Hydromythology and Prediction using Available Information

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How to Predict in Data Poor Basins?

- Lack of streamflow data means that model calibration opportunities are restricted.
- Typically there is also a lack of detailed meteorological data.
  - Reanalysis data
  - NWP model outputs
  - Extrapolation
- Satellite information can provide good surface vegetation cover information.
- DEMs are becoming excellent.
- Many regions have adequate soil information.
- Groundwater information is often lacking.
- Climate and sometimes land use changes are occurring.
- Can we find the appropriate data and parameters for PUB in data poor regions?
Stop the Bullet or Dodge the Bullet?
Stop Hydromythology Now!

- **Defn:** *Older concepts that have been dismissed by scientific investigation but persist in hydrological models.*
- **Examples:**
  - Radiation is impossible to estimate with normal meteorological data
    - Evapotranspiration can be estimated by temperature and wind functions
    - Temperature index melt of snow and soil thaw
  - **Snowfall determines snow available for melt**
    - Sublimation = 0
    - Snowfall gauge correction = snow redistribution loss
  - Soils can be represented as uniform porous media and subjected to clever mathematical manipulations
    - Macropores = 0
    - Green-Ampt or Richard’s Eq. can work “as is” or are still physically based when heavily calibrated from streamflow
  - **All land surfaces drain freely to streams with quick flow at overland flow velocities**
    - Hortonian overland flow
    - Contributing area = 100%
  - Frozen soils behave like unfrozen soils
    - Calibration of unfrozen soil infiltration for frozen conditions
Science or Mythology?

- Conceptual models sometimes accept mythology and “calibrate” to live with it.
- Models must reject mythology and incorporate scientific advances.
Process-based Catchment Modelling

- Multi-scale modelling, selected field studies and remote sensing can be used for finding appropriate model structure and parameters.
- Appropriate parameterisations help diminish “hydromythodologies”.
- Modelling using our understanding of hydrological processes is both scientifically satisfying and a robust approach to dealing with non-stationary systems.

- Failures of uncalibrated modelling at research basins are instructive. Embrace our failures.
  - What are the limits to prediction of the physically based approach?
  - How can conceptual and physically based approaches be used in process based catchment modelling?
Research Basins

- Marmot Creek
- Smith Creek
Cold Regions Hydrological Model Platform: CRHM

- Modular, object oriented – purpose built from C++ modules
- Modules based upon +45 years of hydrology research at Univ of Saskatchewan and Environment Canada
- Range of complexity and physical basis available in modules
- Structure set by user depending on objective function
- Parameters set by knowledge rather than optimization
- Hydrological Response Unit (HRU) basis
  - landscape unit with characteristic hydrological processes/response
  - single parameter set
  - horizontal interaction along flow cascade matrix
  - Model tracks state variables and flows for HRU
- Coupled energy and mass balance, process algorithms applied to HRUs via module selection
- HRU connected aerodynamically for blowing snow and via dynamic drainage networks for streamflow
- Flexible - can be configured for prairie, mountain, boreal, arctic basins
- Sub-basins connected via Muskingum routing

Pomeroy et al., 2007 *Hydrol. Proc.*

Tom Brown, CRHM Modeller
Rationale for CRHM Platform

- Frustration with adding locally important process algorithms to existing hydrological models
- Frustration with trying to fit inappropriate structure of existing models to basins
- Frustration with inability to fit conceptual spatial representations to reality.
- Frustration with models that only focus on streamflow response to precipitation
- Frustration with attempts to teach modelling to hydrologists using antiquated computer languages, difficult user interface, limited documentation of models
- Frustration with the lack of a graphical system to evaluate model inputs and outputs
Hydrological Response Units

- A HRU is a spatial unit in the basin that has 3 groups of attributes
  - biophysical structure - soils, vegetation, drainage, slope, elevation, area (determine from GIS, maps)
  - hydrological state – snow water equivalent, snow internal energy, intercepted snow load, soil moisture, depressional storage, lake storage, water table (track using model)
  - hydrological flux - snow transport, sublimation, evaporation, melt discharge, infiltration, drainage, runoff. Fluxes are determined using fluxes from adjacent HRU and so depend on location in a flow sequence.
- HRU need not be spatially continuous but must have some approximate geographical location (e.g. in a catena) or location in a hydrological flow sequence
Hydrological Response Units

