Glacier contribution to Runoff

Renoj J.Thayyen

**National Institute of Hydrology
Roorkee**

Why study glaciers???

- Water resource
- Climate change indicator
- Climate proxy
- Regional/ macro scale climate regulator.
- sediment transfer
- Indicator of change in regional hydrology

Hindu Kush –Himalayan Region is the water tower of Asia feeding to major Rivers flowing through world's most populous regions

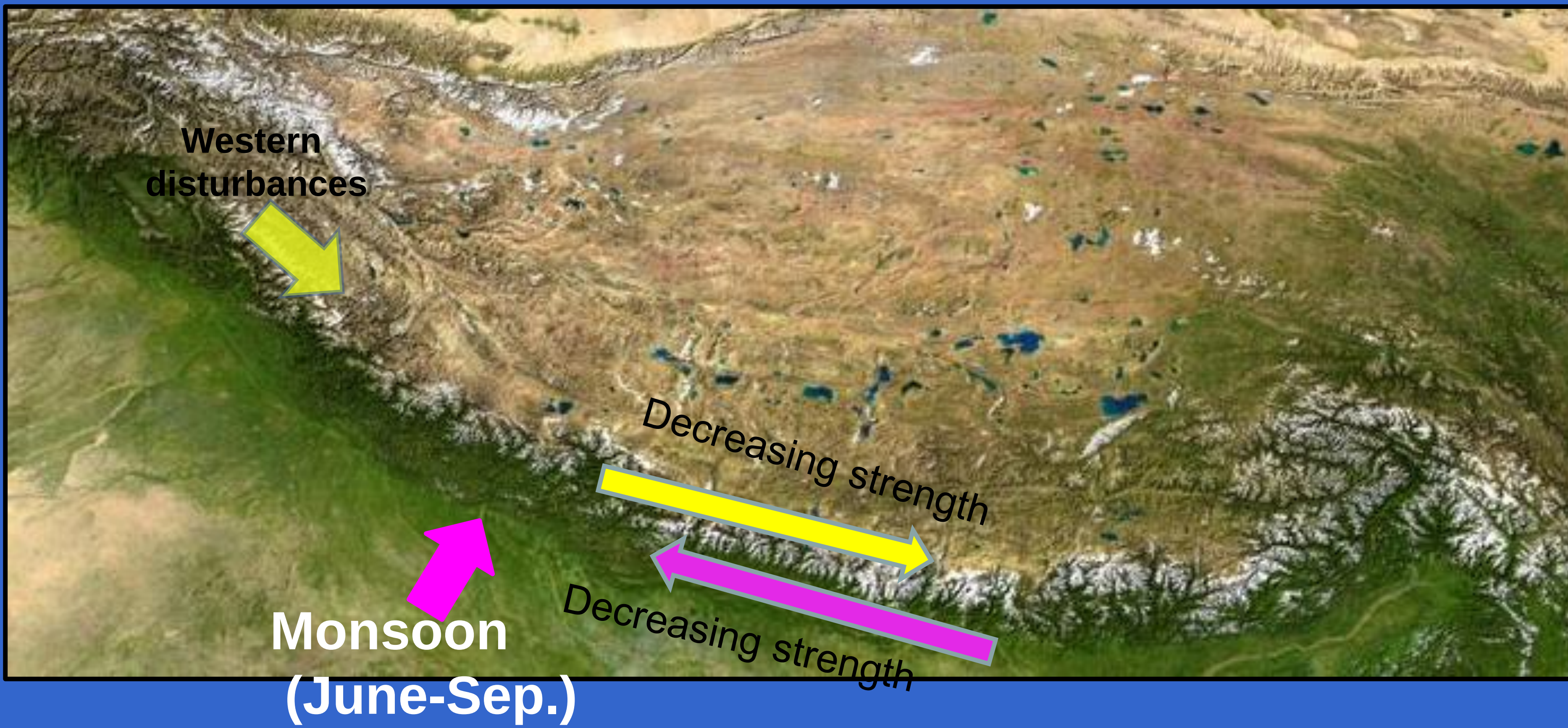
Himalayan River basins, Glacier cover & Population

Basin name	Basin area, km^2	Glacier area, km^2	Glacier area, %	Population, 10^6
Indus	1,139,814	20,325	1.78	211.28
Ganges	1,023,609	12,659	1.24	448.98
Brahmaputra	527,666	16,118	3.05	62.43

NAP-2012

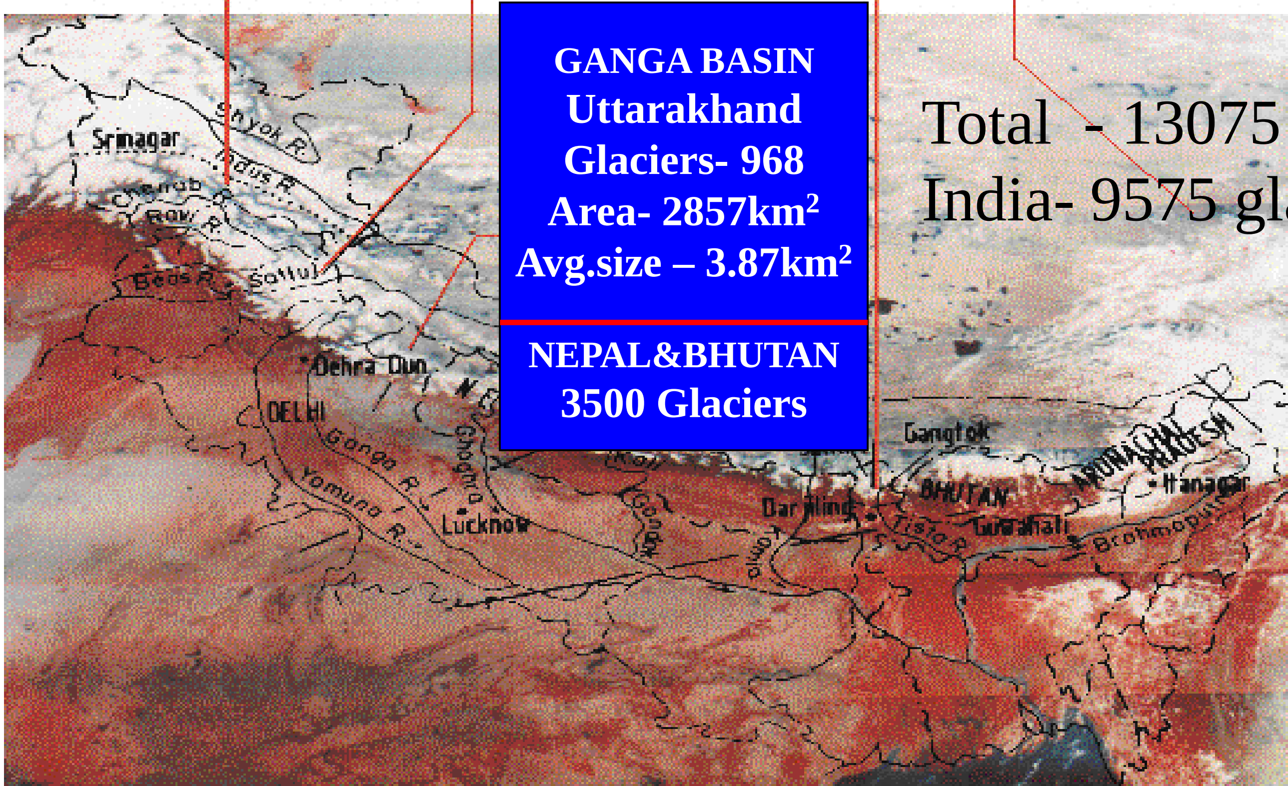
Water resource potential of the Himalayan river basins - India	
Name of the River Basin	Average Annual Potential of the River BCM
Indus (up to Border)	73
Ganga	525
Brahmaputra, Barak & Others	585

Precipitation control on Runoff of Himalayan Rivers



Distribution of Glaciers in the Himalaya

INDUS BASIN		BRAHMAPUTRA BASIN	
J&K Indus,Nubra,Shyok, Jhelum,Gilgit Glaciers - 5386 Area – 29163 km^2 Avg.size – 10.24 sq.km	**H.P** Chenab,Beas,Ravi Satluj Rivers Glaciers –2786 Area –4466 Avg.Size – 3.35km^2	**SIKKIM** Tista River Glaciers – 449 Area – 706 km^2 Avg.Size –1.59km^2	**ARUNACHAL** Kamang River Glaciers –162 Area –228km^2 Avg.Size – 1.41 km^2



GANGA BASIN
Uttarakhand
Glaciers- 968
Area- 2857km^2
Avg.size – 3.87km^2

NEPAL&BHUTAN
3500 Glaciers

Total - 13075
India- 9575 glaciers (GSI)

How glacier change is impacting the Downstream flows: General views

Stream flow response to glacier change- Alpine catchment Present understanding

“ the total stream flow is reduced in years of positive glacier mass balance, when water is withdrawn from the annual hydrological cycle and put into glacier storage. The opposite occurs in years of negative glacier mass balance since water is released from long-term glacier storage, thereby increasing the stream flow.” (Hock et al.,2005)

“discharges will be highest when deglaciation is rapid”. (Benn and Evans,1998)

?

Barnett et al.,(Nature,2005) transferred this knowledge to the Himalayas stated that "But in the HKH region, there may (for the next several decades) appear to be normal, even increased, amounts of available melt water to satisfy dry season needs. The shortage when it comes, will likely arrive much more abruptly in time; with water systems going from plenty to want in perhaps a few decades or less. It appears that some areas of the most populated region on Earth are likely to 'run out of water' during the dry season if the current warming and glacial melting trends continue for several more decades".

