YIELD SERIES FOR HYDRO ELECTRIC PROJECTS IN RAINFALL VARIABILITY SCENARIO

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ABSTRACT
A large number of hydro electric projects are coming up in the Himalayas in India. In order to finalise the power potential of these projects a reliable estimate of water availability (yield) series is essential. Most of the project catchments are having three distinct elevation bands consisting of rain fed catchment, permanent snow cover catchment and extended snow catchment during the winter. The measured long term discharge data is available only at few gauge and discharge sites along the major Himalayan rivers, while a number of projects are being planned on tributaries, where no long term measured discharge data is available. Further, there is a high variability in rainfall due to Himalayan physiography and orographic pattern of precipitation. In these scenarios getting a proper estimate of water availability series for the hydro electric projects is a major challenge before the project planners. The present paper describes the methodology to transfer the long term measured discharge data of a gauge and discharge site to different project locations of the same basin by catchment area proportioning and yield correction factor. For the purpose of illustration, a case study of Kameng basin has been presented, where the long term discharge data is available only at Bhalukpong and Bichom G&D sites, while more than 25 hydroelectric projects are at different stages of planning in this basin. Further, there is a major variation in rainfall in Bichom, Kameng upper and Kameng Lower sub basins. For developing a yield model, the catchment area in different elevation bands of G&D sites and project catchments has been estimated by GIS mapping of digital elevation model. The permanent snowline in Kameng basin is at EL 5000 m. The extended snow catchment during the winter has been considered between elevations 3000 m to 5000 m. An annual yield model has been developed for long term measured discharge at Bhalukpong G&D site with catchment area of 10450 sq.km. This yield model has been tested with measured long term discharge data of Bichom G&D site with catchment area of 2277 sq.km. Based on the tested parameters of the yield model, the possible yield has been estimated for those projects where no long term discharge data is available. The long term water availability series for the projects in the basin has been estimated on the basis of long term measured discharge series of G&D sites by applying catchment area correction factor and yield correction factor. For developing the yield model, the sub basin wise average annual rainfall have been worked out using 12 years annual average Tropical Rainfall Measurement Mission (TRMM) data in Geotiff format. The TRMM rainfall has been compared with measured ground rainfall at different rain gauge stations available in the basin.

1.0 INTRODUCTION

Hydrological inputs play a major role in planning, designing and successful operation of a water resources project. The economics and sizing of every project is dependent on hydrological parameters. Water resource projects involve a huge investment, it is, therefore, very necessary to carry out the detailed hydrological studies and assess hydrological parameters rationally. A number of hydroelectric projects are being proposed in Himalayas, where discharge data is available only at a few gauge and discharge sites. In order to finalise the power potential for these projects a reliable estimate of water availability series is essential. For diversion project with and without pondage, the minimum desirable length of gauge and discharge data at project location and rainfall data in project catchment is about 10 years. Usually the observed data for desired locations and desired length are not available / collected and inputs are to be prepared using data transfer and data extension techniques.

The discharge records available at a G&D site in Himalayan terrain cannot be transferred to project site in catchment area proportion due to high variability in rainfall. Further, most of the project catchment is having rain fed catchment, permanent snow cover catchment and extended snow catchment during the winter. In such scenarios there will be different yield at different locations of a basin. Hence, to get a proper estimate of water availability a yield correction factor along with catchment area proportion is required to transfer the measured discharge of a G&D site to a proposed hydroelectric project diversion site. The present paper describes the methodology to

transfer the long term measured discharge data of a gauge and discharge site to different project locations of the same basin by catchment area proportioning and yield correction factor.

2.0 INPUT DATA REQUIRED

For developing yield model at desired locations of a river reach in a basin the following input data are essential:

- Catchment area map
- Hypsometric details of catchment
- Elevation of Permanent snowline
- Transitional snow zone
- Catchment representative rainfall
- Observed long term discharge at minimum two locations in the same basin
- Upstream diversion
- Any other consumptive/non-consumptive use

3.0 DATA VALIDATION

Before using the data for hydrological computations it is necessary to ensure the quality of data through proper validation. The purpose of data validation is to ensure the records accurately reflect the catchment's behavior, eliminate or reduce the effects of extraneous influences, eliminate doubtful data. The various methods for validation of rainfall data are concurrent plots of recorded data of same period for different rain gauge stations in the basin, monthly plots, annual plots, auto validation by single mass curve, double mass curve etc.

