to 1995) to match the same line as the hourly data.

RC2.18 Figure 2: some of the light (less than 10 mm) daily runoff values are very difficult to discern. Although it is realized that the figure is for example purposes only it is important to note some of the occurrences of runoff, especially during the warm season. Suggest that the color shading start at a higher value of blue or that two colors are used, not white and/or a note about what value is considered ‘measurable’ on this figure.
AC 2.18 Thanks for this feedback. Both you and Referee 1 thought the same, and I agree this figure can be much improved.
MC 2.18 Created a new figure to better see the small runoff events: now have two additional figures, one zooming in on spring snowmelt events and another one zooming in on summer events, to better see those events.

RC2.19
DATA REVIEW only refers to the English web links, except where noted. 1962-2011 DATA ON SOILS, RUNOFF, AND SNOW. All data was checked for outliers. Phosphate- P: Data: Watershed 1 1991 has values an order of magnitude higher than all other values. Runoff: should mention in the manuscript that daily peak flow values are also available as this information can be very useful. Runoff data: ‘NA’ occurs in the Runoff and Peak columns not the Flag Indicator column. The flag for the ‘NA’ values is ‘m’. Snow Water Equivalent: snow Density units are listed as ‘Mg/cm3’. Should be ‘g/cm3’ according to the format given in the data file. French version ‘mg/cm3’ should also be ‘g/cm3’. Soil Moisture Content: depths are wrong for d60_d90 and d90_d120. Ok for French version. Within dataset some values for the deeper intervals are very low (for soils with clay contents greater than 20%) and must be due to sand pockets. Soil Nitrate Phosphorus: Dictionary: Depth intervals, some errors in both English and French versions. Soil Nutrients: English Dictionary: French version comes up. Soil Nutrients Dataset: years and depth should be in same format of other soil files (eg Soil_Nitrate_Phosphorous). Watershed Management: Dictionary: System, n is missing from word ‘rotation’. Watershed Management Data: under ‘System’ Column there is ‘wheat-GM fallow’. This should be ‘wheat-green manure fallow’ according to the Dictionary and to the ‘Management Systems Details’ data set. Some cells are lacking information where it is expected; for example: Column D (Previous Crop) rows 33, 127-133; Column E rows 51, 99, 151. METEOROLOGICAL DATA. Dates of start and finish and parameters were noted for daily and hourly data. Data was only spot reviewed. No issues were noted. DIGITAL ELEVATION DATA. The description and README.txt file was read. Data was not reviewed. Description file ; 2nd last sentence; “(random toughness)”?
AC2.19 Thank you for also taking the time to review the datasets, and for picking up on those errors and queries. The datasets are published separately to this data note (they have their own dois), therefore corrections to the datasets are via a separate process. We will contact Agriculture and Agri-food Canada to undertake the corrections; it will take some time. This corrections will include: correcting Phosphate-P data, correcting the snow density units, correcting the soil moisture content depth intervals, correcting the errors in the depth intervals of the soil nutrients, correcting the link to the soil nutrients English dictionary, ensuring consistency in depth and year formats between files, correcting spelling mistakes, and ensuring data or missing data notations are in all cells.

MC2.19 In this data note manuscript, we have added information in the Runoff section of the manuscript referring to the daily peak flow values that are available in the dataset. We have also described that missing data for runoff and peak runoff are shown by an NA, and that missing data is flagged with an ‘m’.

