Snowmelt Runoff Modelling- Critical to Hydropower projects

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Rainfall Vs Snow

Rainfall	Snow
•Liquid Water	•Crystalline water
•Produces immediate runoff	•Delayed Runoff
•Predictable Runoff	•Difficult to predict

Frozen water

- 80% of Total Fresh Water on earth is in Solid State
- About 30 % of the World's Land Cover is seasonally covered by snow & 10 % is permanently covered by Glaciers
- A large uncertainty & sensitivity lies in these frozen reservoirs
- Excessive snowmelt contributes to rise in global sea level

Himalayan Hydrology

- Supports major perennial Rivers of Northern & Eastern India
- Snowmelt mostly occurs in April, May & June months
- States of H.P, Haryana, Punjab, J&K, Delhi, U.P., Uttarakhand, Bihar, West-Bengal are directly affected
- Altitude in Himalayas controls temperature and precipitation
- Climate varies from hot & moist tropical in lower valleys to cool temperate at about 2000 m and tends towards polar at further higher altitudes
- Rainfall increases with altitude upto 2500 m and then starts to decrease

Snow-Melt Runoff

- In snowmelt, runoff is the surface runoff produced from melting of snow
- It is one of the major component of Global Hydrologic Cycle
- Contribute in High Fractions of Annual Runoff in Himalayan River Basins.
- Mountain snow fields act as natural reservoirs, storing precipitation from the cool season, when most precipitation falls and forms snow-packs, until the warm season when most of the snow-packs melt and release water into rivers

Modelling- Why necessary?

- During Summer/ Monsoon, Snow-melt component is quite large and in combination with extreme event may result in severe flooding
- Rapid snowmelt may even trigger landslides and debris flows.

Important for

- Design Flood Studies
- Flood Forecasting
- Timely & Correct Information about the snow cover & likely volume of runoff is of vital importance for managing of water resources as well as mitigating disasters

Importance of Snowmelt modelling to hydro projects

- To know amount of water likely to come due to snow melt in lean season
- Domestic/ Industrial Supply of Water in Lean Season
- Flood Control
- Irrigation Supply
- Hydropower Generation
- Reservoir Management
- Study of Impacts of climate change / Global Warming

Snowmelt Runoff Modelling- Approaches

Temperature Index Approach

- Also called Conceptual Index Approach
- Air Temperature is used to approximate snowpack energy exchange.
- Empirical models based on the assumption of Linear relationship between snow melt rate and Mean daily air temperature
- Requires Less Input Parameters

Snowmelt Runoff Modelling-Approaches

Energy budget approach

- Physical Model i.e. based on strict physical phenomenon
- Energy exchange at Snow surface through exchange of Short Wave & Long Wave Radiation , Energy Fluxes due to Sensible Heat, Latent Heat, Soil Heat and Rainfall
- Accuracy is high but extensive data requirement

Snowmelt-Runoff Model (SRM)

- SRM - a conceptual, deterministic, degree day hydrologic model used to simulate daily runoff resulting from snowmelt and rainfall in mountainous regions.
- Requires daily temperature, precipitation, and daily snow covered area values as input parameters
- Developed by Martinec (1975) in small European basins
- Latest Version - WinSRM Version 1.11
- Can be applied in mountain basins of almost any size and any elevation range
- The Hydrology Laboratory supports and distributes the Snowmelt Runoff Model free of charge at United States Department of Agriculture (USDA) website www.ars.usda.gov/Services

SRM Inputs

- Input variables - temperature, precipitation and snow covered area
- Area-elevation curve of the basin
- Other basin characteristics such as forested area, soil conditions, antecedent precipitation, and runoff data are useful for facilitating the determination of the model parameters.

Uses of SRM

- Simulation of daily flows in a snowmelt season, in a year, or in a sequence of years
- Short term and seasonal runoff forecasts
- Evaluating the potential effect of climate change on the seasonal snow cover and runoff

SRM- Model Structure

$$Q_{n+1} = [c_{Sn} \cdot a_n (T_n + \Delta T_n) S_n + c_{Rn} P_n] \frac{A \cdot 10000}{86400} (1 - k_{n+1}) + Q_n k_{n+1}$$

where:

- Q = average daily discharge [$m^3 s^{-1}$]
- c = runoff coefficient expressing the losses as a ratio (runoff/precipitation), with c_S referring to snowmelt and c_R to rain
- a = degree-day factor [cm $^oC^{-1} d^{-1}$] indicating the snowmelt depth resulting from 1 degree-day
- T = number of degree-days [^oC d]
- ΔT = the adjustment by temperature lapse rate when extrapolating the temperature from the station to the average hypsometric elevation of the basin or zone [^oC d]
- S = ratio of the snow covered area to the total area
- P = precipitation contributing to runoff [cm]. A preselected threshold temperature, T_{CRIT}, determines whether this contribution is rainfall and immediate. If precipitation is determined by T_{CRIT} to be new snow, it is kept on storage over the hitherto snow free area until melting conditions occur.
- A = area of the basin or zone [km^2]

SRM- Model Structure

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

$$k = \frac{Q_{m+1}}{Q_m}$$ (m, m + 1 are the sequence of days during a true recession flow period).

n = sequence of days during the discharge computation period. Equation (1) is written for a time lag between the daily temperature cycle and the resulting discharge cycle of 18 hours. In this case, the number of degree-days measured on the nth day corresponds to the discharge on the n + 1 day. Various lag times can be introduced by a subroutine.

$$\frac{10000}{86400} = \text{conversion from } cm \cdot km^2 d^{-1} \text{ to } m^3 s^{-1}$$

T, S and P are variables to be measured or determined each day, c_R, c_S, lapse rate to determine ΔT, T_{CRIT}, k and the lag time are parameters which are characteristic for a given basin or, more generally, for a given climate.