The discharge data is validated through internal consistency check within the data set and by external consistency checks with respect to discharge/rainfall data of other sites before using the same for water availability analysis. The observed discharge data should be checked for its internal and external consistency. The internal consistency test is primarily meant for a single data series and used to detect typical typographical errors/mistakes committed at data entry level between individual measurements. In order to detect such errors, flow data of a G&D site can be analyzed in the form of annual hydrographs and mass curve of annual discharge of different years. Also gauge and corresponding discharge can also be plotted to assess the reliability of observed flows at a particular site. The external consistency of discharge data can be checked by calculating the specific yields and comparing the same with upstream and downstream sites, multi station plotting, rainfall-runoff comparison, runoff-runoff comparison etc

4.0 YIELD MODEL AND YIELD CORRECTION FACTOR

The yield correction factor can be worked out by developing an average annual yield model at G&D site where long term measured discharge data is available. The same can be tested on the other G&D site of the basin and after testing the parameters of the model it can be used to assess the yield at any other project location in the basin. The yield correction factor is the ratio of average annual yield at project location and average annual yield at G&D site. The average annual yield at any project location or a G&D site is the average annual runoff in million cubic meter. The same can also be estimated in millimeter using the relationship:

Average annual yield (mm) = (average annual runoff in million cubic meter x 1000 / catchment area (km^2).

At a G&D site where long term observed discharge data is available a yield model for average annual yield can be developed for yield component from rainfall, permanent snow cover and extended snow cover. Before developing an average annual yield model, the measured discharge and rainfall records should be validated for their consistency to establish the accuracy of records. The average annual yield at a G&D site can be computed from the observed and consistent discharge records. The permanent snowline and extended snow cover during the winters in a basin can be estimated by comparing the satellite imageries of different years. The area between different elevation bands can be estimated by GIS processing of digital elevation model. The SRTM or

ASTER DEM which are freely available can be used. For estimating the representative average annual rainfall for the catchment the measured rainfall if available or 12 years (1998-2009) average annual Tropical Rainfall Measurement Mission (TRMM) data of NASA and JAXA can be used. Based on the representative catchment rainfall the yield component from rainfall can be estimated assuming a suitable runoff coefficient. The snow melt yield above permanent snow line can be estimated using WMO formula. The yield from extended snow catchment can be estimated for estimated yield component from rainfall, estimated snow melt yield above permanent snow line and observed average annual yield at G&D site.

5.0 CASE STUDY-KAMENG BASIN

The river Kameng is one of the right bank tributary of Brahmaputra river. It joins the Brahmaputra river about 11 km upstream of Tejpur town. The drainage area of Kameng river lies approximately between longitudes 92º 00' 00" to 93º 20' 55" E and latitudes 26º 38' 00" to 28º 59' 50" N. The river Kameng drains about an area of 12,500 km^2. The total length of river is about 200 km. The rivers Pacha, Pachi, Pachuk, Bichom, Papu and Dikrain are the main tributaries of the Kameng. Kameng River originates at an elevation of about 5000 m. The major drainage area of Kameng river lies in Arunachal Pradesh, India.The topography of Kameng Basin in upper reaches divides itself into two distinct zones i.e. Greater Himalayas and Lower Himalayas. The Greater Himalayas abounds with Glaciers mostly covered with permanent snow above elevation 5000 m while lower regions in Himalayas are generally rain fed. The topography of the basin is hilly with steep slopes in upper regions and moderately plain areas in lower regions. The majors tributaries in the basin are perennial due to runoff from snow melt and as such offer great hydro-power potential. A catchment area plan of Kameng river showing locations of Bhalukpong G&D site, Bichom G&D site, Pachuk-I HE project location and catchment area of different sub-basins is shown in Figure 1.