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 nutrient concentrations~~s~~ are rare—on ~~seasonally~~ 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 depth, density and water equivalent, soil moisture, and soil nutrient concentration were monitored on the three 5 ha hillslopes over a 50-year period (1962 – 2011). Digital elevation data are available for the three hillslopes at a 2 m horizontal resolution, and, for one of the hillslopes (Hillslope 2), at a 0.25 m horizontal resolution. Runoff from the hillslopes was generated episodically during snowmelt and occasional rainfall events. ~~Edge-of-field~~Hillslope runoff was measured with a 0.61 m H-flume. Daily runoff nutrient concentration data are available for nitrate-N (March 1971 – April 2011), ammoniacal-N~~um~~ (February 1996 – April 2011), and ~~orthophosphate~~ phosphate-P (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~~ provide 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~~.~~ (Coles et al., 2018b). 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-term experimental datasets that do exist in such regions are diminishing quickly (Laudon et al., 2017). ~~However, f~~For hillslope-scale long-term experiments over seasonally-frozen ground, such records are particularly~~, to our knowledge, non-existent~~ uncommon. Here we present an unusually-long ~~-~~50-year record for a set of three monitored agricultural hillslopes in southwest Saskatchewan, Canada that includes runoff, runoff nutrients, snowpack, soil moisture, and 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 in dry agroecosystems, 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 (also referred to as 'watersheds' in the dataset) 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~~ hillslopes 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 (Coles et al., 2018b). These DEMs were obtained by mounting the Leica Viva GS15 rover to a side-by-side vehicle at a height of 2 m above ground surface. The vehicle was driven methodically up and down each hillslope, achieving full coverage of each hillslope (Coles et al., 2018b). The GPS was set to automatically collect points every two meters and at instances when the elevation change exceeded 0.15 meters (Coles et al., 2018b). The survey was referenced to a permanent Agriculture and Agri-food Canada benchmark located near to the hillslopes, to give elevations in meters above sea level. Location data for these DEMs are in the projected coordinate system UTM Zone 13N with GRS 1980 datum. 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 (Coles et al., 2018b). 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~~ topography~~on the hillslope~~. These DEMs were obtained by mounting the laser scanner at the top of a 15 ft scaffolding tower located on the east margin of Hillslope 2, and also from the top of a vehicle parked in the northeast corner of the hillslope. The elevation data are relative elevations (not absolute elevations). Location data for these DEMs are in the projected coordinate system UTM Zone 13N with GRS 1984 datum. Additional information on the generation of the 2 m and 0.25 m DEMs can be found in Coles et al. (2018b).

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} (Coles and McDonnell, 2018).~~.~~ 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 predominantly under an annual rotation of wheat (*Triticum aestivum* L.) and fallow (Table 1). 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.) without use of herbicides or mineral

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fertilizers 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 largely been under ~~largely~~ conventional tillage practice with a heavy-duty cultivator.~~,~~ with the exception of the period 1993-2011 when Hillslope 2 was switched to ~~zero~~ no tillage practice, with weed control entirely with herbicides.~~.~~ ~~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~~to 2011, runoff, runoff nutrient concentration, snowpack characteristics, soil moisture, and soil nutrient concentration ~~have been~~were monitored on the hillslopes. The year 2011 marked the final year of regular monitoring of the hillslopes by the Swift Current Research and Development Centre of Agriculture and Agri-food Canada. In 2013 and 2014, monitoring of runoff, snowpack characteristics and soil moisture was undertaken in collaboration with the University of Saskatchewan; these data are presented separately (Appels et al., 2017; Coles and McDonnell, 2018). If regular monitoring of the hillslopes resumes, the data repository will be updated accordingly. -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~~Previous research with this dataset

These data have proven valuable for the study of a variety of research questions related to the interactions between agricultural practices, climate, hydrology, and nutrient export. ~~The long-term data from the hillslopes have so far been used to investigate~~Studying the effects of agricultural practices on nutrient export and water quality, Nicholaichuk and Read (1978) showed guideline-exceeding N and P concentrations in runoff from unfertilized hillslopes. Schneider et al. (2019) used the long-term data set to show that the conversion to no-till farming caused an increase in snowmelt-runoff, which subsequently increased nutrient exports. Cessna et al. (2013) found an increased amount of herbicide exported in runoff from conservation tillage hillslopes, due to the increased use of herbicides. McConkey et al. (1997) showed that soil erosion was greatest in April during snowmelt-runoff events over partially-frozen soil, and that erosion occurring during rainfall-runoff events was relatively unimportant. Hydrological process studies at this site include Coles et al. (2018a), who explored the hierarchies of importance of various controls on snowmelt-runoff generation. Appels et al. (2017) and Coles and McDonnell (2018) used single melt season intensive data collection to quantify the spatial patterns of hydrological variables and the generation of snowmelt-runoff connectivity over low-angled terrain. Finally, climate change studies at this site have shown warming winter and spring temperatures, decreasing snowfall amounts and a resultant decrease in snowmelt-runoff amounts, earlier spring runoff timing, and an increase in summer rainfall amounts but no change in rainfall-driven runoff (Cutforth et al., 1999; Coles et al., 2017). ~~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).

