The Importance of Snowmelt Runoff Modeling for Sustainable Development and Disaster Prevention

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Water

\[ \text{H}_2\text{O} \]

- Gas - Water Vapor
- Liquid - Rivers and Oceans
- Solid – Ice and Snow

Very strange substance (38 anomalies)
- Water shrinks on melting
- Hot water freezes faster than cold (clustering)
Precipitation

- Rainfall
  - Liquid water
  - Produces immediate runoff
  - Predictable runoff
- Snowfall
  - Crystalline water
  - Delayed runoff
  - Difficult to predict
Why snowmelt runoff modeling?

- Drinking water supply
Why snowmelt runoff modeling?

➢ Flood control structures
Why snowmelt runoff modeling?

- Irrigation
Why snowmelt runoff modeling?

- Hydropower generation
Why snowmelt runoff modeling?

- Reservoir management
Types of models

- Physical models
  - Based on strict physical laws
  - Mass and energy balance
  - Accuracy is high

- Conceptual Index models
  - Empirical relationship to approximate mass balance
  - Requires less parameters
Physical Models

- SNTHERM - US army corps CRREL
- LSM (land surface model)
- VIC (variable infiltration capacity) - U Washington
- WATCLASS (Watflood/class) - Env. Can
- SHE (Systeme Hydrologique Europeen) physically based, distributed, continuous
- Streamflow and sediment simulation, Abbott et al.
Conceptual Index Models

- SRM (Snowmelt Runoff Model) - USDA
- PRMS (precipitation runoff modeling system) - USGS
- SLURP (simple lumped reservoir) - Env. Can.
- UBC Watershed Model
- TOPMODEL (hydrologic simulation model) - Beven
Snowmelt Runoff Model

- Developed by Martinec
- Estimation of daily stream flow in Mountain basins
- Degree-day model (temperature)
- Applied in 25 countries for more than 80 basins
- Simple and Efficient
SRM methodology

Remote Sensing Data

Snow Cover Mapping
- Region of interest
- Cloud extrapolation
- Elevation zones

Meteorological data
- Daily temperature
- Daily precipitation

Snow cover depletion
- Daily snow coverage

Snowmelt Runoff Model

Parameters
- Critical temperature
- Recession coefficient

DEM

Snowmelt Runoff Simulation Forecast
SRM parameters

- Temperature (meteorological data)
- Precipitation (meteorological data)
- Daily Discharge
- Snow covered area (Remote Sensing data)
- DEM (topo map)
Heart of the model

\[ Q_{n+1} = \left[ C_{sn} \cdot a_n (T_n + \Delta T_n) \cdot S_n + C_{rn} \cdot P_n \right] \frac{A \times 10000}{86400} \cdot (1 - k_{n+1}) + Q_n \cdot k_{n+1} \]

Q = average daily discharge \([m^3s^{-1}]\)

c = runoff coefficient: losses as a ratio (runoff/precipitation), with \(c_{sn}\) referring to snowmelt and \(c_{rn}\) to rain

\(a = \) degree-day factor \([cm \cdot ^\circ C^{-1} \cdot d^{-1}]\) indicating the snowmelt depth resulting from 1 degree-day

T = number of degree-days \([^\circ C \cdot d]\)

\(\Delta T = \) the adjustment by temperature lapse rate \([^\circ C \cdot d]\)

S = ratio of the snow covered area to the total area

P = precipitation contributing to runoff \([cm]\). Threshold temperature, \(T_{CRIT}\), determines whether this contribution is rainfall or snowfall

A = area of the basin or zone \([km^2]\)

k = recession coefficient indicating the decline of discharge in a period without snowmelt or rainfall

n = number of days
Parameters

- Runoff coefficient, $c = \frac{\text{runoff}}{\text{precipitation}}$
- Degree day factor, $a$
  - Amount of heat for a 24 hrs with a 1 °C departure from a reference temperature. Converts number of degree-days into snowmelt depth
- Temperature lapse rate, $\gamma$
  - Temperature change with the height
- Critical temperature, $T_{\text{crit}}$
  - Determines whether precipitation is snow or rain
- Rainfall contributing area, RCA
- Recession coefficient, $k$
  - Decline of runoff in a period without precipitation
- Time Lag, $L$
  - Time elapsed between the center of mass of the effective rainfall/snowmelt and the peak of direct runoff
Case Study

- **Study Area**
  - Located at Kullu District Himachal Pradesh, India
  - Geographical location: 31° 20′-32° 25′ N, and 76° 55′-77°55′ E.
  - Total area of the basin is 1790 km².
  - Elevation difference from 800 m. to 6600 m. asl (Tichu Glacier).
  - Temperature: min T=1 °C, max T=30 °C (Bhuntar 1000 m asl)
  - Annual rainfall approximately 1000 mm (Bhuntar 1000 m asl)
Methodology

RS data

Snow Cover Mapping

DEM

Elevation zones

Overlay

Meteorological data

Snowmelt simulation
Thematic Layers

- Elevation zones
- Snow cover maps
- Temperature distribution
- Rainfall distribution
Elevation Zones Map [m]
Calibration of Cr, Cs=0.5

Discharge $[m^3/s]$
Variation of Snowmelt and Rainfall Runoff coefficients

- Cs
- Cr
Actual discharge vs simulated (2000-2001)

\[ y = 0.9142x + 5.9438 \]

\[ R^2 = 0.9733 \]
Martinec-Rango SRM (validation 1998-1999)
Actual discharge vs simulated (1998-1999)

\[ y = 0.976x + 3.8314 \]

\[ R^2 = 0.7933 \]
Results

• Martinec-Rango overestimates discharge during snowmelt season (10%) and underestimates in winter time (38%)

• It is possible to make short time forecasts (3-4 days), and approximate forecasts (1-2 month)
Limitations of Present Study

1. Snowmelt Runoff Model was developed for small European basins, but watersheds are highly varying all over the world.
2. Gauging stations are very less (Bhuntar)
3. Lapse rate is a good approximation of temperature variation vs elevation
4. Often discharge data is not available.
5. Very less snow gauging stations are available
6. Interpolation of Snow Cover Area

Future Scope of Work

1. Reasonable temporal resolution of SRM inputs would significantly increase the accuracy of the model and allow SRM working in forecasting mode.
2. Weather simulation - long-term forecasts
3. Cost factor
System of Notification in Emergency Situations
Scenario of Central Asia

- Melt water is the major source of water
- Hydropower, Irrigation
What is being done?

- Data collection for similar project in Uzbekistan
  - Practical application
  - Higher temporary resolution of satellite imagery
  - Availability of discharge data

- Close cooperation with interested ministries
  - Ministry of Water and Agriculture
    - Around 100,000 sq km are under agriculture
  - Ministry of Nature Protection
  - Ministry of Emergency Situations
    - More than 20 large water bodies
  - Meteorological service
Thank You