"additional contribution of meltwater to the runoff in the period of strong glacier retreat is clearly reflected in the high average runoff, particularly between 1940 and 1950. The minimum runoff in the period n 1975-80 is connected with the significant storage of water into positive glacier mass balance". (Rothlisberger and Lang,1987)

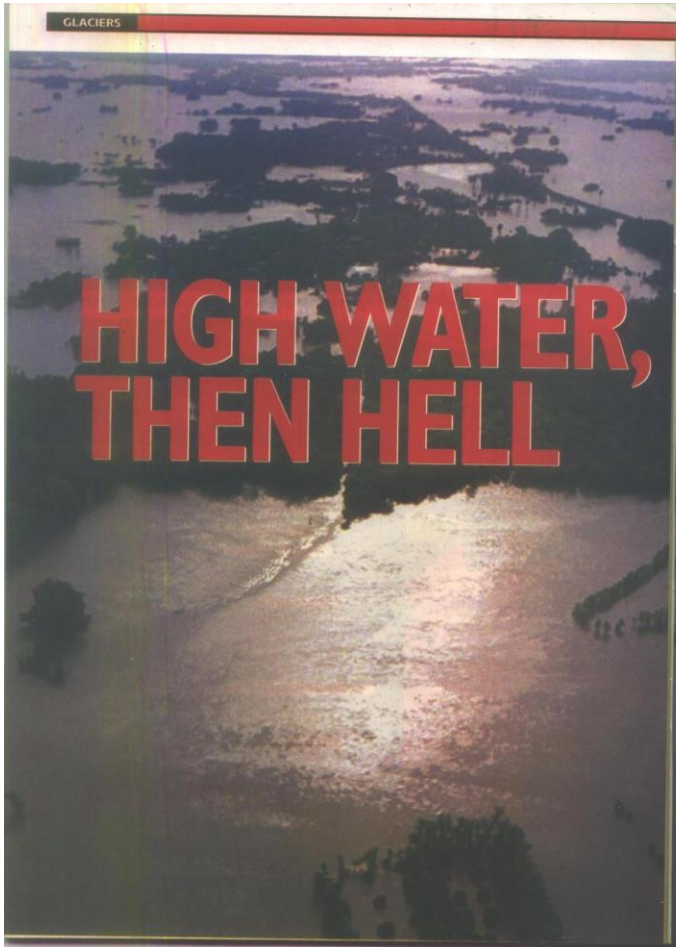
?

1. “as these glaciers retreat due to global warming, river flows are increased in the short term, but the contribution of glacier melt will gradually decrease over the next few decades” (IPCC, 2007,Chapter 3 Freshwater).

&

2. “the enhanced melting of glaciers leads at first to increased river runoff and discharge peaks and an increased melt season” (IPCC, 2007, Chapter 1, Assessment of Observed Changes ……..).

The concept of increased river runoff due to enhanced glacier melting in the beginning and reduced river flows later have huge influence on the way climate change impact is perceived for Himalayan rivers .



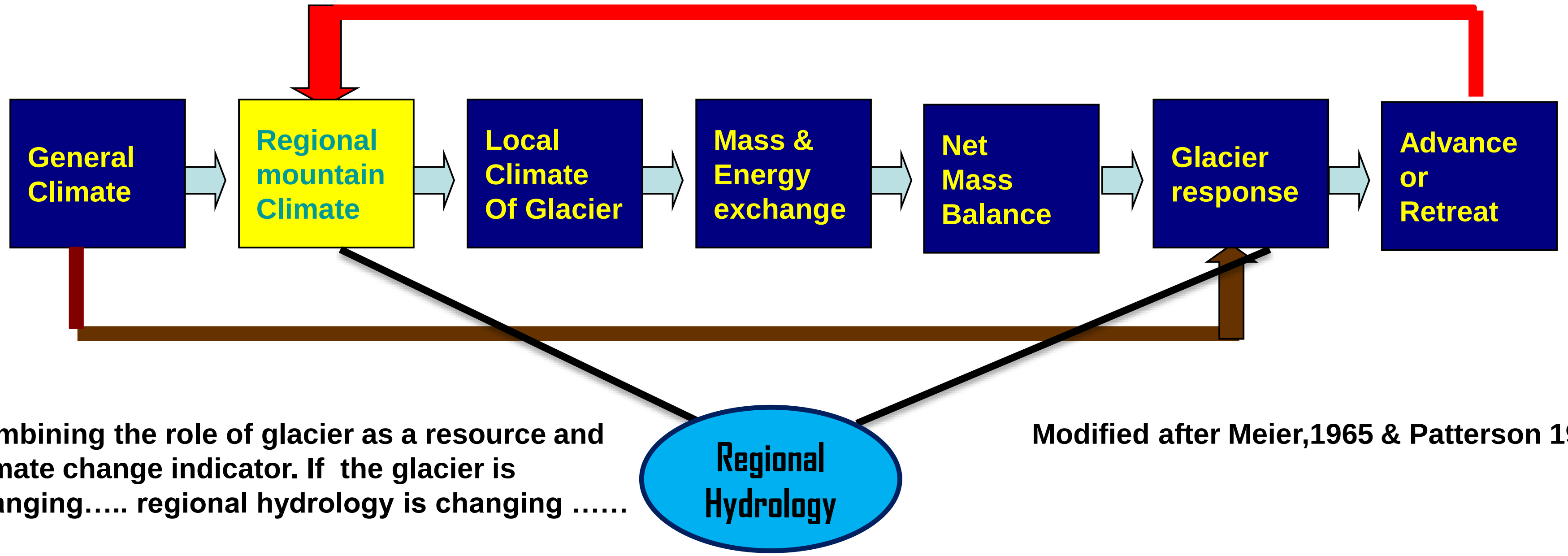
Outlook Magazine July 25 2005

Runoff components of mountain catchments

- **Glacier**
- **Snow**
- **Rain**
- **Permafrost**
- **Groundwater (Springs)**

Do we need a new perspective of glacier contribution to downstream flow in the Himalayan region ?

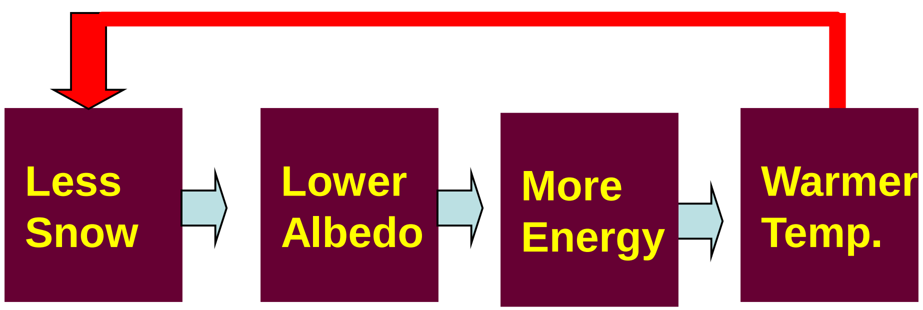
Climate - Cryospheric system forcing, feedback and Regional Hydrology



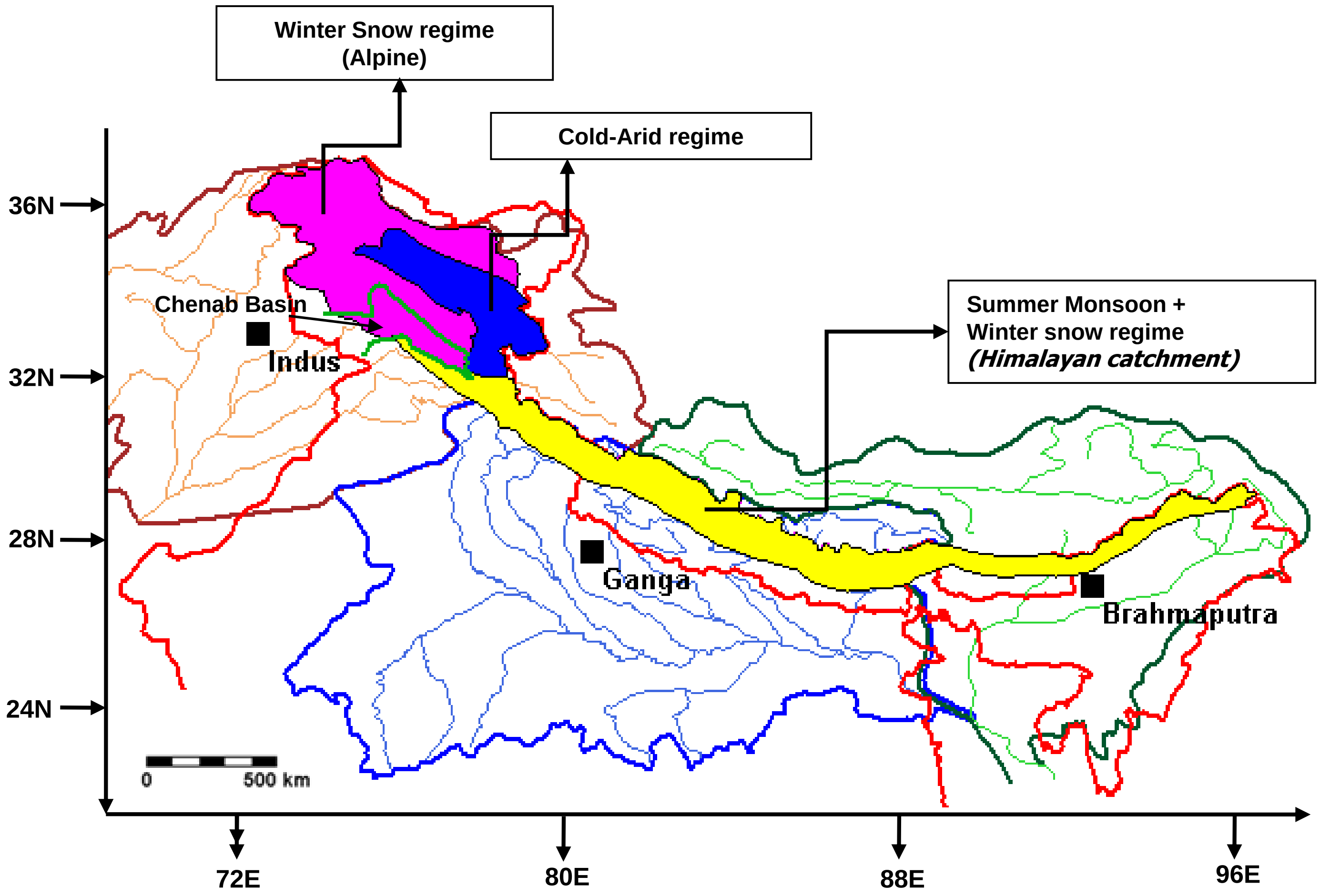
Combining the role of glacier as a resource and climate change indicator. If the glacier is changing….. regional hydrology is changing ……