If elevation range of basin exceeds 500 m, it is recommended to subdivide it into elevation zones of about 500 m each.

Assessment of Model Accuracy

SRM uses 2 well established criteria

- Coefficient of Determination
- Deviation of Runoff volume

Remote Sensing Inputs

- Satellite Image from the Visible Range gives information about the snow-cover
- IR band is utilised in separating cloud cover from snow cover
- A few of them can be utilised to predict the amount of snow melt generated
- Image in visible spectrum gives the Snow cover
- Image in Band-10 gives the Albedo information (Important from energy reflection point of view)

Remote Sensing Inputs

- Snow Cover Area (SCA) -from MODIS / AWiFS satellite data
- Glacier Cover Area (GCA) –from AWiFS satellite data
- Land Surface Temperature (LST) –from MODIS satellite data (8-Day LST product MOD11A2)
- Incoming Solar Radiation (SR) –f(elevation, slope, aspect, Julian day, lat., long.)
- Snow Albedo(α) –MODIS satellite data (Daily SCA Product MOD10A1)
- Land Cover –Mapped with AWiFS satellite data
- Snow persistence Index (SPI) –from MODIS satellite data (8-Day SCA Product MOD10A2)
- Digital Elevation Model, Slope, Aspect –ASTER data
- Field measured discharge, Rainfall data

Availability of remote Sensing Data

Table 3 Some of the possibilities of remote sensing for snow cover mapping.

Platform Sensor	Spectral Bands	Spatial resolution	Minimum area size	Repeat period
Aircraft Orthophoto	Visible/NIR	2 m	1 km^2	flexible
IRS				
Pan	Green to NIR	5.8 m	2 km^2	24 days
LISS-II	1 – 3 Green to NIR	23 m	2.5 – 5 km^2	24 days
WiFS	1 Red / 2 NIR	188 m	10 – 20 km^2	5 days
SPOT				
HRVIR	1 – 3 Green to NIR	2.5 – 20 m	1 – 3 km^2	26 days
Landsat				
MSS	1 – 4 Green to NIR	80 m	10 – 20 km^2	16 – 18 days
TM	1 – 4 Green to NIR	30 m	2.5 – 5 km^2	16 – 18 days
ETM-Pan*	Visible to NIR	15 m	2 – 3 km^2	16 – 18 days
Terra/Aqua				
ASTER	1 – 3 Visible to NIR	15 m	2 – 3 km^2	16 days **
MODIS	1 Red / 2 NIR	250 m	20 – 50 km^2	1 day
	3 – 8 Blue to MIR	500 m	50 – 100 km^2	1 day
NOAA				
AVHRR	1 Red / 2 NIR	1.1 km	10 – 500 km^2	12 hr
Meteosat				
SEVIRI	1 – 3 Red to NIR	3 km	500 – 1000 km^2	30 min
	12 Visible	1 km	10 – 500 km^2	30 min

Acronyms:

ASTER = Advanced Spaceborne Thermal Emission and Reflection Radiometer • AVHRR = Advanced Very High Resolution Radiometer • HRVIR = High Resolution Visible and Near Infrared • IRS = Indian Remote Sensing • LISS = Linear Imaging Self-scanning Sensor • MIR = Middle Infrared • MODIS = Moderate Resolution Imaging Spectroradiometer • MSS = Multi-Spectral Scanner • NIR = Near Infrared • Pan = Panchromatic • SEVIRI = Spinning Enhanced Visible and Infrared Imager • SPOT = Satellite Pour l'Observation de La Terre • TM = Thematic Mapper • WiFS = Wide Field Sensor • ETM-Pan = Enhanced Thematic Mapper - Panchromatic

(*) Landsat 6 and 7 only (**) Depends on availability

Why Snowmelt runoff critical for hydropower projects

- Most of Hydropower potential in India is in Himachal Pradesh, Uttarakhand, J&K & Arunachal Pradesh in Himalayan region with high concentration of glaciers
- Significant portion of catchments covered by seasonal snow during winter
- Predicting lean season flows for right sizing of projects and optimum operation
- Ascertaining effects of climate change / global warming and consequent changes in lean season flows

Conclusion

- Determination of snowmelt runoff correctly through Snowmelt Runoff Modelling is very helpful in optimum planning of hydropower potential of a basin and commercially beneficial operation of hydropower projects as viability of hydropower depends on lean season flows which in turn mostly depends on snow melt runoff.