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4 Available data series

The available data are summarized in Table 21 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 (on at least one of the hillslopes) and 28 years saw measureable hillslope-scale runoff during non-melt rainfall-runoff events (also on at least one of the hillslopes). Because the flumes are so small, the minimum measureable instantaneous flow through the flume is 0.07 L. Assuming a reliable reading would need 30 seconds at that flow rate, this translates to a minimum measureable daily flow of 0.000049 mm/day (Hillslope 1), 0.000045 (Hillslope 2) and 0.000043 mm/day (Hillslope 3). The dataset includes data on daily runoff (mm) and daily peak flow (L s^{-1}). Any missing data are shown by an NA and also flagged with an ‘m’.

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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. Prior to 1993, the flumes were in the open and heated with propane-fueled heaters under the flumes. After 1993, the flume sides and bottoms were electrically heated with resistance heaters and the flumes were in a small building that was also electrically heated (Figure 3).– There is no runoff data fFrom March 1969 to November 1970 as ,the flumes were not operational monitored. Therefore, we do not have runoff data for that period. No runoff was measured during 1970. A heavy rainfall event on 14 June 1964 caused flow rates to exceed the flume capacity. Runoff during this event is reported as NA in the dataset, but total daily runoff was estimated to be

~~values~~ 72 mm with a peak flow of 60 mm h^{-1} ~~(can be found in~~ , ~~and the runoff for that event was subsequently estimated by~~ McConkey et al., ~~(~~1997). Table 3 provides a summary of the runoff statistics.

4.2 Runoff nutrient concentrations

Nutrient concentrations in the runoff were measured on a daily basis during runoff events, from runoff samples taken from the flume at the downstream outlet of each hillslope. Concentration data (in mg L^{-1}) are available for nitrate-N (1971-2011), ~~ammonium~~ ammoniacal-N (1996-2011), and ortho~~orthophosphate~~ phosphate-P (1971; 1991-2011).

Prior to 1993, on days with appreciable runoff, water samples were collected manually in 0.5-L glass containers at mid-morning (10:00 h ± 30 min) and mid-afternoon (15:00 h ± 30 min).- -From 1993 onward, 0.5 L samples were collected using an automated water sampler (ISCO 3700 Portable Sampler, Isco, Inc.), previously described by Cessna et al. (2013).~~Sample collection protocols and quantification methodologies are described in Cessna et al. (2013).~~ The collected water samples were filtered (No. 42, Whatman International filter papers, Maidstone, England) and then analyzed for dissolved NO_3-N and orthophosphate-P according to the analytical procedure of Hamm et al. (1970) and for ammonium-nitrogen (NH_4-N) according the analytical procedure of ~~(~~Gentry and Willis (~~,~~1988). The runoff nutrient concentration data are summarised in Table 4.

4.3 Snow depth, density, and water equivalent

Snowpack data were determined for each hillslope by manual snow surveys each year between 1965 and 2011. At nine points on each hillslope (as shown in Figure 1), an average s~~S~~now depth (cm) was determined from multiple locations in the close vicinity of the point with a graduated rod and ~~and~~ density (g cm^{-3}) was measured once per point as the mass of snow of measured depth taken in in a 7.5-cm diameter core; the mass was determined in the field with a calibrated spring scale. ~~-were measured, and~~ The snow water equivalent (SWE; cm) was calculated from average snow depth ~~times~~multiplied by density.~~, 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. These data are summarised in Table 5.