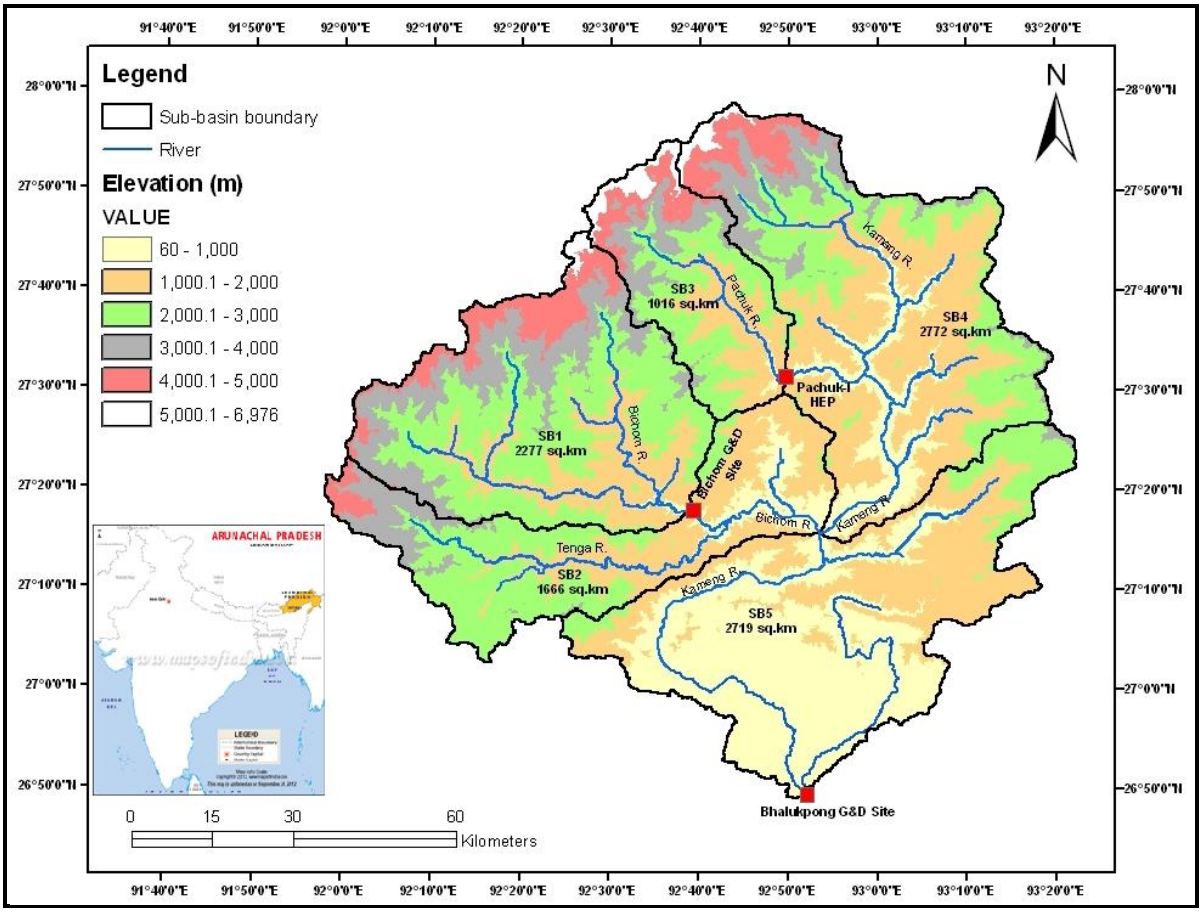

Figure 1. Catchment area plan of Kameng river at Bhalukpong G&D site, Arunachal Pradesh

Kameng river in its upper reaches generally flows in north-south direction, taking numerous large turns in its course. This river flows in river valley near the Seppa town. About 20 km downstream of Seppa, it is joined by a right bank tributary i.e. Bichom river. Thereafter it takes a turn and flows in westerly direction. The river in its lower reaches is also known as Jia Bhareli.

For the case study an average annual yield model at Bhalukpong G&D site has been developed based on the observed discharge data of 18 years. The same has been tested for long term observed average annual yield of Bichom. The yield model parameters have been adopted to estimate the average annual yield and developing a 10 daily series for Pachuk-I HE project by multiplying the Bichom observed discharge series with the yield correction factor and catchment area correction factor.

