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Flow Variation in Astore River under Assumed Glaciated Extents Due to Climate Change

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Abstract

Various researchers have concluded the existence of many glaciers in doubt by the end of this century due to global warming phenomenon. The great Himalayas are also under such stress. The recent acceleration in rainfall pattern resulted the ever worst destruction due to floods (2010) in Pakistan. Many Watershed models, capable of incorporating the climate change scenarios have been developed in this regard to predict the future flows. But it is not easy to select the most appropriate model for a particular watershed to get the best results. In this regard, the paper is an effort where the analysis has been made on Astore Watershed, Pakistan, by considering the model results obtained from the three watershed models i.e. UBC Watershed Model, HBV-Met and HBV-PRECIS. The results are obtained by considering different glaciated extents of 100%, 50% and 0% under future climate scenario (SRES A2), simulated by PRECIS Regional Climate Model for (2071-2100). For changed climate scenario, discharges for the simulations at 100% reduction in glaciated area were -72%, -15% and -46% for HBV-Met, HBV-PRECIS and UBC Watershed Model respectively.

Key Words: *Astore Watershed, UBCWM, Glaciers, Retreating glacial extent, Glacier and Snowmelt modeling*

1. Introduction

The global increasing atmospheric temperature is a continuous threat for many of the glaciers of the world. The modification of glaciers has always been a vital sign of climate variation. Various researchers have concluded the existence of many glaciers in doubt by the end of this century. The glaciers are considered to be the natural reservoirs of water. The depletion of glaciers is directly proportional to the depletion of water reserves. Therefore, it is very important to study the future glaciers and their response under changed climatic conditions.

(Paul et al., 2004) reported that the glaciers are experiencing the crumple for the last 20 years or so. The climatological behavior of an area can be estimated from the increase or decrease in the extent of glaciers present there. The overall reduction in the glaciated extent of the mountains is a very clear indication of global warming (Houghton et al., 2001). Glaciers in the European Alps have been reported to reduced back by more than 2 km which is in fact the result of an increase in temperature by 1^{o}C , observed from 1850 to 1970 (Böhm et al., 2001). The change in the Alpine landscape due to this very minute rise has been acknowledged by comparing previous postcards with fresh snaps of the similar locations (Zangl and Hamberger, 2004). The great Himalayas are also under such stress and retreating (Mastny, 2000). Although (Hewitt, 1998) stated about the growth of the bigger glaciers in the Central Karakorum as well but as a whole temperatures in the Himalayas have augmented drastically in the last hundred years (Bhutiyani et al., 2007).

Precipitation is also a key factor in climate variation process. (Folland et al, 2001) stated the likelihood of increase in the precipitation to 1% from 0.5% in every 10 years in the 20th century for some high areas of Northern Hemisphere. . Statistical insignificant variations in the precipitations for many parts of the world and as well for Himalayas have been reported by researchers like (Zhai et al., 1999) and (Archer and Fowler, 2004) for the last 100 years.

In the light of above discussion it is very important to estimate river flows by considering different probable scenarios of future climatic. Such meteorological conditions are exercised as input to a hydrological model of river basin to compute the subsequent flows. The downscaling of precipitation and temperature series can be pertained to observed temperature and precipitation series with the help of simple rules of transformations (Akhtar et al, 2008).The change of water reserves because of the change in glacier area is imperative to know. But the present models are not consistent enough to compute the response efficiently with respect to the change in the glaciated areas. (Shakir et al 2010), stated that the on hand research regarding climatic parameters and glaciated extents, is not enough and further inputs are still required.