Sequential HRU – landscape connectivity

HRU 1

HRU 2

HRU 3

outflow

HRU – draining directly to stream
Estimating Radiation for Energy Balance

- Theoretical superiority of energy balance calculations are well known for calculating sublimation, snowmelt and evapotranspiration.
- Energy balance estimations are robust and appropriate for extreme events, climate and land use change studies.
- Use of energy-balance is restricted by difficulty in obtaining measured solar radiation data.
CRHM data requirements

- CRHM normally requires hourly or daily values of:
  - Air temperature, humidity, precipitation,
  - Wind speed, Solar radiation
- CRHM can estimate incoming longwave and net radiation from shortwave
- Solar radiation can be
  - measured,
  - estimated from NWP reanalysis data,
  - estimated from observed sunshine hours or
  - estimated from empirical techniques that rely on air temperature
Edmonton 1979-2000

\[ y = 0.938125x + 35.1599 \]

\[ R^2 = 0.812256 \]
Empirical atmospheric transmittance equations

- $Q_{si}$ can be calculated directly if the atmospheric transmittance is known.
- Many similar relationships, all give similar results:
  - Bristow and Campbell and Walter et al.
  - Annandale
- All use a simple relationship between daily atmospheric transmittance and the range of daily air temperatures.
Edmonton 1979-2000

\[ y = 0.888663x + 18.2169 \]
\[ R^2 = 0.8194 \]
CRHM Snowmelt Simulation

The graph shows the snow water equivalent (SWE) in millimeters (mm) from March 10 to March 25. The lines represent different simulations:
- Measured Qsi
- NARR
- NCEP
- CBW

The SWE values decrease significantly over the period, with fluctuations at certain dates.
Canadian Prairie Runoff Generation

Snow Redistribution to Channels

Spring melt and runoff

Dry non-contributing areas to runoff

Water Storage in Wetlands
What does the Hydrograph Tell Us?

Smith Creek, Saskatchewan

Drainage area ~ 450 km²

snowmelt peak

No baseflow from groundwater

Streamflow m³ per second

0 5 10 15 20 25
01-Jan 31-Jan 02-Mar 01-Apr 01-May 31-May 30-Jun 30-Jul 29-Aug 28-Sep 28-Oct 27-Nov 27-Dec

Average 1975-2006
1995 High Year
2000 Low Year

[Graph showing streamflow data for Smith Creek, Saskatchewan, with peaks in May and snowmelt peak, and notes on drainage area and no baseflow from groundwater.]
Variable Connectivity and Storage in Prairie Drainage Networks
Non-Contributing Areas to Streamflow a Prairie Characteristic

Smith Creek
Established 2007 to study effects of wetland drainage on contributing area dynamics and streamflow generation
Instrumentation of Smith Creek

Hydrometeorological Station

- 11 dual rain gauges
- 7 wetland level recorders

Completed Summer 2007
Snow, Soil and Wetland Surveys
Smith Creek Basin Characteristics

Drainage Network

Spot Satellite Image
LiDAR – Light Detection and Ranging – for high resolution topography
LiDAR-Derived Drainage Network

Aggregation of channel and sub-basin segments
Derivation of Wetland Depressions

Figure 3. (a) Original 10-m LiDAR DEM, (b) filled depressionless 10-m LiDAR DEM, and (c) “cut/fill” output for Smith Creek basin.
CRHM Prairie Module Structure