Modified after Meier,1965 & Patterson 1994

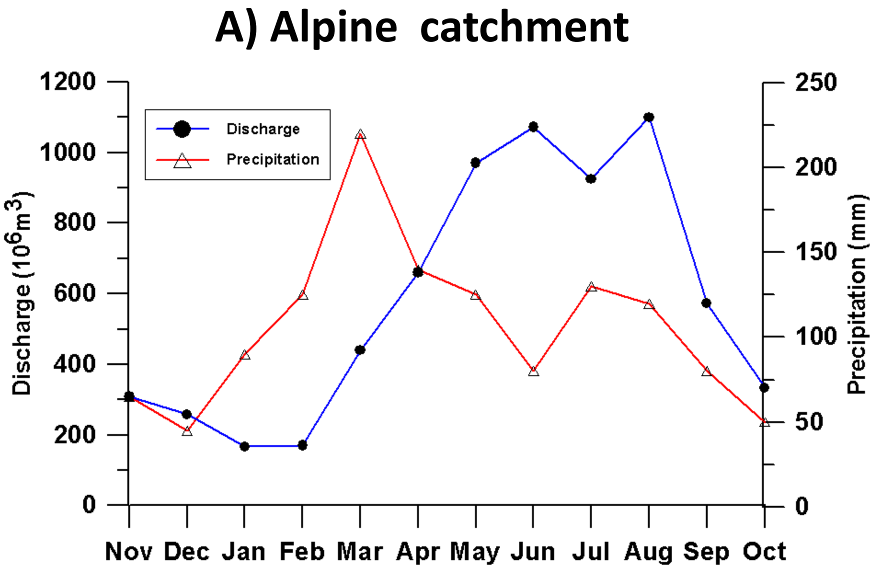
Albedo feedback



Glacio-Hydrological regimes of the Himalaya

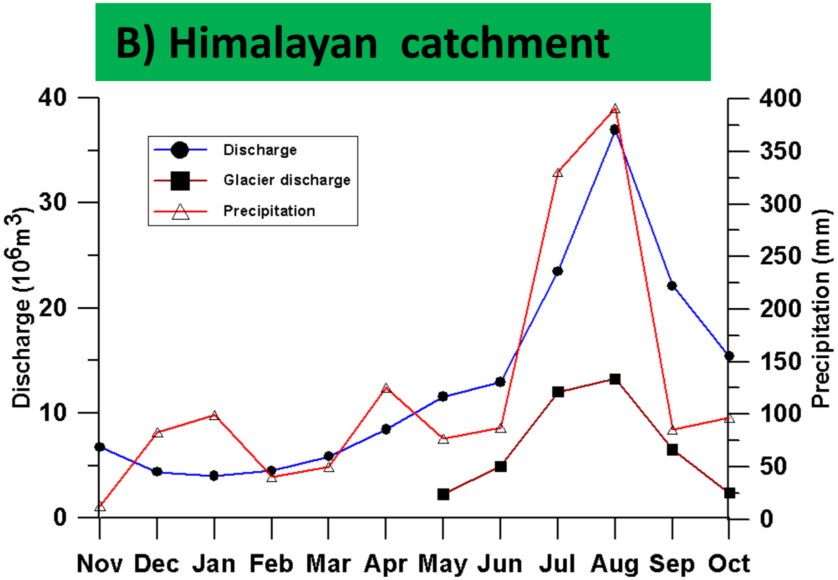


Thayyen & Gergan, 2010, *The Cryosphere*



Characteristics of glacio-hydrological regimes of the Himalaya

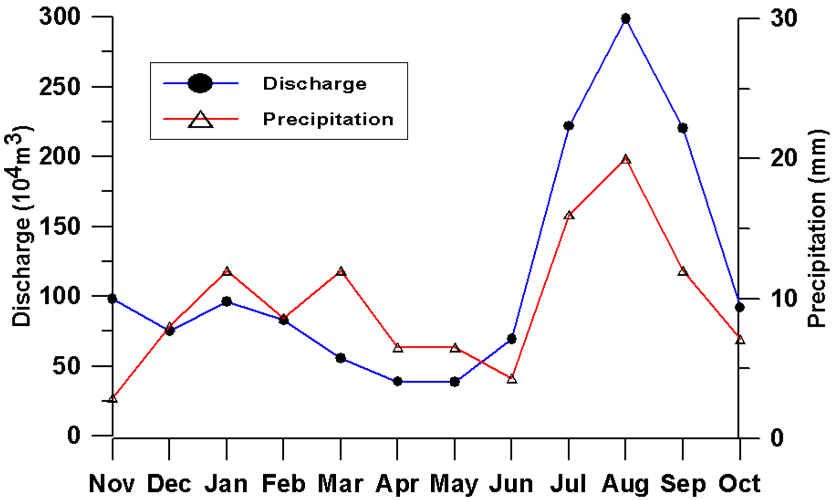
In Alpine glacier hydrological system, peak glacier runoff contributes to other wise low flow period of annual stream hydrograph governed by lower precipitation in summer.



Himalayan glacier hydrological system is characterized by the peak glacier runoff contributing to the crest of the annual stream flow hydrograph from monsoon in July and August months.

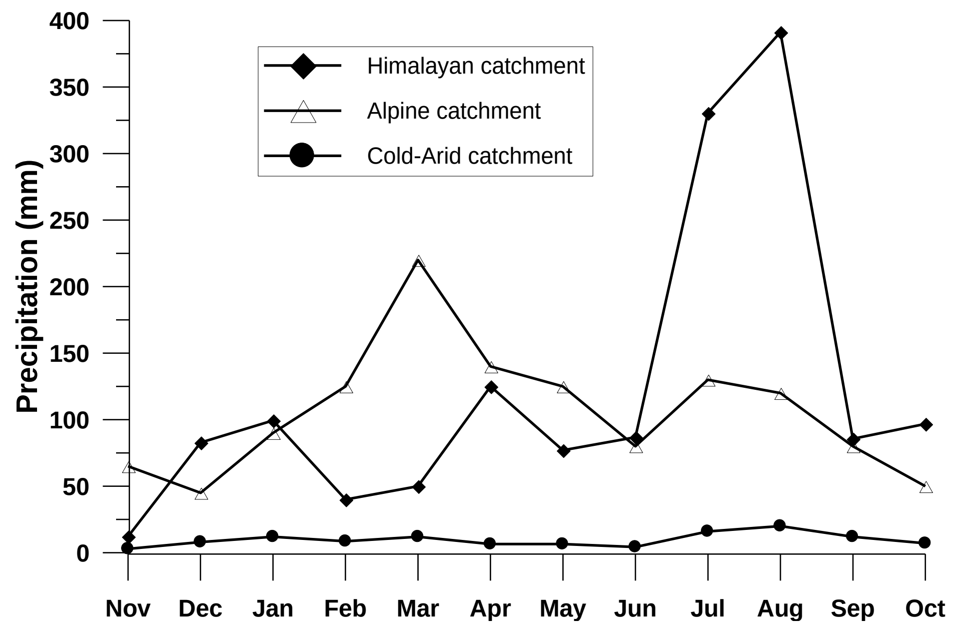
(**Thayyen &Gergan, The Cryosphere 2010)**

C) Cold – arid catchment



In the cold-arid regions of the Ladakh, annual discharge peak occur in the month of July and August mainly due to higher glacier melting during the period.

Temporal distribution of precipitation in these three glacio-hydrologic regimes of the Himalaya shows domination of monsoon over WD's in the Himalayan catchment and WD's over summer precipitation in the Alpine catchment. Arid conditions prevails in the Ladakh range with annual precipitation of 115mm.