The intent of this effort is to observe the impact of climate change on the future water resources of Astore Watershed in the Upper Indus Basin (UIB) region under different glacial coverage scenarios by using University of British Columbia UBC Watershed Model. For this purpose, the results of very useful studies done by Akhtar et al (2008) are taken in to consideration. Akhtar used Regional Circulation Model RCM PRECIS nested to the Global Circulation model GCM HadAM3P under condition of SRES A2 greenhouse gas emission scenario to get future climate trends of the Astore watershed. The SRES stands for Special Report on Emission Scenario. In 2000, the Intergovernmental Panel on Climate Change has described SRES in a special report. It is agreed that the way human are using the resources of the world is the major cause of climate change or in other words global warming. In this particular report around forty scenarios were discussed in which the possible suggestions regarding future land use and greenhouse gas pollution and other harmful emitters were considered. Later in the IPCC 3rd Assessment Repot (TAR) and in the 4th Assessment Report (AR4), only six scenarios of the SRES were given major importance which is A1F1, A1B, A1T, A2, B1 and B2.

The concept of the A2 scenario is more related to those countries which are self dependent. The theory is based on the concept of divided world where all the nations are maneuvering themselves. The trend of all the countries is towards economic progress. The predicted future trends were used by Akhtar as input into the HBV hydrological model to estimate the discharge of three river basins in the present and future climate. This particular study only focuses the results for Astore watershed as further analysis by University of British Columbia Watershed Model (UBCWM) was only performed on Astore watershed so that future trends of flows in Astore River can be sensed.

2. Study Area

The Astore watershed is situated in Pakistan having the latitude 35^{o}33' and longitude 74^{o}42' and covers an area of about 3990 km^2. The location map of the study area is as shown in Figure 1. Pakistan Meteorological Department PMD has only one station i.e. Astore climatological station in this area whose elevation is 2168m a.s.l.

Fig. 1: Astore Watershed in Pakistan map

The Astore watershed is highly elevated area and the maximum elevation reaches even above 8000m a.s.l. The major area of the watershed stays covered with snow and glaciers in winter and normally has an average of 607 km^2 which is around 15% of the total area.

3. UBC Watershed Model

The UBC Watershed Model has been used in this study to model the discharges as a result of snowmelt, glacier melt, rainfall and ground water. The model was developed for Fraser River System in British Columbia (Quick and Pipes, 1976). Since most of the watershed model for glacier and snowmelt modeling use the concept of area-elevation bands, therefore, altitude is crucial variable while representing the mountain flows. The input parameters required to run the UBC model are daily maximum temperatures and daily minimum temperatures along with the daily precipitation data. The characteristics of the watershed as input data cannot be denied for reliable modeling. The soil moisture and ground water characteristics are very important to determine role of estimated flow as fast, medium and slow components of runoff (M.C. Quick.1977). Figure 2 shows the schematic diagram of the model. This is very helpful in understanding the theme of the Model.

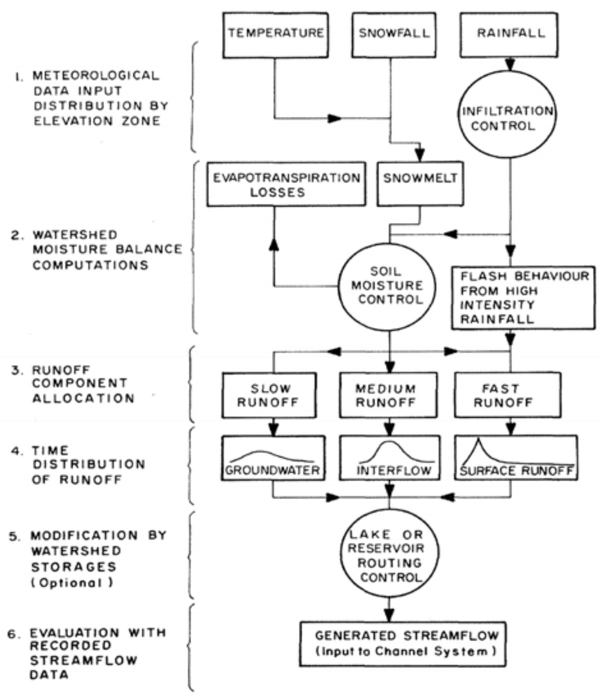

Fig. 2: UBC watershed model generalized flow chart

4. Methodology

Methodology implemented for this research work is as follows:

