A Fellow Speaks: Pursuing Snow to Advance Canadian Hydrology

John W. Pomeroy, (Centre for Hydrology, University of Saskatchewan, Canada)

It is a rare honour to be elected a Fellow by the AGU for hydrological research conducted primarily in Canada and it is my hope that this reflects positively not only on the growing capacity of "Canadian Hydrology" but on increased international recognition of the accomplishments of Canadian hydrologists. With many traits shared with the circumpolar, high altitude and temperate world, Canadian hydrology is distinctive due to long winters dominated by snow and ice processes followed by a rapid spring snowmelt freshet. Runoff is impeded by the tremendous storage capacities of poorly-drained post-glacial landscapes, causing dramatic variation in runoff contributing areas. This is in addition to the temperate zone hydrological phenomena that prevail in summer and fall. Add to this mix our vast river basins and an incredibly low density of both observations and hydrologists and one has a science that is full of excitement, adventure and great challenges. It is an environment that demands collaboration and it is not uncommon for a small team of Canadian hydrologists to be investigating an area equivalent to that of a small to moderate sized European country or US state. It is in this context that my colleagues, students and I have tried to make contributions to hydrology.

My early research was as a student of Professors Donald Gray and David Male in the Division of Hydrology at the University of Saskatchewan studying snow redistribution, sublimation and melt (Gray et al., 1988; Pomeroy and Gray, 1990, Pomeroy and Male, 1992). The seasonal snowmelt provides over 80% of annual runoff in the Canadian Prairies and while its melt rate is governed by spring energetics, the melt volume and areal depletion are governed by wind redistribution. After developing a device to measure it (Pomeroy and Male, 1988; Brown and Pomeroy, 1989), we found that mass fluxes from blowing snow transport exceeded prairie agricultural runoff, did not heed catchment drainage divides, could be managed by retaining crop stubble or wooded shelterbelts, and that in-transit sublimation could return over one-third of seasonal snowfall to the atmosphere, reducing snowmelt volumes proportionately (Pomeroy and Gray, 1995). This understanding resulted in the Prairie Blowing Snow Model (PBSM), the first of its kind (Fig. 1, Pomeroy et al., 1993). PBSM or its parts have been included in other models (e.g. Bowling et al., 2004; Gelfan et al., 2004) and has been fully distributed (Essery et al., 1999).

The Division of Hydrology conducted some of the earliest Canadian hydrology research and emphasised rigorous physics-based field and modelling studies. High demands were placed on us there because of the challenges we faced – every known hydrological model had been shown to fail in the Canadian Prairies due to their inappropriate conceptual and physical basis for application in a sparsely-gauged semi-arid cold region, and so the Division advanced cold regions instrumentation, process understanding, physically-based algorithms and modelling and eventually attracted Environment Canada's National Hydrology Research Institute (NHRI) from Ottawa to Saskatoon.