5.1 Yield model for Bhalukpong G&D site

The catchment area of Kameng river at Bhalukpong G&D site is about 10450 km^2. The permanent snow line in the Kameng basin is at elevation 5000 m. The observed discharge data at Bhalukpong G&D site is available from the year 1990-91 to 2009-10. This data has been checked for its consistency by mass curve. The data of year 1990-91, 1991-92 and 1992-93 has been found inconsistent hence, the same has not been considered. Further, the data of year 1998-99 has been corrected to make it consistent with rest of the data. For the consistent data of 17 years for the period 1993-94 to 2009-10 the average annual yield at Bhalukpong G&D site is 25476 million cubic meter (2438 mm). For this average annual yield, the yield model has been developed considering runoff from the snow melt contribution above permanent snow line of 5000 m elevation, snow melt contribution from the catchment between elevation 3000 m to 5000 m and rainfall from the rain fed catchment below elevation 5000 m. Here, it is important to mention that from the area between elevation bands 3000 m to 5000 m the runoff contribution is both from rainfall as well as snow melt as the snow line extend up to elevation 3000 m during the winters. The snowmelt contribution from the area between elevation bands 3000 m to 5000 m has been estimated to get the average annual yield as per observed discharge.

To estimate the catchment area between different elevation bands, the hypsometric curve for Bhalukpong G&D site catchment has been prepared by GIS processing of SRTM DEM. From the hypsometric curve the area above permanent snowline at EL 5000 m has been found as 136 km^2 and the area between elevation 5000 m and 3000 m has been found as 1778 km^2. The hypsometric curve of Bhalukpong G&D site catchment is given in Figure 2.

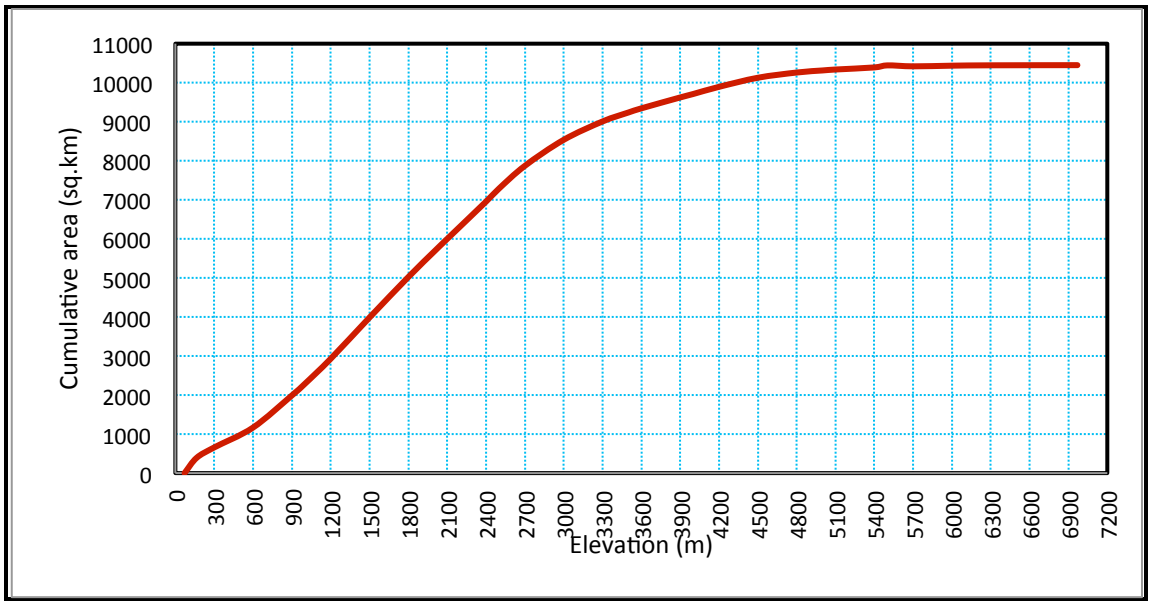

Figure 2. Hypsometric curve at Bhalukpong G&D Site of Kameng river

Catchment representative rainfall has been assessed from the 12 year average annual TRMM rainfall data of NASA and JAXA for the period (1998-2009). The same has been compared with the

rain gauge records available in the basin. The TRMM rainfall pattern of the Kameng catchment is shown in Figure 3, where it can be seen that the average annual TRMM rainfall is almost matching with the ground rain gauge records barring a few exceptions.