4.1 Data Collection

The flow data was gathered from Surface Water Hydrology Project SWHP, Pakistan. The data from (1975-2004) was collected having a total duration of 29 years. The climatological data comprising of Min and Max temperatures and the precipitations over a period of 50 years i.e. from (1960-2010) was collected from Pakistan Meteorological Department PMD Lahore Office. Finally, SRTM Shuttle Radar Topography Mission a 90 m Digital Elevation Model (DEM) was downloaded from internet source. The LandSat were downloaded from www.landsat.org of the study area to estimate the glaciated area. This is shown in Figure 3 which is a combination of tiles 149-36 and 149-35.

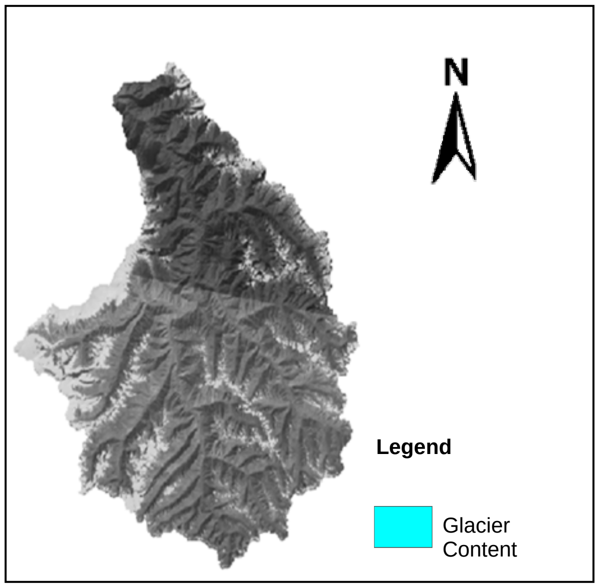

Fig. 3: LandSat imagery covering Astore Watershed where cyan color is the glaciated area of the watershed

In Figure 4, a graphical representation of the climatological data (Max daliy temperatures, Min daily temperatures and daily Precipitation) for year 1997 is shown. This is in fact the main input climatological data for UBC Watershed Model. The UBC was calibrated for this year.

4.2 Data Analysis

The average temperatures for the Astore basin were plotted from 1960 till 2010 as shown in Figure 5. A significant increase in the temperatures was found as shown by the trend line plotted.

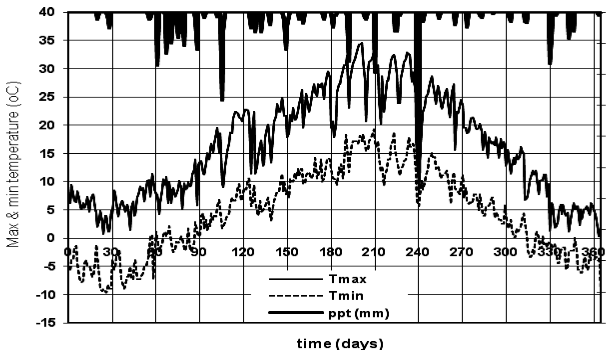

Fig. 4: Climatological data of the year 1997 for modeling flows of Astore watershed

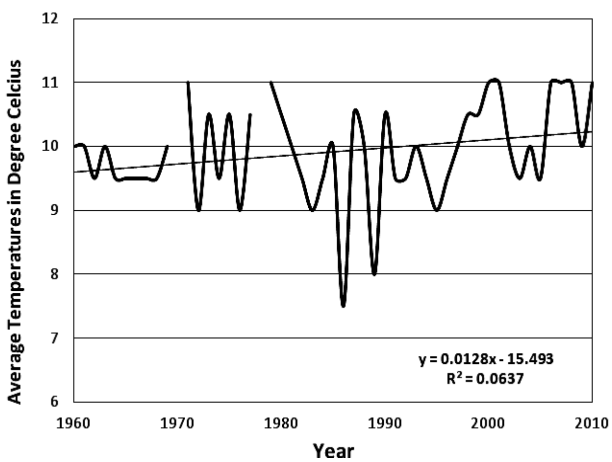

Fig. 5: Average Annual Temperatures for Astore Watershed from 1960 -2010

The precipitation data was also plotted and it is shown in the Figure 6. The behavior shown by the trend line depicts that the change in the precipitation pattern plotted from 1960-2010 is insignificant.