(Thayyen &Gergan, The Cryosphere 2010)

Factors controlling glacier discharge contribution to the stream flow

Percentage glacier cover in the catchment

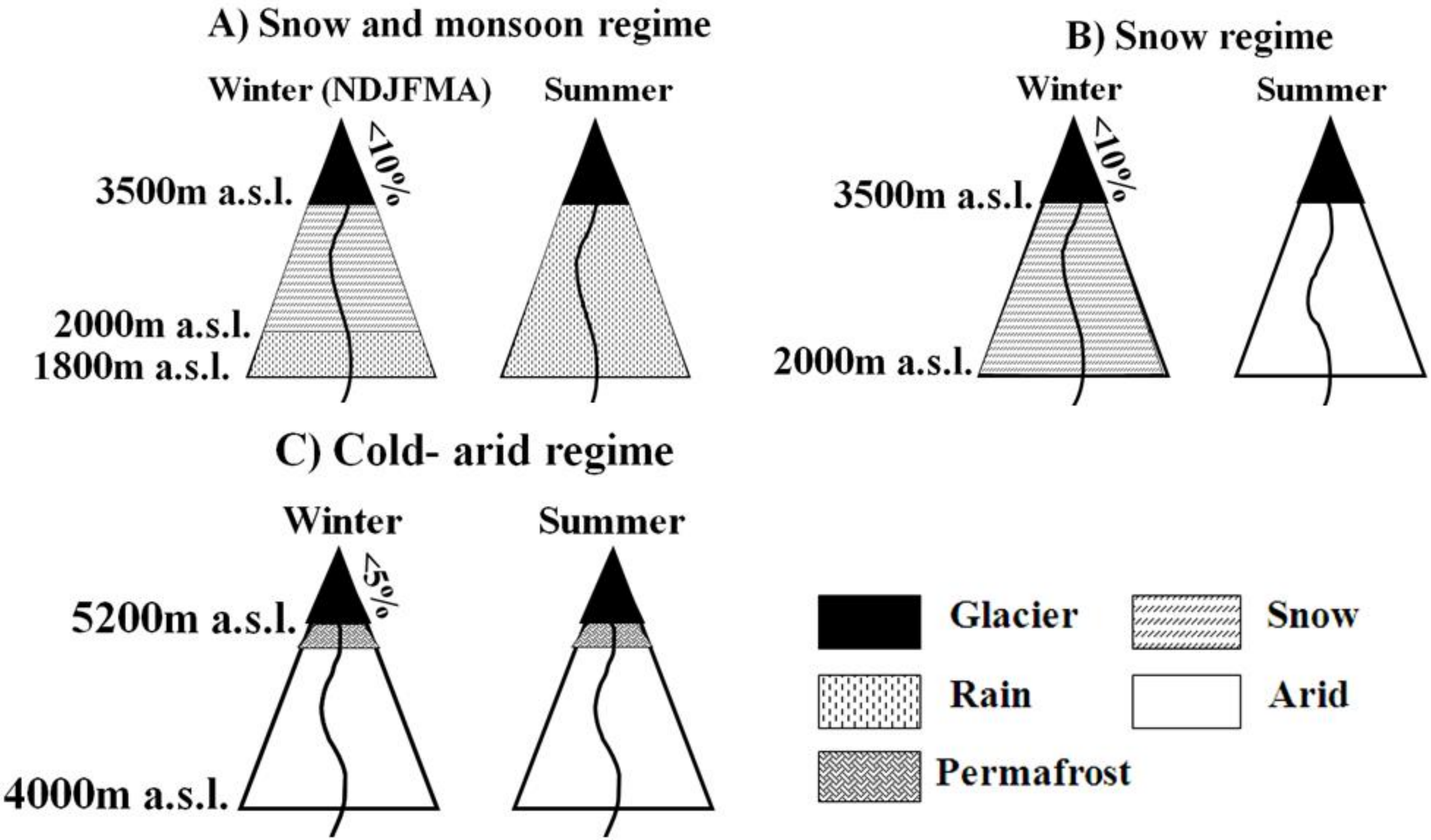
Spatial and temporal distribution of Precipitation & Temperature

Forms of Precipitation

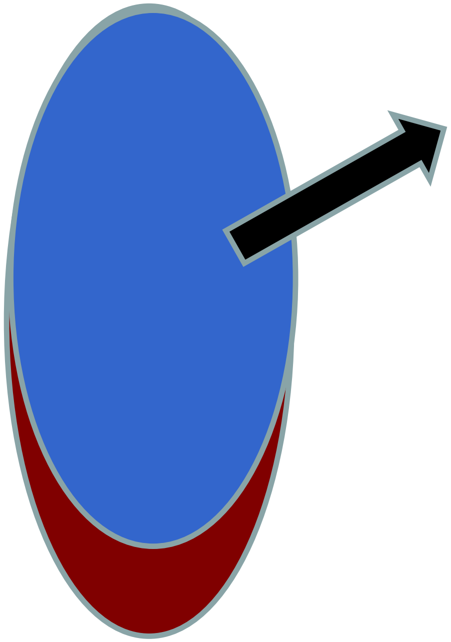
a. **Snowfall- delayed runoff (Seasonal & Instantaneous- Albedo)**
b. **Rainfall - No delay , enhanced melting (Raindrop temperature, Latent heat release during refreezing of rainwater.**

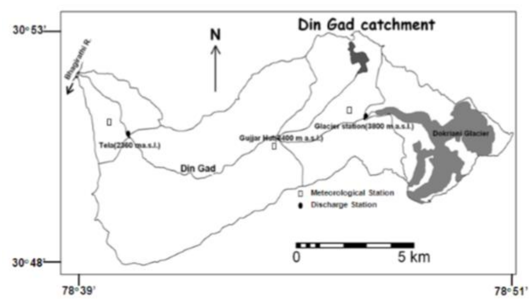
Spatial and temporal distribution of Precipitation & Temperature

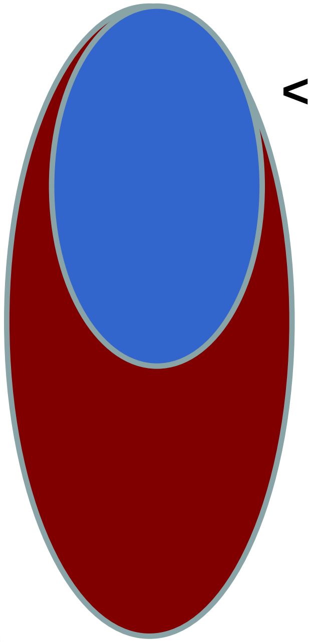
Effect of glacier contribution is determined by the downstream hydrology



Role of Glacier cover in the catchment runoff





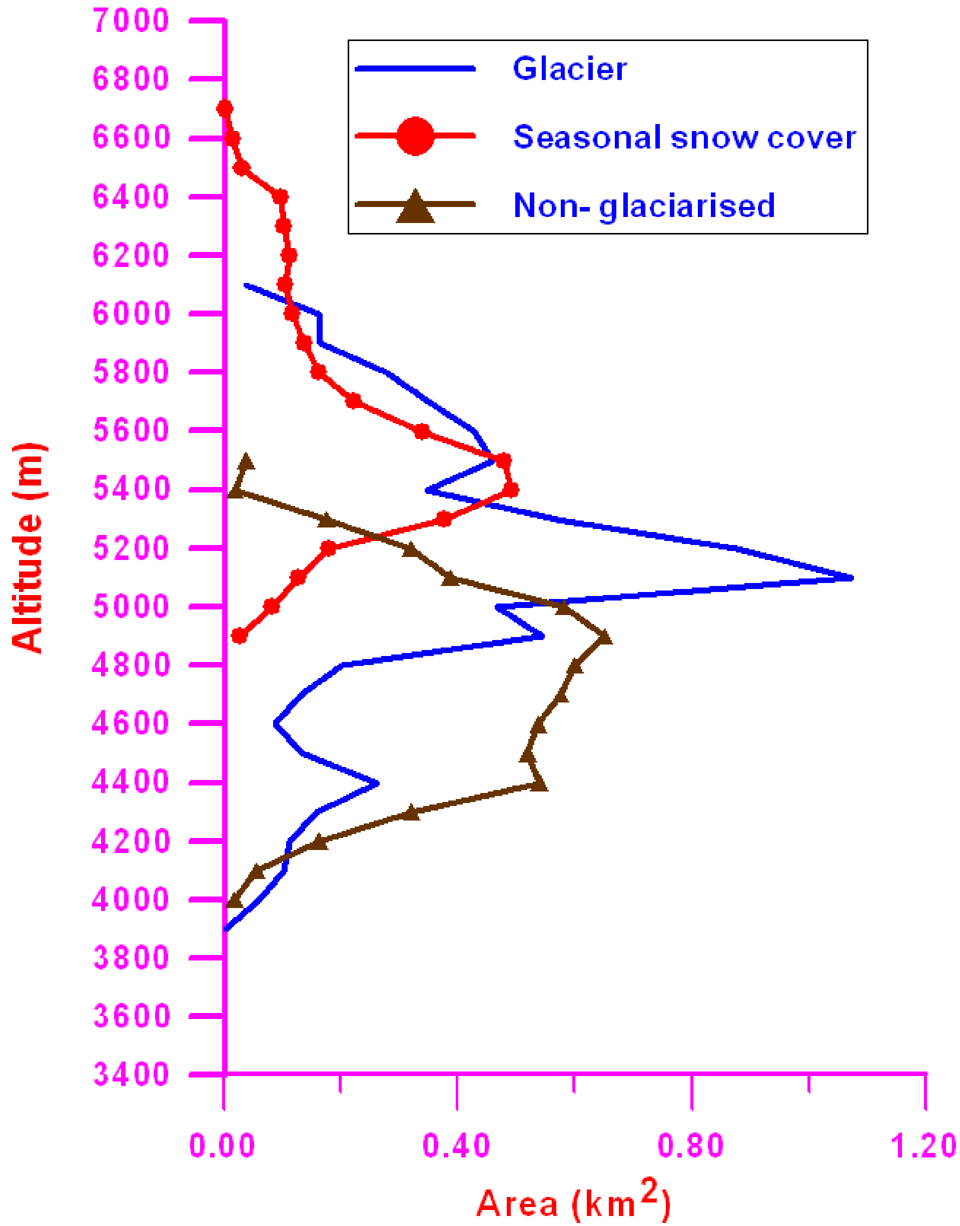


Glacier dominant Runoff

Precipitation dominant runoff

" Runoff from mountain glaciers is naturally buffered or regulated in a way benefal to man, producing increased runoff at times of high temperature or deficient precipitation and storing water when the need for it lower" *(Meier & Roots 1982)*