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~~fall~~,~~ prior to freeze-up (sometime in September-November), and in ~~April~~spring~~,~~ following ~~spring~~ snowmelt (sometime in April-May). The measurements were taken at the same nine points on each hillslope at which snow characteristics were measured (Figure 1), at five depth intervals per point: 0-

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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 a volumetric basissoil moisture using average bulk density across the hillslopes derived from occasional measurements from mass of soil taken in by the soil cores of a known volume and depth method. These bulk densities 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. Soil moisture data in the dataset are reported in cm of water for each soil profile depth interval. A summary of the soil moisture aggregated over the entire 0-120 cm soil profile is presented in Table 6.

4.5 Soil nutrient concentrations

A subsample from the same -samples collected for soil moisture in fall and spring was air-dried and analyzed for NO_3-N (1970-1992; 1994-2010), bicarbonate-extractable (Olsen) P (1970-1992; 1994-2010), and ammoniacal-N (1970-1992) and bicarbonate-extractable (Olsen) P (Hamm et al., 1970). Data are reported in the dataset in units of concentration (mg L^{-1}) and mass (kg ha^{-1}). A summary of the fall soil nutrient concentration data is presented in Table 7.

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4.6 Meteorology

To complement the hillslope data, meteorological data are available from the Environment and Climate Change Canada 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) precipitation (snowfall and rainfall), temperature, wind speed and direction, and snow depth, and hourly (1995-present) temperature, wind speed and direction, and relative humidity 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 concentrations, snowpack, soil moisture, soil nutrient concentrations, and crop and tillage data. Herbicide and sediment concentration data are not included in this dataset. In addition to this, wWe have also 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~~nutrient concentrations, snowpack depth, density and water equivalent, soil moisture, ~~and~~ soil ~~chemistry~~nutrient concentrations, and crop and tillage data. Digital elevation data are also available for the three hillslopes at a 2 m horizontal resolution, and, for one of the hillslopes (Hillslope 2), at a 0.25 m horizontal resolution. 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.

Acknowledgements

This hillslope dataset exists thanks to the hard work of many Agriculture and Agri-food Canada researchers, technicians, and students over the last six decades. Don Reimer and Marty Peru are thanked especially for their dedicated technical service to the hillslopes from 1971 to 1994, and from 1995 to 2011, respectively. We thank Warren Helgason, Michael Solohub and Amber Peterson (University of Saskatchewan) and Mark Russell, Cuyler Onclin, and Samson Mengistu (Environment and Climate Change Canada) for their surveying efforts to create the DEMs.~~.~~ We thank Willemijn Appels for her contributions to the dataset, and Chris Spence and Charles Maule for their earlier reviews of this manuscript.

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~~F~~Figures and tables

Table 1. Crop rotation† (and tillage) history of the three hillslopes.

Time Period	Hillslope 1	Hillslope 2	Hillslope 3
1962-1976	F-W (blade and conv‡ till)	W-F (blade and conv till)	F-W (disc and conv till)
1977-1980	Unfertilized grass for hay (no-till)	Unfertilized grass for hay (no-till)	F-W (disc and conv till)
1981-1986	F-W-W-W-W-F (conv till and cultivator)	F-W-W-W-W-F (conv till and cultivator)	F-W (conv till and cultivator)
1987-1992§	W-F (conv till and cultivator)	W-F (conv till and cultivator)	W-F (conv till and cultivator)
1993-2002¶	W-GM (conv till and incorporated)	W-F (no-till)	W-F (conv till and cultivator)
2003-2011	W-GM (conv till and incorporated)	W-LP (no-till)	W-F (conv till and cultivator)

†F - fallow, W - spring wheat (*Triticum aestivum* L.), grass (*Psathyrostachys juncea* (Fisch.) Nevski), GM - green manure chickling vetch (*Lathyrus sativus*), LP - pulse crop, lentil (*Lens culinaris* L.) or field pea (*Pisum sativum* L.) in alternating pulse crop years,
‡conv till – conventional tillage with cultivator including harrows or rod-weeder used in last operation before seeding with hoe drill.

Table 2~~1~~. Summary of data available and years recorded.