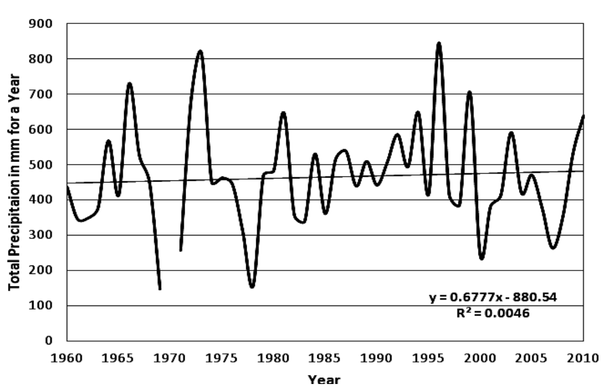

Fig. 6: Total Annual Precipitation for Astore Watershed from 1960 -2010

The study area was processed by the help of GIS applications to get the elevation bands of the area. Figure 7 is showing the performed classification. The area was divided into eight bands with legend showing the elevation range used in classification.

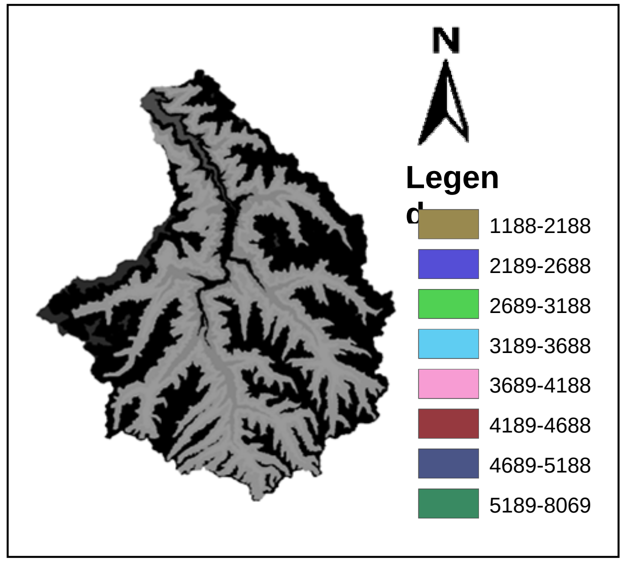

Fig.7: Eight area elevation bands of Astore Watershed using GIS tools

4.3 Input Data Preparation

The input data for UBC Model was prepared according to the requirement of Model. Table 1 shows the details of each band covering the band area, the glaciated zone and the mid elevations for each band.

Table 1: Glaciated Areas estimated from LandSat and elevations bands distribution

Band No.	Band Mid Elevation (m)	Area of Band (km^2)	Area of Glacier (km^2)
1	1688	43.8	0
2	2439	133.9	0
3	2939	338.15	0
4	3439	679.8	0
5	3939	1135.99	0
6	4439	1208.46	156.16
7	4939	351.73	351.73
8	6629	99.14	99.14

4.4 Calibration of the Model

Discharge data is not the prime need of UBC Model to operate. In fact, for the modeled flow it is used to analyze the degree of accuracy. The Doyian stream gauging station data was used here which is the stream gauging station of SWHP at Astore River. Calibration results are plotted in Figure 8 where the mean daily estimate is 87 cumecs and observed mean daily is 80 cumecs for year 1997. The statistical analysis shows that the coefficient of determination 0.95 and coefficient of model efficiency is 0.93.