Glacier Hypsometry & Glacier runoff influence



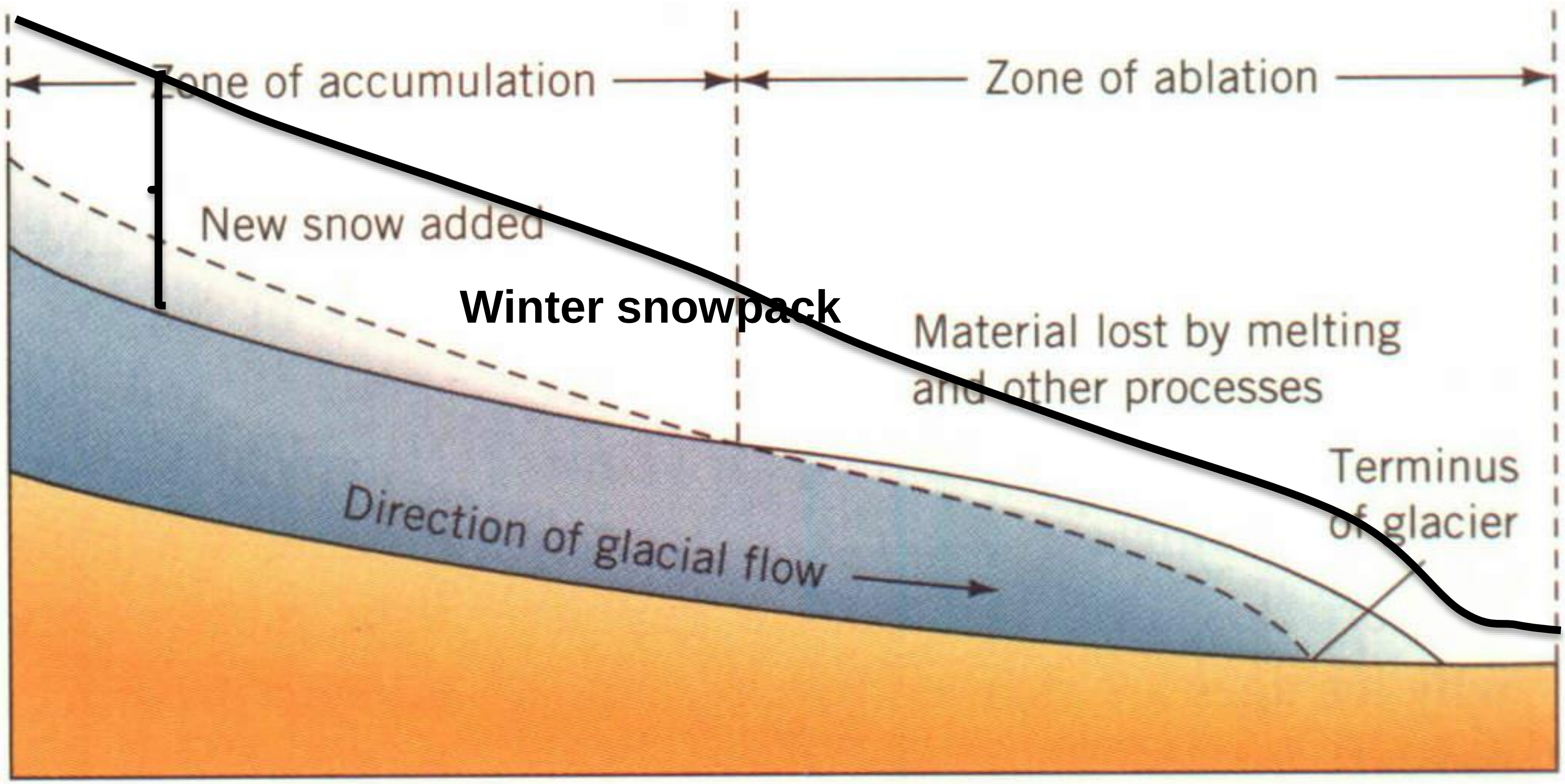
Glacier basins have large areas free of glaciers and runoff contribution from these area is governed by the precipitation characteristics and influence the discharge from the glacier.

Glacier runoff components

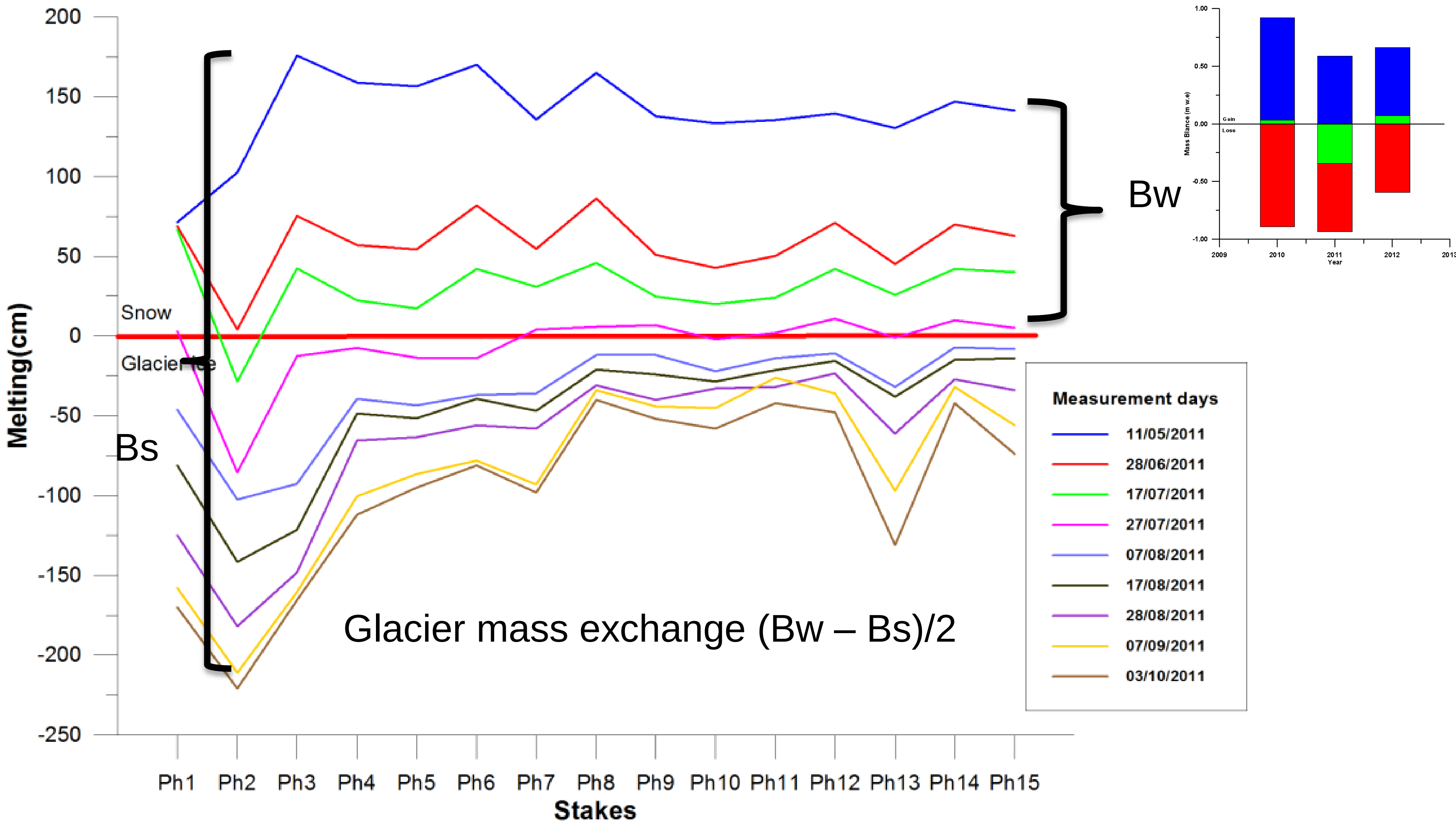
- Winter mass balance
- Summer Mass balance
- Net Mass Balance / Glacier degradation derived runoff
- Mass turn over (Bw-Bs)/2
- Internal glacier drainage

Glacier Mass turn over

Net mass balance is a poor indicator to assess the glaciers role in down stream flow……. We need glacier mass turn over values