Since 'running back to Saskatoon' is more than just a song to me, most of my career has been based there with either the University of Saskatchewan or Environment Canada. However, research on cold regions does not always need to be conducted from a cold region and I was fortunate to have stints with the US Forest Service Rocky Mountain Forest and Range Research Station in the USA and the University of East Anglia School of Environmental Sciences in England under the supervision of Dr. R.A. Schmidt and Professor Trevor Davies respectively. This led to research on forest hydrology and snow chemistry (Pomeroy and Schmidt, 1993; Pomeroy et al., 1991) that I sustained when later appointed to NHRI. One could not ask for a better institution than NHRI in its prime because of strong funding support, well-fitted laboratories in a new building and talented colleagues to work with. Our research on arctic, subarctic, boreal forest and prairie hydrology, improvements to land surface schemes and snow ecology led to an improved understanding of importance of snow interception and sublimation by evergreen forest canopies (Fig. 2, Hedstrom and Pomeroy, 1998; Pomeroy et al., 1998a), forest modification of the energy balance (Harding and Pomeroy, 1996; Pomeroy and Granger, 1997), the impact of boreal forest disturbance on hydrology (Granger and Pomeroy, 1997; Elliot et al., 1998; Pomeroy et al., 1997; 1999), snow chemistry (Pomeroy and Jones, 1996; Jones et al., 1999; Marsh and Pomeroy, 1999; Pomeroy et al., 1999), snow-atmospheric fluxes (Marsh and Pomeroy, 1996; Pomeroy et al., 1998b; Pomeroy and Essery, 1999) and snow ecosystems (Jones et al., 2001). In support of GEWEX, we instrumented basins in the arctic-taiga transition north of Inuvik, NWT (Trail Valley Creek); a mountain sub-arctic basin in the Yukon Territory (Wolf Creek), the Saskatchewan boreal forest (Prince Albert Model Forest) and the university's Kernan Crop Research Farm just outside of Saskatoon for snow process studies and model testing. With these research basins we could now better estimate, upscale and model snow redistribution (Pomeroy et al., 1997; Li and Pomeroy, 1997; Pomeroy and Li, 2000), snow interception (Pomeroy et al., 2002), and ablation and frozen soil infiltration in complex terrain and vegetated basins (Faria et al., 2000; Gray et al., 2001; Pomeroy et al., 2003).

The demise of NHRI in the late 1990s led to migration with my brave family to a lecturing post which turned into a personal chair at the University of Wales, Aberystwyth on the beautiful west coast of Wales. It was an excellent opportunity to learn the Welsh language. With support of colleagues at "Aber", we built strong collaborations with US and at "Aber", we built strong collaborations with US and UK government laboratories to study snow-vegetation atmospheric and hydrological interactions along a mountain transect from Colorado to the Yukon. This permitted detailed investigations of snow cover depletion (Pomeroy et al., 2004; Essery and Pomeroy, 2004), shrub tundra impacts on snow (Pomeroy et al., 2006, Bewley et al., 2007), radiation inputs (Hardy et al., 2004; Sicart et al., 2004, Essery et al., 2008; Pomeroy et al., 2008, 2009) and snowmelt modelling (Marks et al., 2008; Reba et al., 2012).

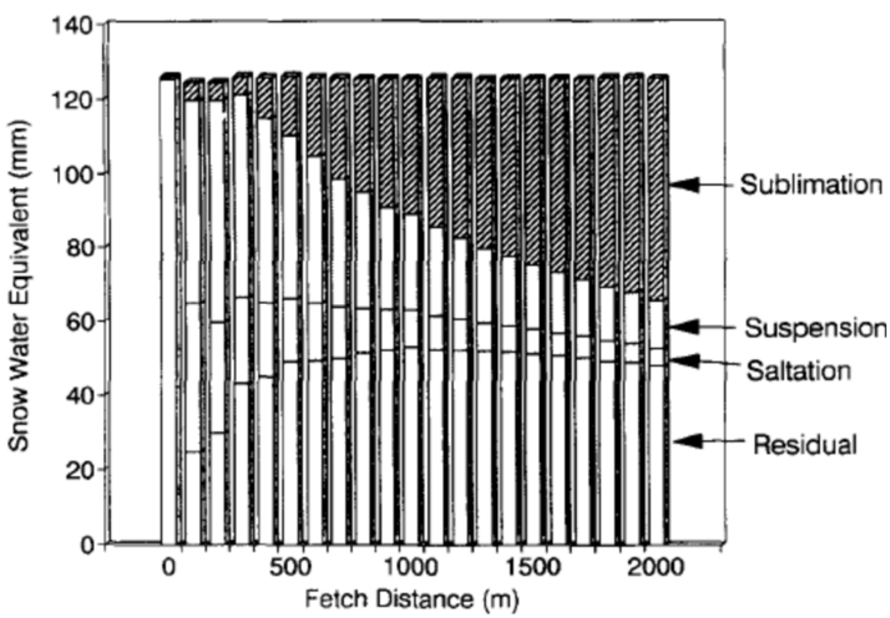

Figure 1. Cross-sectional view of the Prairie Blowing Snow Model applied to sequential control volumes along a fetch, showing annual quantities of snow eroded and then sublimated in-transit, or transported via saltation and suspension. Residual is the remaining premelt surface snowpack. Adapted from Pomeroy et al. (1993).