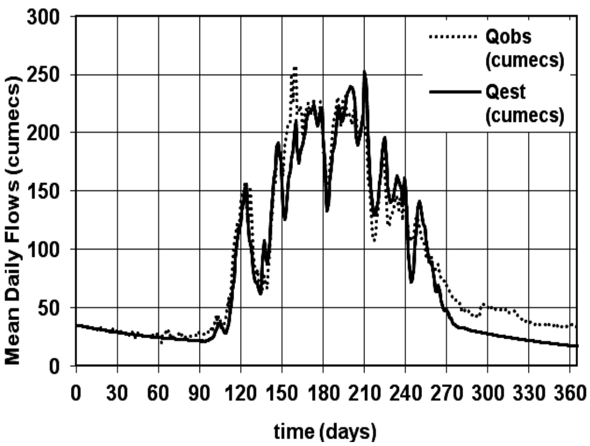

Fig.8: Calibration of UBC Model for year 1997

The component distribution of glacier melt, snow melt, groundwater contribution and rain is as shown in Figure 9. In this Figure it is obvious that the contribution from the precipitation is almost negligible when compared to the others.

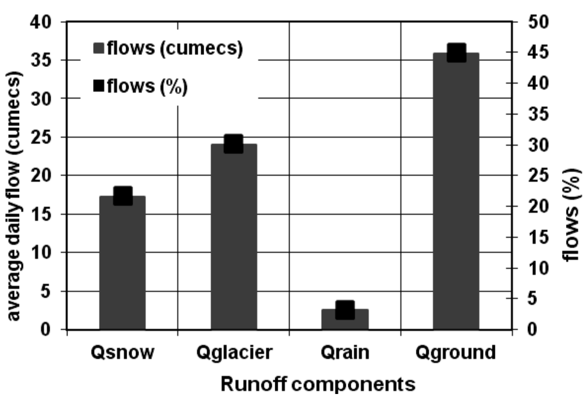

Fig. 9: Components of runoff in Astore River at Doyian stream gauging station

4.5 Validation of the Model

Before further analysis, encouraging validation of the calibrated model for 1997 was performed for certain years. Figure 10 shows the validated statistical results for the year 1996. The coefficient of determination was found to be 0.97 whereas the coefficient of model efficiency was 0.92. Further, it was also found that the observed mean discharge is 198 cumecs and the estimated is 164 cumecs for the same year showing that the validation has strong agreement with daily observed discharges for Doyian stream gauging station.

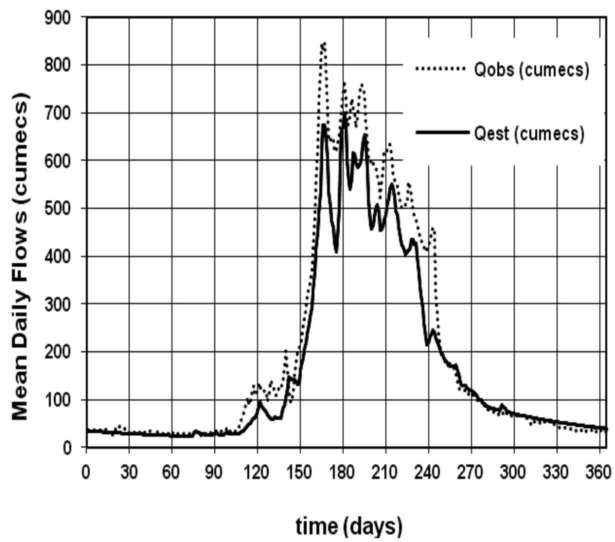

Fig.10: Validation of UBC Model for year 1996

4.6 Application of the Model

In this study, the glaciated area for Astore watershed for the year 1997 was assumed to be 100%. From Figure 5 and Figure 6, it is evident that there is a significant increase in in the temperatures of the Astore Watershed, while the change in the precipitation pattern is insignificant. It is very unfortunate that much is not available for projecting the future glaciated extents; hence, assumption was made for the future reduction in glaciated area.