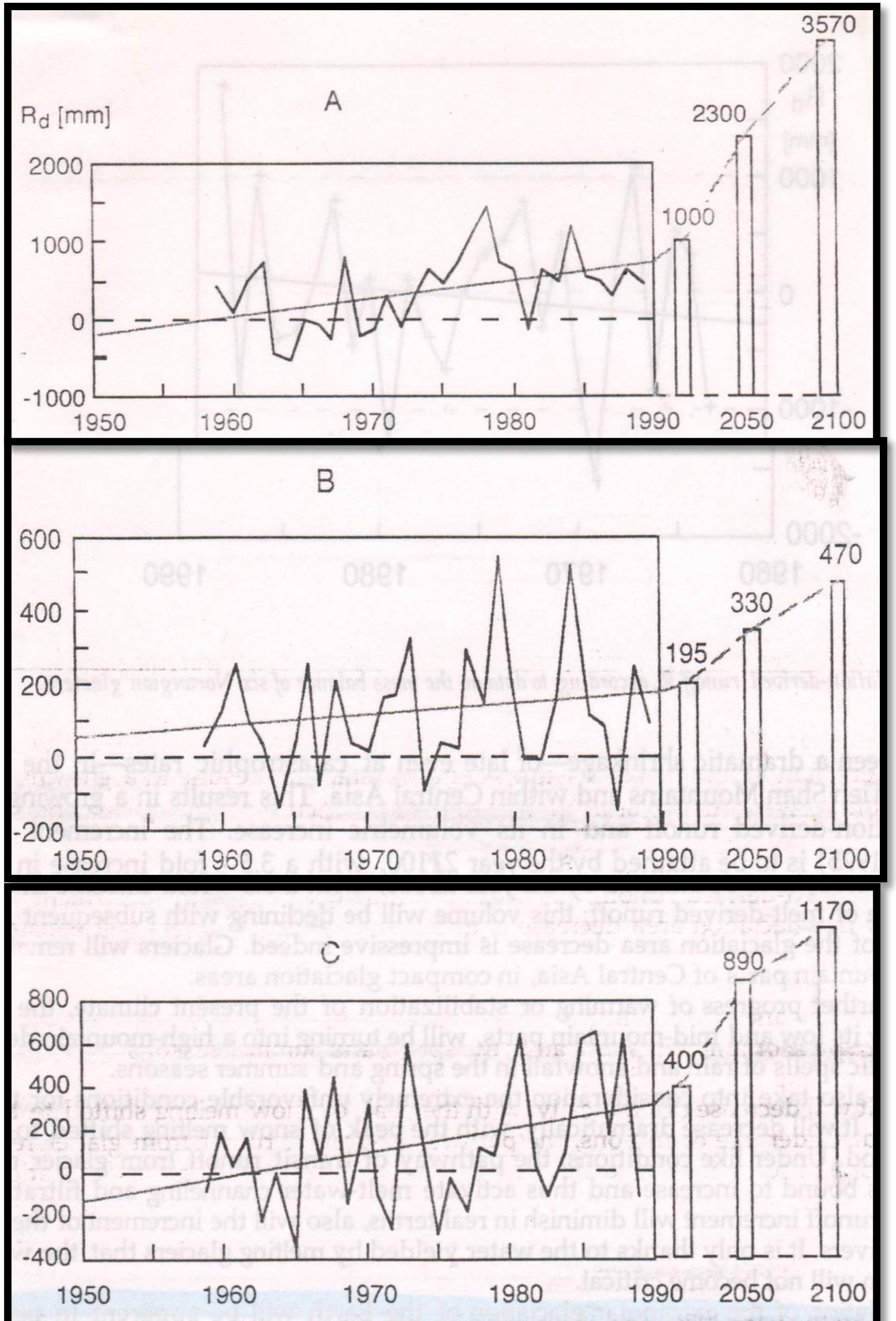


Glacier Mass turn over
Examples – Phuche glacier, Leh, Ladakh



What we know from Alpine studies

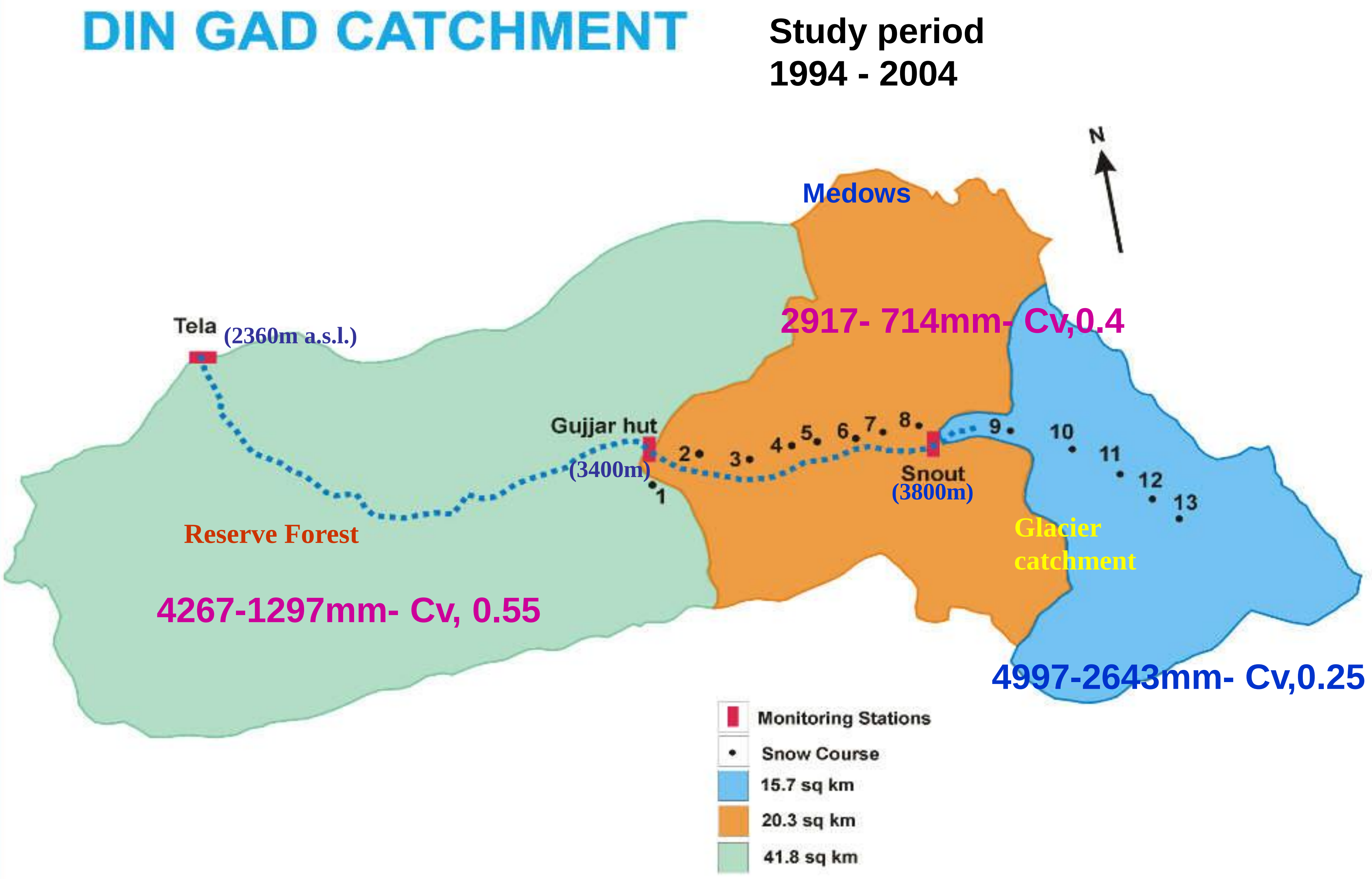
- Glaciers contribute to the stream flow during otherwise low flow conditions.
- During the positive mass balance period glacier hold water.
- During negative mass balance years glacier release the stored water.
- Higher melting of the glacier during the warm period lead to higher stream flow during the initial period which declines after the glacier size reduces to threshold,

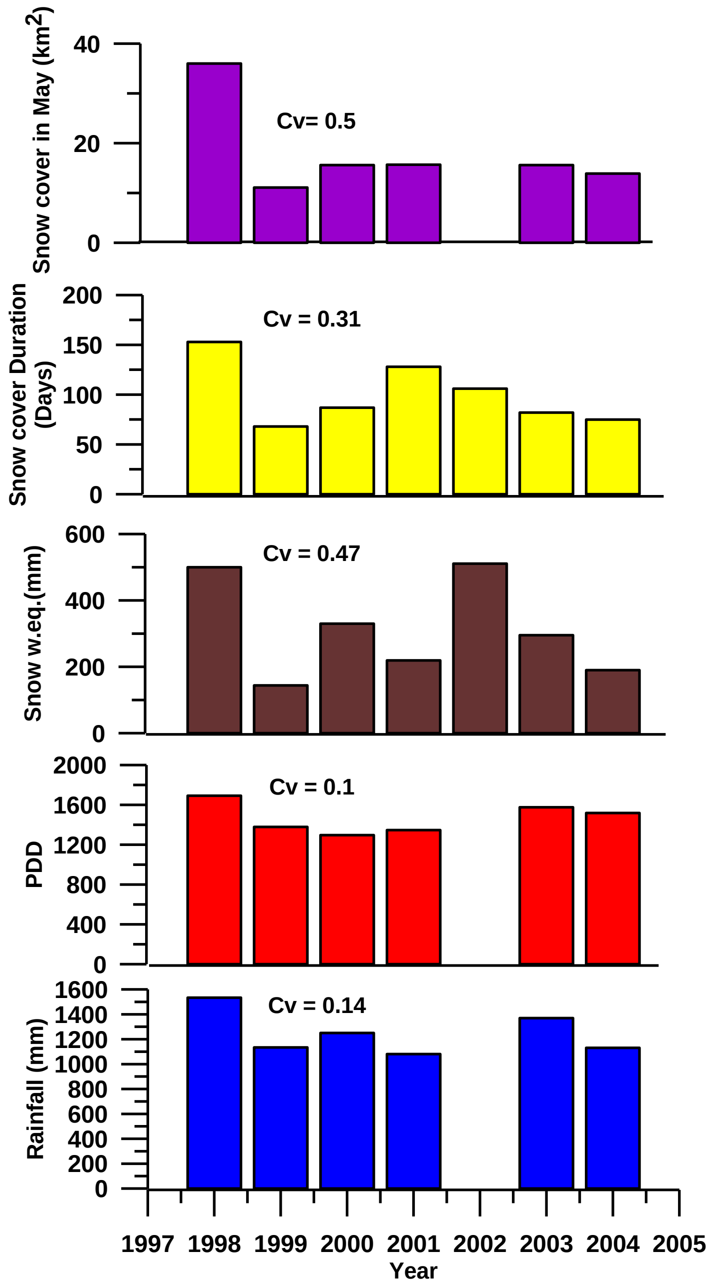


Glacier degradation derived runoff and probable future trend in various glacier melt regimes