Since appointment in 2003 as the Canada Research Chair in Water Resources and Climate Change to anchor a new Centre for Hydrology at the University of Saskatchewan, I have worked with colleagues and students to re-instrument the venerable Marmot Creek Research Basin in the Canadian Rockies and upscale this to the Canadian Rockies Hydrological Observatory, based from the Coldwater Laboratory in the spectacular Kananaskis Valley. We instrumented a prairie wetland basin, Smith Creek, in eastern Saskatchewan - an area of dramatically increased streamflows, increased rainfall and wetland drainage. Research on how climate change impacts northern hydrology has revitalized Wolf Creek Research Basin as part of the International Polar Year. The Centre for Hydrology (www.usask.ca/hydrology) includes government hydrologists as well as academics and students, has recently led two national research networks on cold regions hydrology and Prairie droughts and an international hydrological decade and contributes to the University of Saskatchewan Global Institute for Water Security which hosts a national network on changing cold regions hydrology and North America's only GEWEX experiment.

At Wolf Creek our observations have shown an increase in tundra shrub height and with models have highlighted the changing role of snow redistribution, variable melt and permafrost soils in generating streamflow (Quinton et al., 2005; Zhang et al., 2010; Bewley et al., 2010; Menard et al., 2013). In Marmot Creek we have focussed on snow redistribution, interception and melt energetics, showing substantial sublimation from alpine blowing snow, importance of slope/aspect and internal energy on snowcover depletion and effects of advected turbulence on convective heat transfer in mountain valleys (DeBeer and Pomeroy, 2010; MacDonald et al., 2010; Helgason and Pomeroy, 2012). Mountain slope and aspect impact radiative transfer (Marsh et al., 2012) to control the influence of small forest clearings on melt rate in forests, with accelerated melt on south facing slopes and retarded melt on north facing slopes (Pomeroy et al., 2009, Ellis et al., 2011, 2013). Sublimation of intercepted snow reduced snow accumulation by half (Pomeroy et al., 2012). Hydrological responses to forest disturbance were moderated in Marmot Creek by desynchronization of melt timing