Data	**Years**
Runoff	
- ~~daily~~ Daily total (mm)	- 1962-1969; 1971-2011
- ~~daily~~ Daily peak flow (L s^{-1})	- 1962-1969; 1971-2011

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Runoff nutrient concentrations (mg L^{-1})	
- NitrateNitrate-N (NO_3-N)	- 1971-2011
- ammonium Ammoniacal-N (NH_4-N)	- 1996-2011
- oOrthoorthophosphate phosphate-P (PO_4^{3-})	- 1971; 1991-2011
- sediment	- 1971-2011 (1971-1993 = occasional; 1994-2011 = almost continuous)
Snowpack	
- Depthdepth (cm)	- 1965-2011 (1-6 surveys per year)
- Densitydensity (mg cm^{-3})	- 1965-2011 (1-6 surveys per year)
- snow water equivalent (cm)	- 1965-2011 (1-6 surveys per year)
Soil moisture content (cm)	
- 0-15, 15-30, 30-60, 60-90, 90-120 cm	- 1971-2011 (April and October)
Soil nutrient (NO_3-NN, NH_4-N, –and PO_4^{3-}P) concentrations (mg L^{-1}):	
- 0-15 cm	- 1970-1992 (April and October)
- 0-15, 15-30, 30-60, 60-90, 90-120 cm	- 1993-2010 (April and October) (NO_3-N and PO_4^{3-} only)
- Crop type and management	- 1962-2011
Meteorology (ECCC data):	
- daily: maximum temperature, minimum temperature, rain, snow, precipitation, snow on ground depth on ground, wind speed and direction	- 1962-2011+ (ongoing)
- hourly: temperature, dew point, relative humidity, wind speed and direction, wind speed	- 199554-2011+ (ongoing)

Table 3. Statistical summary of runoff data.

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	Hillslope 1	Hillslope 2	Hillslope 3
Mean annual runoff (mm)	25.4 ± 33.9	34.9 ± 38.9	20.5 ± 21.8
Maximum daily runoff (mm)			
- Annual (Jan-Dec)	45.2 (9 Apr 1965)	48.7 (25 Feb 1986)	28.5 (11 Apr 1974)
- Spring (Feb-Apr)	45.2 (9 Apr 1965)	48.7 (25 Feb 1986)	28.5 (11 Apr 1974)
- Summer (Jun-Aug)	8.9 (16 June 1995)	12.1 (1 July 1982)	9.2 (3 Jun 1976)
Mean (± std) daily runoff (mm)			
- Annual (Jan-Dec)	0.07 ± 0.93	0.10 ± 1.14	0.06 ± 0.69
- Freshet (Feb-Apr)	0.26 ± 1.81	0.37 ± 2.21	0.21 ± 1.30
- Summer (Jun-Aug)	0.01 ± 0.22	0.01 ± 0.24	0.02 ± 0.33
Maximum daily peak flow (L s^{-1})			
- Annual (Jan-Dec)	119.2 (1 Jul 1982)	233.3 (1 Jul 1982)	132.2 (1 Jul 1982)
- Freshet (Feb-Apr)	85.8 (8 Apr 1965)	115.3 (9 Apr 1965)	64.00 (11 Apr 1974)
- Summer (Jun-Aug)	119.2 (1 Jul 1982)	233.3 (1 Jul 1982)	132.2 (1 Jul 1982)
Mean (± std) daily peak flow (L s^{-1})			
- Annual (Jan-Dec)	0.17 ± 2.30	0.25 ± 3.29	0.19 ± 2.60
- Spring (Feb-Apr)	0.55 ± 3.71	0.79 ± 4.99	0.50 ± 3.27
- Summer (Jun-Aug)	0.12 ± 2.55	0.20 ± 4.20	0.22 ± 3.86

Table 4: Statistical summary of runoff nutrient concentration data.