Case Study -1 Himalayan catchment

Study period
1994 - 2004

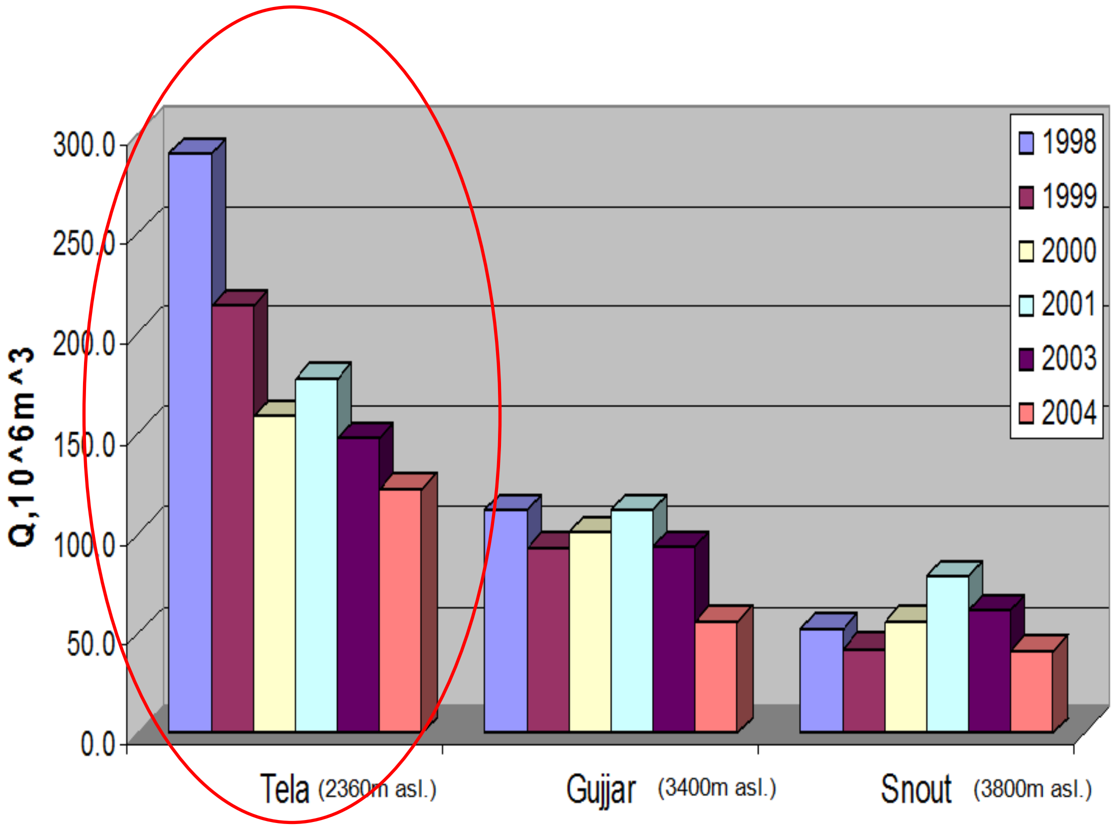




Headwater stream flow

Role of various hydrological components

Glacier runoff forcing on Stream flow variations- Monsoon system

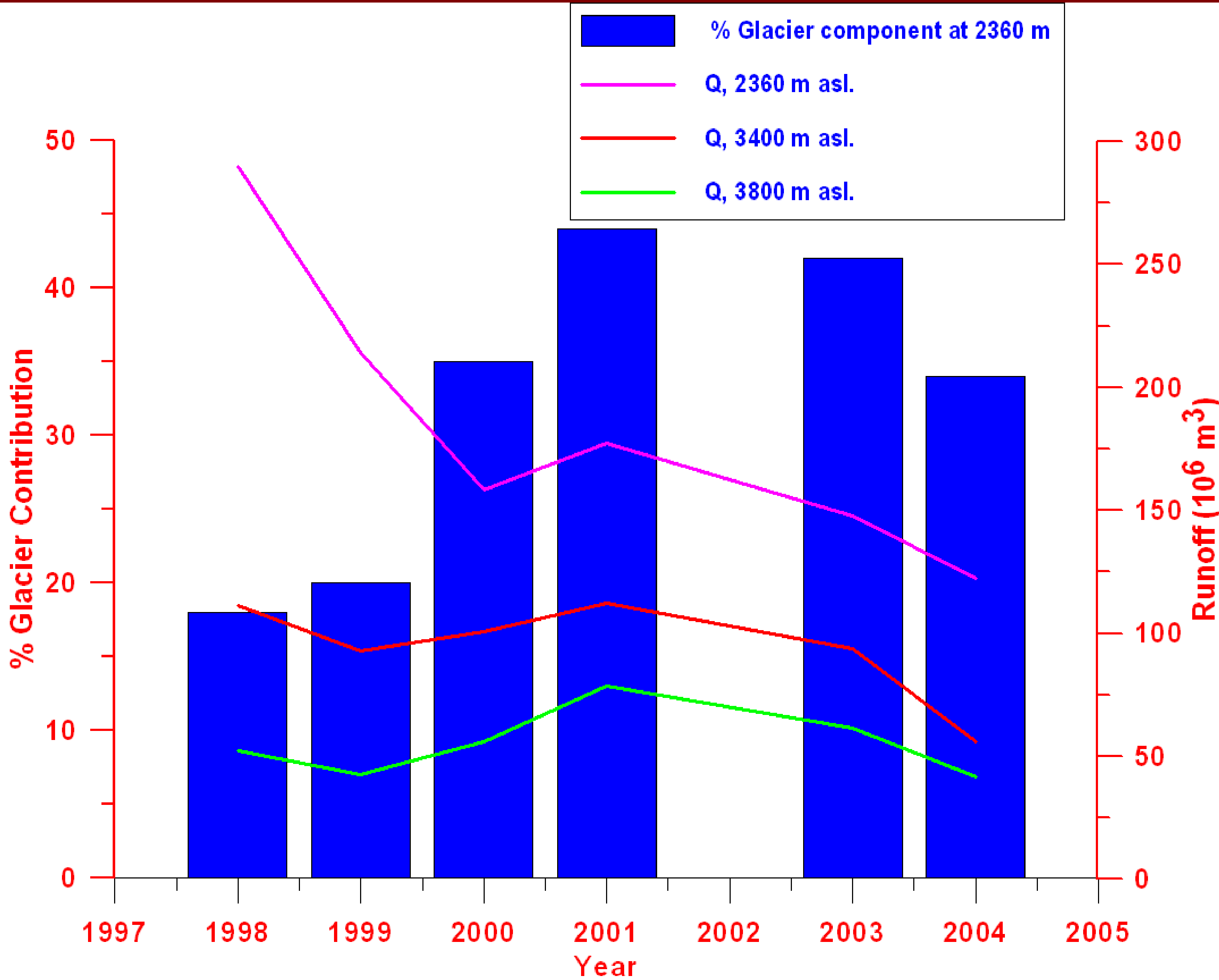


Nival-Monsoon Zone

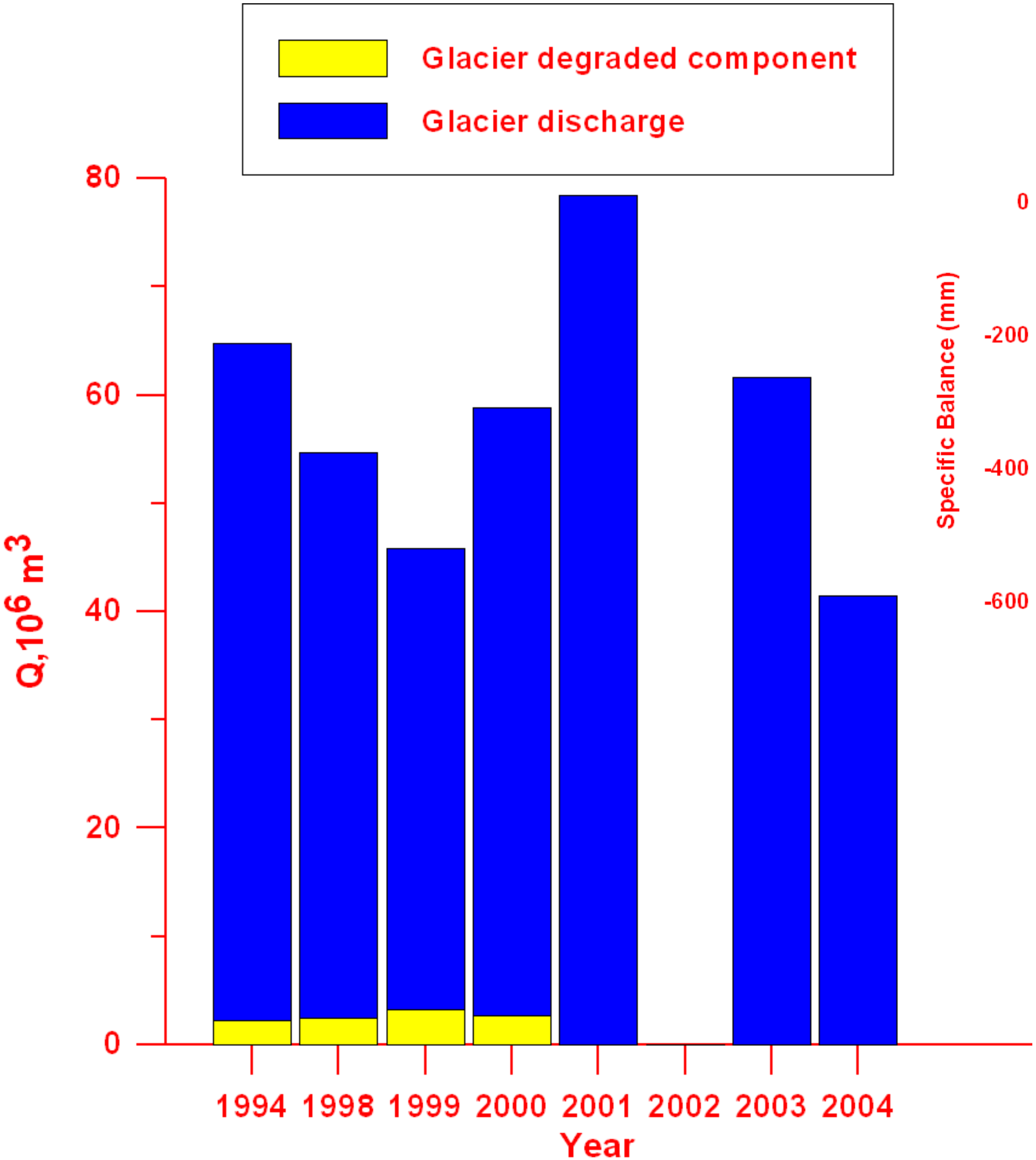
Enhanced glacial degradation in a warming climate will not translate as increase in river flow as suggested by IPCC 2007.