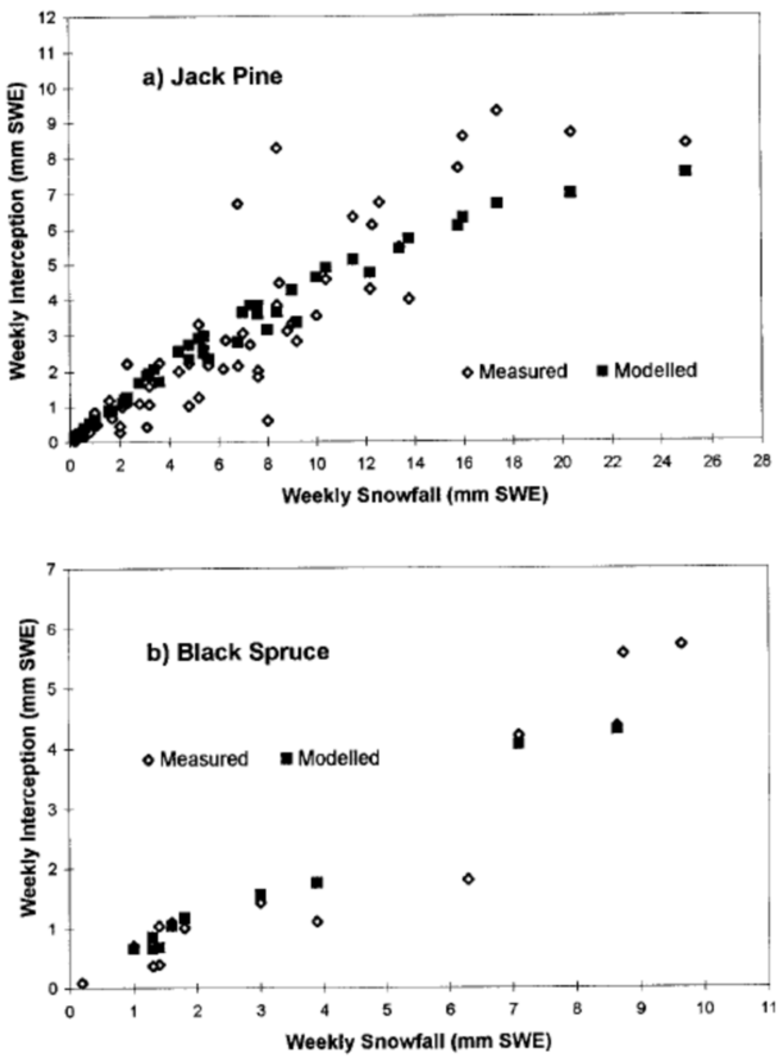

Figure 2. Modelled and measured snow interception against measured snowfall in two boreal forest stands. Adapted from Hedstrom and Pomeroy (1998).

(Pomeroy et al., 2012). Observations of a large rain-on-snow flood in Marmot Creek in June 2013 are driving the next phase of research.

In the Canadian Prairies, modelling based on studies of blowing snow, melt, evapotranspiration, and infiltration to frozen soils and long term observations of increasing rain/snow proportion and increasing multiple day precipitation events has documented unmeasured turbulent heat fluxes to snow, hydrological drought development and demonstrated a multi-year hydrological memory caused by depressional storage due to hysteresis between depressional storage and contributing area (Helgason and Pomeroy, 2012; Fang and Pomeroy, 2008; Armstrong et al., 2010; Shook and Pomeroy, 2011, 2013). A comprehensive model of prairie hydrology including simple wetland dynamics has been developed (Fang et al., 2010) and used to evaluate the impact of wetland drainage in Smith Creek, Saskatchewan (Pomeroy et al., 2010). Drainage or restoration substantially altered discharge rates and long term flow volumes. Recent research is seeking to understand the role of wetland drainage and climate change in the widespread prairie flooding of 2011.

The Snow Acoustic Sounding System (SAS2) is an acoustic reflectometry device based on a new theory of snow thermo-acoustics that is capable of observing the depth, density, wetness, temperature and structural properties of a snowpack without invasive measurements (Kinar and Pomeroy, 2009). It is expected that this device will improve the performance of cold regions hydrological modelling and flood forecasting.

Frustration with repeated hydrological model failure in Canada due to weak physical or inappropriate temperate zone conceptual bases led to the development of the Cold Regions Hydrological Modelling platform (CRHM) with former Division of Hydrology hydrological modeller, Tom Brown as the CRHM programmer. CRHM is a flexible, modular, physically-based model that simulates hydrological processes for a wide range of environments (Pomeroy et al., 2007; Dornes et al., 2008; Fang and Pomeroy, 2009; Ellis et al., 2010). Outside of Canada, it has been tested successfully in Spain, China, Chile, and Germany (Lopez Moreno et al., 2012; Zhou et al., 2014). It has been developed as the core of an ensemble flood forecast system for the 51,000 km^2 Smoky River basin, Alberta (Pomeroy et al., 2013). Its algorithms support improvements to Environment Canada's MESH large scale model (Dornes et al., 2009). Recent developments include improved precipitation phase discrimination (Harder and Pomeroy, 2013) and multi-objective evaluation of uncalibrated prairie and mountain hydrological models derived from CRHM (Fang et al., 2010, 2013). CRHM is a contribution to the IAHS Decade on Prediction in Ungauged Basins (PUB), and demonstrates my fundamental philosophy – that predictive uncertainty can be reduced by improving our understanding of hydrological processes and basin function and reflecting this in physically-based algorithms applied in an appropriate model structure.

References can be found at http://www.usask.ca/hydrology/Pubs.php .