Prairie HYdrology Design and Analysis Product (PHYDAP)

The purpose of the Prairie HYdrology Design and Analysis Product (PHYDAP) is to provide users with robust data with which to design and analyze water engineering infrastructure affected by Canadian Prairie runoff from small drainage basins. The long time series of the product allows for the calculation of the frequency of different annual runoff magnitudes. The product also includes data that demonstrate how this frequency may change with alternate climate and wetland distribution. The product is available in formats that allow it to be used in conjunction with several common hydraulic modelling platforms. With site-specific hydraulic information (e.g., elevation, infrastructure design), this can facilitate the estimation of changes in runoff and flooding at specific locations.

Background

PHYDAP addresses a crucial data and information gap. There are no tools or data products available for hydraulic design and analysis that have been developed for the unique challenges of Canadian Prairie drainage basins. Runoff frequency and magnitude estimates used to design Canadian Prairie infrastructure are commonly estimated from historical streamflow gauge records. Applying this method has four key disadvantages on the Canadian Prairies.

1. Large rivers such as the Saskatchewan River and its tributaries derive much of their flow from the Canadian Rockies and foothills and so their flow records cannot be used to estimate prairie runoff.
2. The very low density of stream gauges measuring prairie drainage basins in the region means it is difficult to find a gauge which is both near the site of interest, and which gauges a basin with similar characteristics (i.e., area, effective drainage area, wetland distribution, soils, land use) (Shook et al., 2015).
3. The method assumes historical flows can be used to design infrastructure for the future but neither the climate nor widespread agricultural practices have been or will be constant (Shook and Pomeroy, 2012; Dumanski et al., 2015; Whitfield et al., 2021).
4. The Rational Method and Soil Conservation Curve numbers are often used to calculate runoff values from these gauged data to design infrastructure. This method assumes runoff is exclusively generated from rainfall even though the majority of historical flood peaks in Canadian Prairie drainage basins have been caused by snowmelt runoff. Furthermore, the method cannot account for the storage of water in wetlands, ponds or other depressions.

Methodology

PHYDAP is the output from hydrological model applications for ~4000 Canadian Prairie basins. These basins delineations are based on the Hydrosheds product (www.hydrosheds.org), which divides the globe into basins with areas approximately100 km^2. These ~4000 prairie basins have been classified into seven types, based on their dominant topography, soils, surficial geology, wetland pond character, vegetation and agricultural practices (Wolfe et al., 2019).

The Cold Regions Hydrological Model (CRHM, Pomeroy et al., 2007) was applied to each basin. The landscape in each basin in each class was represented the same in CRHM, using the typical values from each class as identified by the basin classification (Spence et al. 2021). The CRHM in each prairie class was forced by geographically distributed long term (30+ years) climate data (i.e., precipitation, air temperature, wind speed and relative humidity) derived from the 10km x 10km historical reanalysis dataset RDRS_V2 (Gasset et al. 2021) and the 4km x 4km WRF-CONUS future simulations (Rasmussen and Liu, 2017).

The model outputs contained in the product are time series of daily rainfall, snowfall, evapotranspiration, snow sublimation, depression storage, and upland and basin runoff in units of millimeters. The model outputs will be available in NetCDF format, so the time series can be extracted for any location based on geographic coordinates. The product also includes R codes that can convert the NetCDF outputs to standard formats as used by hydraulic modelling platforms. It is in these platforms that users can convert the water budget time series to hydraulic fluxes. Users can simulate small scale hydraulics, including the fill and spill of depressions, overland and/or through channel flow, the damming of flows by roads, and the effects of culverts and gates. It is recommended that the product is used with a hydraulic model platform capable of simulating overland flows in addition to channel flows. Streamflow and inundated area frequency and magnitudes can be calculated directly from the time series of the daily outflows and flooded areas produced by the hydraulic model. R code for this purpose is provided with the product. R is open source, can easily read outputs from nearly any hydraulic model, and has freely available code to fit those frequency distributions applicable to the Canadian Prairie (Zhang et al., 2020).

FAQ During Stakeholder Consultations

1. How will the hydrological model be able to simulate the effects of precipitation, given the very sparse network of precipitation gauges on the Canadian Prairies?

> The models are being run for a long period of time (+30 years) with past and future climate datasets that are known to represent well the climate of the Canadian Prairie (Rasmussen and Liu, 2017; Gasset et al. 2021). While the climate data product selected to run the hydrological model can misrepresent specific historical events, the long time series does represent the distribution of rainfall events so we are confident the representation of the water budget time series is fit for the purpose of input into hydraulic models to derive runoff frequency and magnitude.

2. How will the hydrological models handle initial conditions?

> The hydrological model is spun-up from an assumed initial state (soil moisture) and depressional storage for six years because it is about this long that soil and depressions "remember" past conditions (Shook and Pomeroy, 2011).

3. Why is CRHM being used for the hydrological modelling?

> CRHM has a proven track record of successful modelling of Prairie hydrological processes in small basins. It is capable of simulating all of the hydrological processes (redistribution and sublimation of blowing snow, radiation-driven snowmelt, infiltration to frozen soils, fill and spill surface runoff, actual evapotranspiration) critical to Prairie hydrology (Pomeroy et al., 2007), but rarely implemented in hydrological models.

4. Since you are outputting the outflows from the hydrological model, why do we need a hydraulic model?

> The hydraulic model provides a detailed representation of the complex hydraulics of the region of interest, which cannot be done by a hydrological model alone. The function of the hydraulic model is to evaluate changes in the local-scale hydraulic properties, such as those originating from drainage of wetlands, or the design of culverts. Using the same hydrological model outputs for each run saves time, as the hydrological model is only run once. More importantly, it reduces the sensitivity of the final output to errors in the meteorological forcings and the

hydrological model design and parameters, as the same inputs are used for each run of the hydraulic model.

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