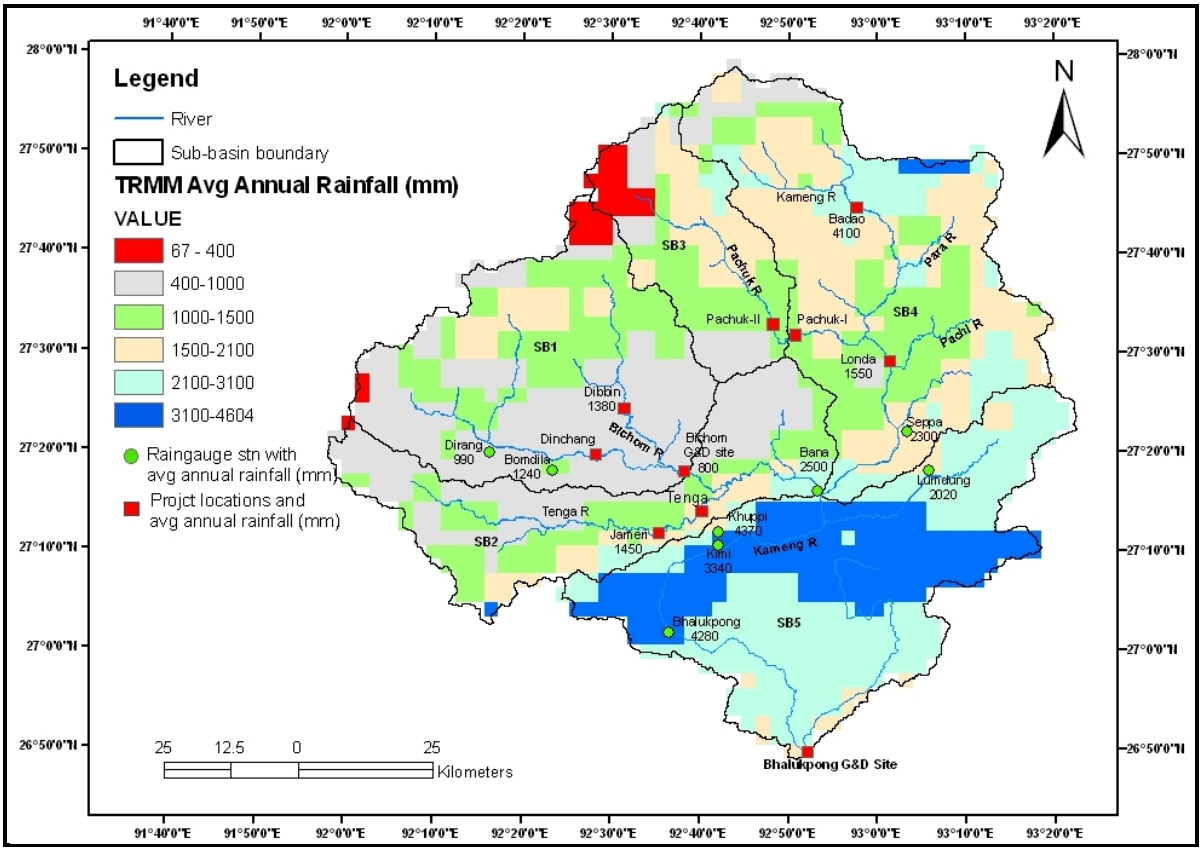

Figure 3. 12 years average annual TRMM rainfall pattern of Kameng basin

The yield model computations to assess the yield components from snow melt and rainfall are given in Table-1.