The results for the future climate (2071-2100), under the condition of SRES A2 attained by Akhtar et al (2008), were incorporated here to get the future flows by using UBC. The PRECIS Model predicted that for Astore Watershed both the temperature and precipitation will be raised to 4.7^{o}C and 1% in winter (October-March) and 4.4^{o}C and 25% in summer (April-September) respectively as shown in Figure 11 and Figure 12.

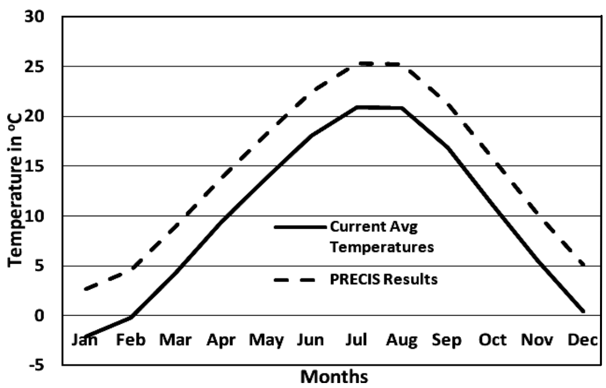

Fig.11: Average Annual Temperature (1960-2010) & future (2071-2100) predicted temperatures by Akhtar using PRECIS for Astore Watershed

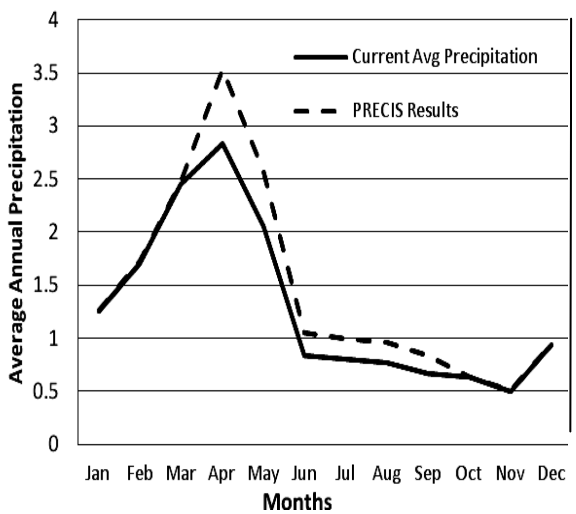

Fig.12 Average Annual Precipitation (1960-2010) and future (2071-2100) predicted Precipitations by Akhtar using PRECIS for Astore Watershed

The analysis for future flows were performed by applying the above future climate conditions (2071-2100) on current present glaciated extent and assuming this extent to be 100%. Further, analysis were performed by assuming the reduction in glaciers by 50% first, and then reduced by 100% (i.e. no glacier condition). Thus, the UBC Model was applied thrice. The results in terms of percentage difference running the UBC Model for these three conditions are given in Table 2. This Table also shows the percentage difference of flows obtained by Akhtar et al (2008) in his research where HBV Met and HBV PRECIS were used to predict future flows.

Table 2: Results showing the predicted future flows for Astore Watershed under different scenarios by HBV Met, HBV PRECIS and UBC Watershed Models

Sr. No	**Mean Change in Discharge (%)**		
	100% Glacier	**50% Glacier**	**0% Glacier**
HBV Met	48%	-12%	-72%
HBV PRECIS	41%	13%	-15%
UBCWM	18%	-22%	-46%

The contribution of the component flows computed by UBC is given in Table 3 as below in which the average annual flows are considered in cubic meters. For the calibrated year 1997, the annual average flow estimated was 87.04m^3/s. This can be seen that the flows are enhanced to 102.5m^3/s for no change in glacier extent and the future climate conditions (2071-2100) were applied. This can also be seen that for assumed scenarios of glacier reduction (by 50% and then by 100% (no glacier condition)) the estimation made by UBCWM was also reduced to 67.48m^3/s and 46.92m^3/s respectively.