Garnier and Ohmura's radiation module

Observation module

Sunshine hour module

Interception module

Walmsley's windflow module

Long-wave module

Canopy effect adjustment for radiation module

Global radiation

Max. sunshine

Temperature, Windspeed
Relative Humidity
Vapour Pressure
Precipitation

Sunshine hour

Rainfall
Snowfall

Adjusted windspeed

Adjusted short- and long-wave radiation

Rain INF
Runoff

Snow INF
Runoff

Evap in recharge and rooting zones

Runoff

Muskimgum routing module

Evap in recharge and rooting zones

Adjusted short- and long-wave radiation

Gray's snowmelt infiltration module, Green-Ampt infiltration

Gray and Landine's Albedo module

PBSM

SWE

albedo

snowmelt

Short- and long-wave radiation

Granger's evaporation module, Priestley and Taylor evaporation module

Evap in recharge and rooting zones

Runoff

Wetland module

All-wave radiation module

Gray's snowmelt infiltration module, Green-Ampt infiltration
Calibration vs Non-calibrated Modelling using LiDAR
HRU and Basin Delineation

Supervised landuse classification

Generation of seven HRUs
HRU Routing and Sub-basin (RB) Routing

(a) Fallow → Stubble → Grassland
    ↓               ↓                  ↓
   Woodland       Wetland → Open Water → River Channel → RB outlet

(b) RB 1 → RB 2 → RB 3 → RB 4 → RB 5 → Smith Creek basin outlet
Smith Creek SWE and $\theta$ Prediction – No Calibration

Observed SWE vs Simulated SWE at Smith Creek Sub-basin 1

- Fallow Obs. SWE
- Fallow Sim. SWE
- Channel Obs. SWE
- Channel Sim. SWE
- Wetland Obs. SWE
- Wetland Sim. SWE

Snow Accumulation (mm SWE)

7-Feb 18-Feb 29-Feb 11-Mar 22-Mar 2-Apr 13-Apr 2008

Observation
Calibrated Simulation
Uncalibrated Simulation

(a) Volumetric Soil Moisture
(b) Volumetric Soil Moisture

14-Apr 19-Apr 24-Apr 29-Apr 04-May 2008
14-Apr 19-Apr 24-Apr 29-Apr 04-May 2009
Runoff Prediction: with calibration (no Lidar) and uncalibrated (Lidar DEM for depressional storage)

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Alpine and Forest Terrain
5/11/2007 00 UTC
GEM-LAM NWP  Grid: 100 m

a) Colour: Surface Temperature
   Vectors: Wind Field
   Contour: Topography

b) Colour: Relative Humidity
   Vectors: Wind Field
   Black: Topography
Winter Snow Redistribution Modelling

Snow blows from north face to south face

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Point Evaluation of Snowmelt Model

2008

2009

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Forest Snow Modelling

Sub-canopy Snowmelt

Snow Interception and Sublimation
Open slopes highly sensitive to irradiation difference, forests are not
HRU Delineation

- Driving meteorology: temperature, humidity, wind speed, snowfall, rainfall, radiation
- Blowing snow, intercepted snow
- Snowmelt and evapotranspiration
- Infiltration & groundwater
- Stream network
Model Tests - SWE

Snow Accumulation at Upper Forest, Marmot Creek

Snow Accumulation at Upper Clearing, Marmot Creek

Snow Accumulation at South-facing Bottom Slope of Fisera Ridge, Marmot Creek

Snow Accumulation at Ridgetop of Fisera Ridge, Marmot Creek
Mean Bias = -0.13
all parameters estimated from basin data
Streamflow Prediction 2007

Marmot Creek Daily Discharge

Mean Bias = -0.068
all parameters estimated from basin data
Hydromythology can be Fought

The perils of calibration with changing hydrology

Victory of understanding over myth
Conclusions

- A variety of process algorithms are available and can be applied in basin scale modelling with data available from standard meteorological stations or from atmospheric models in data poor regions.

- Remote sensing, basic soils information and local research catchments provide the means for discriminating appropriate HRU and defining model structure – these approaches can be extended to data poor regions.

- Remote sensing and process experiments from research basins can be used to parameterise models, reducing the need for calibration from streamflow. Success depends on appropriate model process structure and spatial representation.

- Model structures and parameterisations can be regionalised from research basins for use in ungauged basins with minimal data.

- Streamflow information can still be used to improve model performance in streamflow prediction
  - Diagnostic evaluation of model failure and recommendations for improvement