Table 1. Yield model at Bhalukpong G&D site of Kameng river

Catchment	Catchment Area (sq.km)	Annual Rainfall (mm)	Snowmelt during six months @ 5 mm/day	Runoff from rainfall (MCM)	Snow melt runoff (MCM)	Observed average annual yield (mm) at Bhalukpong for the period (1993-2010)
Permanent snow cover	136		912.5		124.10	
SB1 and SB2 excluding permanent snow cover	3915.8	1440		5074.88		
SB3 and SB4 excluding permanent snow cover	3679.2	2400		7947.07		
SB5	2719	3914		9577.95		
Area between EL 3000m-5000m	1778	1548			2752.34	
Total				22599.90	2876.44	
Average annual runoff from rainfall and snowmelt (MCM)				25476.34		
Total Catchment Area (sq.km)				10450.00		
Average annual yield (mm)				2437.93		2437.89

Due to high rainfall and very steep slope of the basin the runoff coefficient for the computed rainfall has been considered as 0.90. The snowmelt component between elevation band 3000 m and 5000 m has been assessed as 1548 mm by hit and trial for observed average annual yield of 2338 mm.

5.2 Testing of yield model of Bhalukpong G&D site at Bichom G&D site

Bichom G&D site is located in the Bichom Sub basin of Kameng basin. The catchment area at Bichom G&D site is 2277 km^2 (SB-1 of Figure-1). The average annual yield for consistent observed discharge for the period 1969-70 to 1980-81 is about 1878 mm. The total catchment area at Bichom G&D site is 2277 km^2, out of which the catchment area above permanent snowline of 5000 m and in elevation band 3000 m to 5000 m is about 23.45 km^2 and 766 km^2 respectively. The hypsometric curve at Bichom G&D site is given in Figure 4.

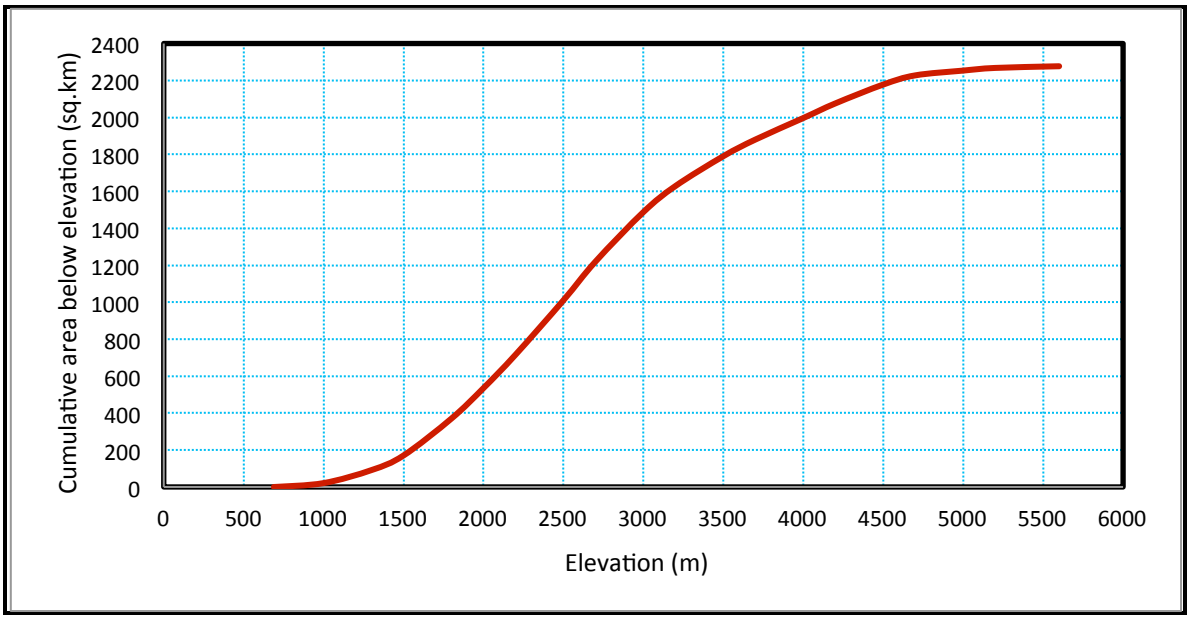

Figure 4. Hypsometric curve at Bichom G&D Site of Bichom river

Since the catchment contributing in the snowmelt component of the yield at Bichom G&D site is the part of the catchment of the yield model developed at Bhalukpong G&D site, hence, assumed and estimated parameters of the snowmelt component has been kept same as that of Bhalukpong G&D site. Catchment representative average annual rainfall as per TRMM has been estimated as 1515 mm. The yield computed at Bichom G&D site is given in Table 2.