Table 3: Percentage component contributions of the runoff computed for Astore River for future climate (2071-2100) under different glaciated extents simulated by UBC

Percent Glaciated Area Extent	**Percent contribution of components of runoff in Astore River Flows**				
	Q_{snow}	$Q_{glaciated}$	Q_{rain}	Q_{ground}	**Average Annual Flows Simulated by UBCWM in m^3/s**
100%	15	49	6	30	102.5
50%	17	27	7	49	67.48
0%	17	0	9	75	46.92

In Table3 Q_{snow}, $Q_{glaciated}$, Q_{rain} and Q_{ground}, are the flows due to snowmelt, glacier melt, rainfall runoff and due to the ground water respectively. It is clear that there is a certain decrease in the overall flows.

This decrease is associated with the decrease in glaciated area of the watershed.

5. Results and Discussion

The results obtained in Table 2 are shown in Figure 13. The Figure 13 shows the hydrologic response of Astore River when modeled by three watershed models i.e. HBV Met, HBV PRECIS and UBCWM. It is found that HBV Met give the extreme results when modeled for the assumed scenarios i.e. where glaciated area is 100% and when assumed 0%.

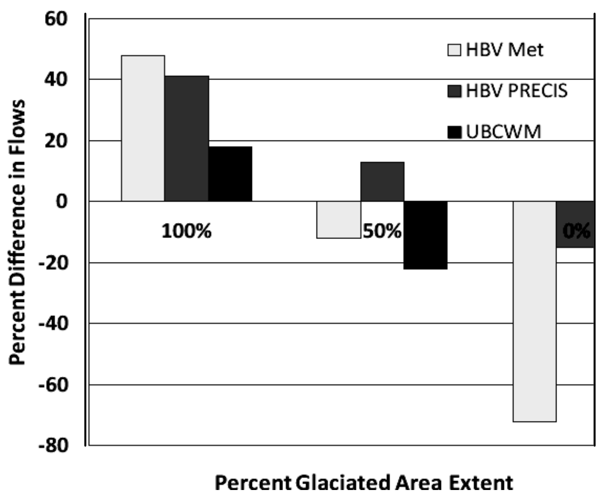

Fig.13 Hydrologic Response of Astore Watershed in terms of Percent Flows under different glaciated scenarios simulated by different Watershed Models

For the condition when 100% glaciated extent and future climate (2071-2100) was assumed, all the models over estimated the resulting flows. This is very obvious and understandable as in this assumption both the temperature and precipitation were enhanced. Therefore, the melting process will be accelerated and it is augmented by the increased precipitation rate. Hence, this will result in generation of overestimated flows. Among the three Models UBCWM overestimated the flow by only 18% while the other two Models suggest an increase which is more than 40% for Astore River provided that Astore watershed achieves the above discussed scenario.

The results for the 50% assumed reduced glaciated area are very interesting. Here, both HBV Met and UBCWM underestimate the flows by -12% and -22% whereas HBV PRECIS still overestimates the flow by 13%.The behavior of HBV PRECIS might be due to the reason that major portion of the flow estimated by HBV PRECIS is not coming out of the glaciers.

Finally consider the results with no glacier condition. It is very interesting to note that under such severe conditions i.e. enhanced temperatures and precipitation with no glaciers exists in the watershed, the modeled flows by HBV PRECIS only loose 15%. This is a clear indication that HBV PRECIS is not considering the due share of glacier extent while modeling.

Under the same scenario, HBV Met underestimates the flow too much to -72%. This narrates that Astore River will be left with only 28% of the current flow under this scenario which is can be somehow acceptable. Hence, the modeled flow by HBV Met is taking its major share out of glacier melt. In the light of above discussion, the results of UBCWM are very much encouraging.

To understand the trend of reduction in flows as discussed above in case of UBCWM, the contributions of the component flows were plotted in Figure 14 for the three glaciated scenarios.