	Hillslope 1	Hillslope 2	Hillslope 3
Nitrate-N (NO_3-N) (mg L^{-1})			
- Minimum	0.01 (16 Mar 1975)	0.01 (16 Mar 1975)	0.0 (12 Mar 1996)
- Maximum	9.9 (17 Mar 2011)	8.1 (22 Mar 2011)	5.7 (18 Mar 2011)
- Mean ± std	1.29 ± 1.62	0.76 ± 0.95	0.95 ± 1.12
Ammoniacal-N (NH_4-N) (mg L^{-1})			
- Minimum	0.0 (12 Mar 1996)	0.0 (12 Mar 1996)	0.0 (11 Mar 1996)
- Maximum	4.6 (23 Mar 2006)	4.5 (4 Feb 2005)	3.3 (1 Feb 2005)

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- Mean ± std	0.44 ± 0.81	0.39 ± 0.57	0.30 ± 0.52
Orthophosphate-P (PO_4^{3-}) (mg L^{-1})			
- Minimum	0.0 (21 Feb 1996)	0.0 (20 Feb 1996)	0.0 (22 Feb 1996)
- Maximum	11.8 (24 Jun 1991)	1.7 (22 Jul 2004)	1.5 (15 Mar 2011)
- Mean ± std	0.52 ± 1.51	0.26 ± 0.24	0.30 ± 0.25

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Table 5: Statistical summary of hillslope-averaged snowpack data (only using data from the last survey before the end of winter).

	Hillslope 1	**Hillslope 2**	**Hillslope 3**
Snowpack depth (cm)			
- Minimum	0.0 (1968, 1970)	0.0 (1970)	0.0 (multiple)
- Maximum	38.4 (1978)	37.8 (1978)	27.9 (1967)
- Mean ± std	12.4 ± 8.06	15.3 ± 8.09	11.0 ± 7.68
-			
Density (g cm^{-3})			
- Minimum	0.0 (1970)	0.0 (1968, 1970)	0.0 (multiple)

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- Maximum	0.45 (1966)	0.4 (1969, 1971)	0.4 (1966)
- Mean ± std	0.25 ± 0.09	0.25 ± 0.09	0.24 ± 0.09
Snow water equivalent (cm)			
- Minimum	0.0 (1968, 1970)	0.0 (1968, 1970)	0.0 (multiple)
- Maximum	11.5 (1978)	12.1 (1978)	7.81 (1967)
- Mean ± std	3.20 ± 2.46	4.19 ± 2.74	2.78 ± 2.07

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Table 6: Statistical summary of soil moisture data (for simplicity, data are aggregated over the five depth intervals and presented for the entire 0-120 cm soil profile, however data are recorded separately by depth interval in the dataset).

	Hillslope 1	**Hillslope 2**	**Hillslope 3**
Fall soil moisture (cm)			
- Minimum	7.77 (2005)	9.48 (2004)	7.23 (2005)
- Maximum	37.7 (1993)	32.6 (1996)	33.2 (1992)
- Mean ± std	20.4 ± 5.72	20.6 ± 6.27	22.1 ± 5.81
-			
Spring soil moisture (cm)			

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- Minimum	7.87 (2008)	11.1 (2008)	10.2 (2008)
- Maximum	34.6 (1995)	40.8 (1995)	36.8 (1997)
- Mean ± std	22.1 ± 4.88	22.8 ± 5.53	23.6 ± 4.61

Table 7: Statistical summary of soil nutrient concentration data.

	Hillslope 1	**Hillslope 2**	**Hillslope 3**
Nitrate-N (NO_3-N) (mg L^{-1})			
- Minimum	0.4 (1995)	0.25 (1997)	0.25 (1997)
- Maximum	19.0 (1981, 1982)	17.7 (2009)	23.0 (1971)
- Mean ± std	4.44 ± 3.86	3.52 ± 3.50	3.36 ± 3.44
Ammoniacal-N (NH_4-N) (mg L^{-1})			
- Minimum	3.32 (1974)	4.07 (1981, 1982)	4.12 (1974)
- Maximum	10.4 (1984)	11.5 (1984)	14.2 (1971)
- Mean ± std	5.61 ± 2.12	5.91 ± 2.47	6.79 ± 3.44
Orthophosphate-P (PO_4^{3-}) (mg L^{-1})			
- Minimum	0.55 (2004)	0.32 (2004)	0.64 (1997)
- Maximum	15.1 (1989)	23.0 (2009)	22.6 (1971)
- Mean ± std	5.76 ± 4.37	6.22 ± 5.83	6.98 ± 3.44