Table 2. Testing of Yield model at Bichom G&D site of Bichom river

Catchment	Catchment Area (sq.km)	Annual Rainfall (mm)	Snowmelt during six months @ 5 mm/day	Runoff from rainfall (MCM)	Snow melt runoff (MCM)	Observed average annual yield (mm) at Bichom for the period 1969-70 to 1981-82
Permanent Snow cover	23.45		912.5		21.40	
SB1 excluding permanent snow cover	2253.55	1515		3072.72		
Area between EL 3000m-5000m	766	1548			1185.77	
Total				3072.72	1207.17	
Average annual runoff from rainfall and snow melt (MCM)				4279.88		
Total Catchment Area (sq.km)				2277.00		
Average annual yield (mm)				1879.61		1878.00

The computations shown in Table 2 verifies the assumed and computed parameters of the snowmelt component of the yield model and assumed runoff coefficient, as the computed yield of 1879.61 mm is almost same as that of the observed yield of 1878 mm.

Now taking the catchment representative rainfall of any hydro electric project catchment and snowmelt component of yield from the developed yield model, the yield can be estimated at any project site in the same basin. The discharge series at project site can be developed by multiplying the observed discharge series of available G&D site with the yield correction factor and catchment area correction factor.

5.3 Computation of yield at Pachuk-I HE Project diversion site

Pachuk-I HE Project is proposed on Pachuk river a tributary of Kameng river in East kameng sub basin (refer Figure-1). The catchment area at diversion site is 1016 km^2, out of which snow cover catchment area above permanent snow line and catchment area between elevation band 3000 m to 5000 m is 42 km^2 and 296 km^2 respectively. The catchment representative rainfall has been computed from TRMM as well as the ground measurement records. In order to develop discharge series at Pachuk-I diversion site based on the observed discharge of Bichom G&D site, the average annual yield has been estimated as 2300.58 mm taking the tested parameters of yield model. The computations are shown in Table 3.

Table 3. Average annual yield computations for Pachuk-I HE project diversion site

Catchment	Catchment Area (sq.km)	Annual Rainfall (mm)	Snowmelt during six months @ 5 mm/day	Runoff from rainfall (MCM)	Snow melt runoff (MCM)
Permanent Snow cover	42		912.5		38.33
SB3 excluding permanent snow cover catchment	974	2030		1779.50	
Area between EL 3000m-5000m	296	1548			458.208
Total				1779.50	496.53
Average annual runoff (MCM)				2276.03	
Total Catchment Area (sq.km)				1016.00	
Average annual yield (mm)				2240.19	

5.4 10 daily discharge series at Pachuk-I HE Project diversion site

The 10 daily discharge series at Pachuk-I HE Project has been computed using the following relationship:

10 daily discharge series at Pachuk-I diversion site = 10 daily observed discharge series at Bichom G&D site x (computed average annual yield at Pachuk-I / observed average annual yield at Bichom G&D site) x (catchment area at Pacuk-I diversion site / catchment area at Bichom G&D Site)

5.0 CONCLUSIONS

There is very high variability in rainfall in different sub basins throughout Himalayas due to Himalayan topography and orographic nature of precipitation. In such scenario the yield series at a project site cannot be generated by simple catchment area proportioning of the observed discharge series at a G&D site. Yield model at those G&D sites where long term measured data is available can be prepared and rainfall as well as snowmelt components of the average annual yield can be estimated. After testing of the yield model with observed discharge of another G&D site, the same based on the catchment hypsometry and spatial variability of rainfall can be applied at other locations to get an estimate of yield and develop long term water availability series. The proposed procedure is open for further development, and it is hoped that it will stimulate discussions and further studies.

6.0 LIMITATIONS

The yield series assessment procedure presented in the paper has certain limitations like assumption of runoff coefficient, snowmelt contribution above permanent snow line etc. This may result some deviations in annual yield assessment at a proposed project site. However the errors associated with the assumptions in the runoff coefficient and snowmelt are likely to have fewer uncertainties in yield series of the project as the yield correction factor is computed in terms of ratio of average annual yield at proposed project site and observed annual yield of G&D site.

Disclaimer: The views expressed in the paper are purely personal and not necessarily the views of the organisation.

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