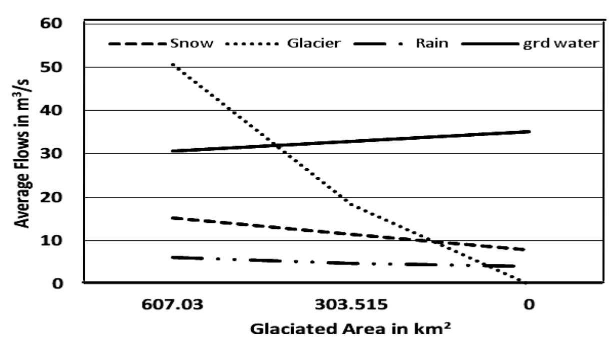

Fig.14 Contributions of the component flows m^3/s plotted against the change in the glaciated area km^2

Figure 14 explains the contributions of component flows. It is quite clear that the presence of glaciated area is very important and for no glaciated condition there would be no contribution of glacier melt in the generated flows. There is a vital and significant decrease in the contribution from glacier melt i.e. from $50.5m^3/s$ to zero.

The reduction in rainfall runoff contribution is in significant. It is found to vary between 6.1m^3/s to 4.1m^3/s. The change in the flow values of the snowmelt i.e. from 15.2m^3/s to 7.8m^3/s and ground water i.e. from 30.7m^3/s to 35.1m^3/s is also significant.

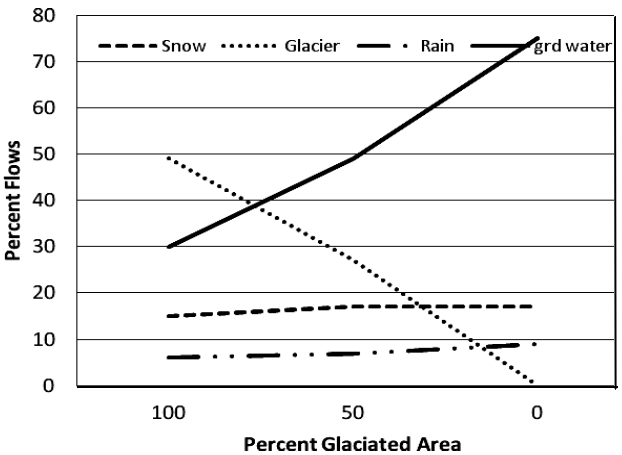

Fig.15 Percent contributions of the component flows plotted against percent change in the glaciated area

In Figure 15 the contributions are plotted in terms of percentage. It is found that with the constant decrease in percentage of glacier melt under the future scenario, the percentage contribution of other components get importance. The percentage of ground water contribution is enhanced to 75% from 30%, when modeled for the scenario of no glaciers. The increase in the percentage of rainfall runoff is from 6% to 9% which is in significant. It is very interesting to note that the contribution from snowmelt was found to be 15% when modeled for 100% glaciated extent. This percentage was increased to 17% for assumed 50% reduction in glaciated extent and sustained for the condition till glaciated extent was 0%.

6. Conclusions

- ✓ Temperatures are increasing in the Astore watershed which assures the occurrence of global warming in the region.
- ✓ There is a certain but very little increase in precipitation of Astore watershed hence, still insignificant.
- ✓ UBC Watershed Model simulates well the observed discharges for the Astore Watershed considering calibrated and validated results.
- ✓ For the glaciated scenario of 100% extent, all Models overestimate the flows and under the scenario of no glacier condition all Models underestimate the flows.
- ✓ Under extreme scenarios HBV Met gives extreme results for modeled flows. The HBV Met over estimates the most for 100% glacier condition and on the same side underestimates the most when no glacier condition is assumed.
- ✓ HBV PRECIS is the only Model which even over estimate flows under the scenario of reduced glaciated extent by 50% and even hardly underestimate flows for no glacier condition.
- ✓ In terms of percentages the glacier melt contribution reduces to zero for no glacier condition whereas the contribution from ground water contribution rose to 75% which was initially 30%.

7. Acknowledgements

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