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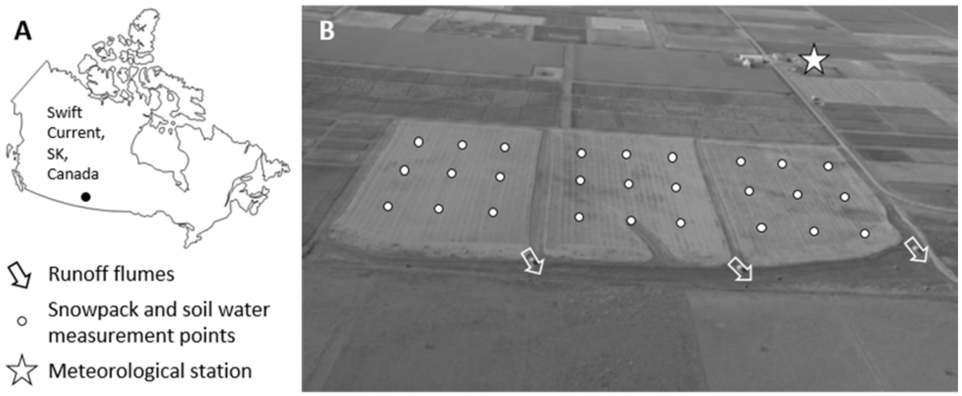

Figure 1: A) Location of the Swift Current hillslopes in Canada. B) Aerial photograph (facing south) of the Swift Current hillslopes (from right to left: Hillslope 1, Hillslope 2, Hillslope 3), taken in a year when wheat was grown. The runoff flumes, measurement locations for snowpack and soil moisture,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

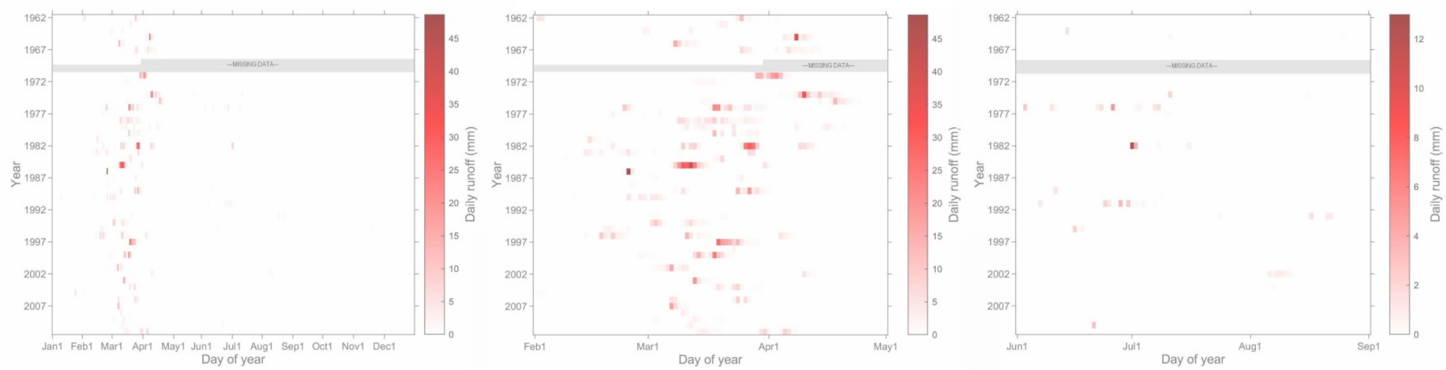

Figure 2: Daily runoff (mm) for the 50-year period (January 1st 1962 to December 31st 2011) on Hillslope 2.

5 Figure 3: Photographs of the runoff shed at Hillslope 2. A) Facing east, at the inflow side of the shed (taken March 2014). B) Facing south, at the outflow side of the shed (taken March 2014). C) Inside the shed, showing a 0.61m H flume, a Stevens water level chart recorder, and an automated ISCO 3700 Portable Sampler.

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