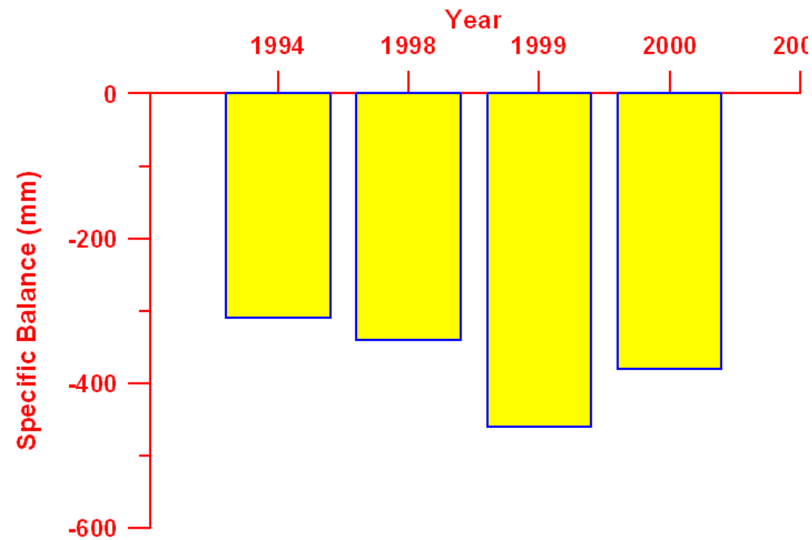
Thayyen & Gergan, 2010, *The Cryosphere*

Recent Headwater River runoff variations & Glacier component



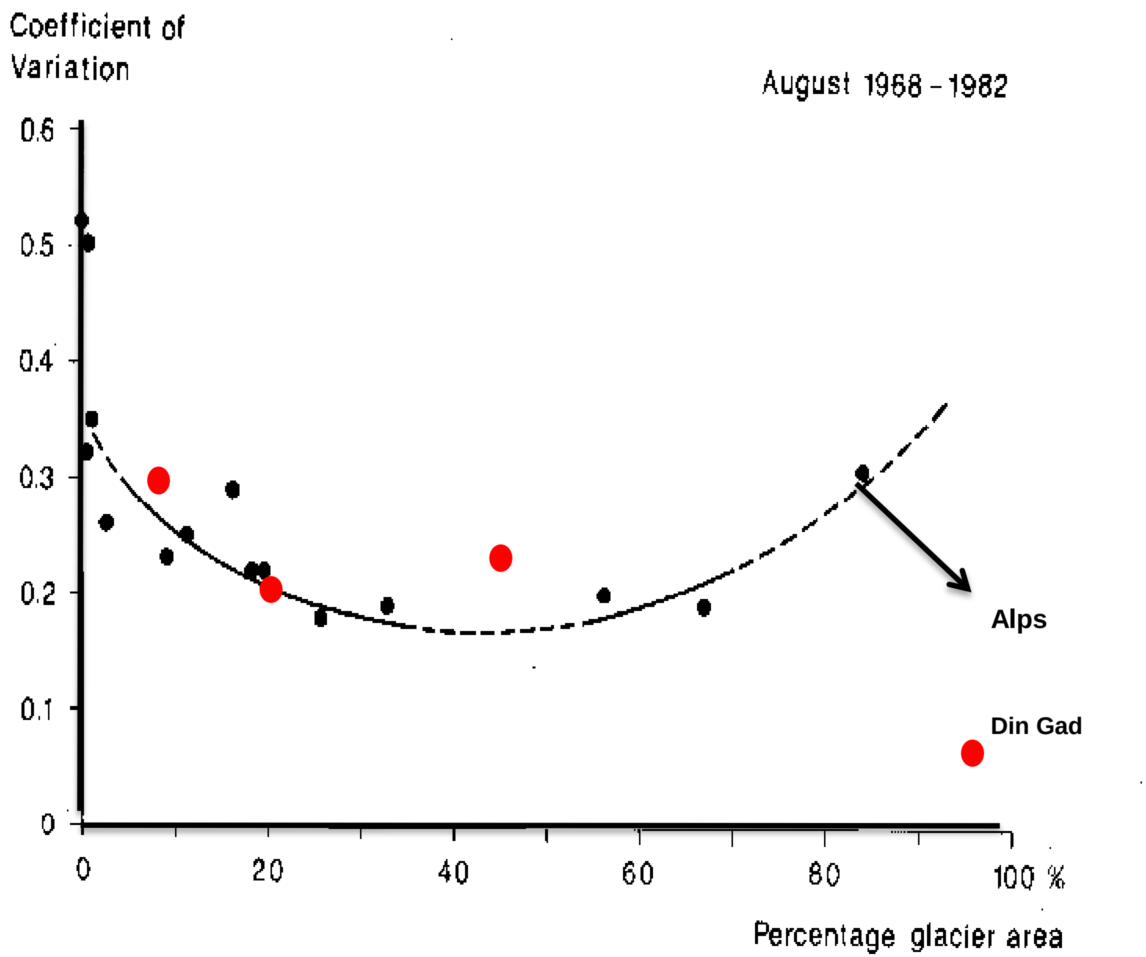
Glacier runoff – Mass Balance relationship
Dokriani Glacier



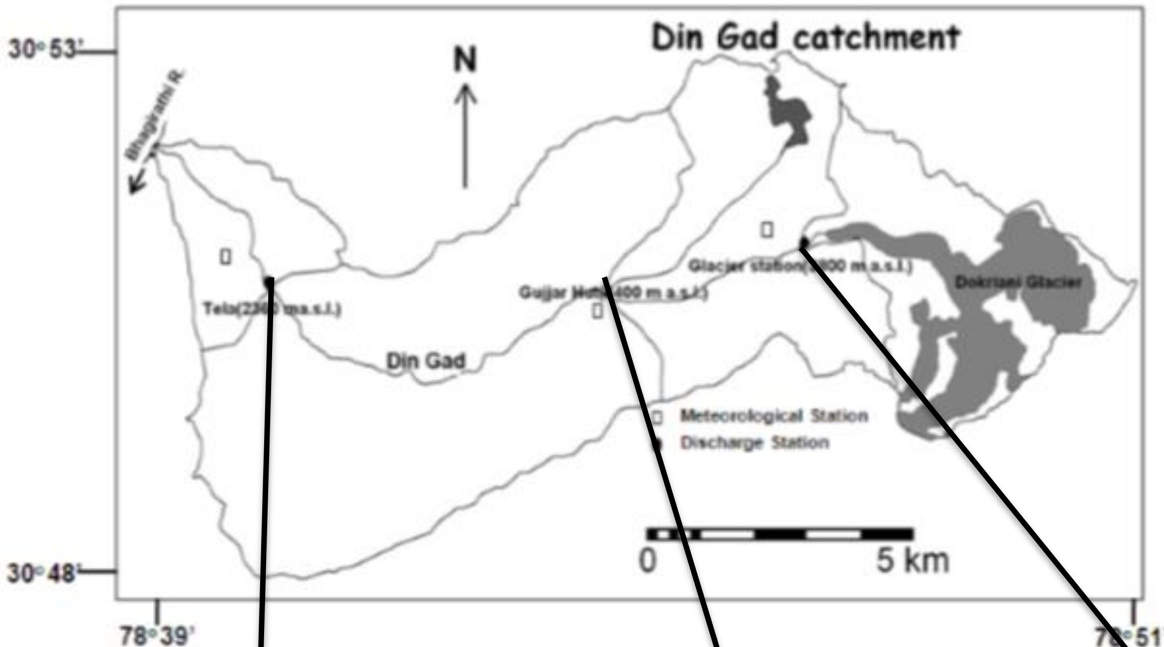


Year	**Snout** Specific Q **mm**	Glacier MB **mm w.e.**	% glacier Degradation derived 44.5 % glacier
1998	3332	340	**4.6**
1999	2717	460	**7.5**
2000	3574	380	**4.7**
2001	4997		
2003	3929		
2004	2643		

Role of glaciers as stream flow regulator reducing the inter-annual runoff variations

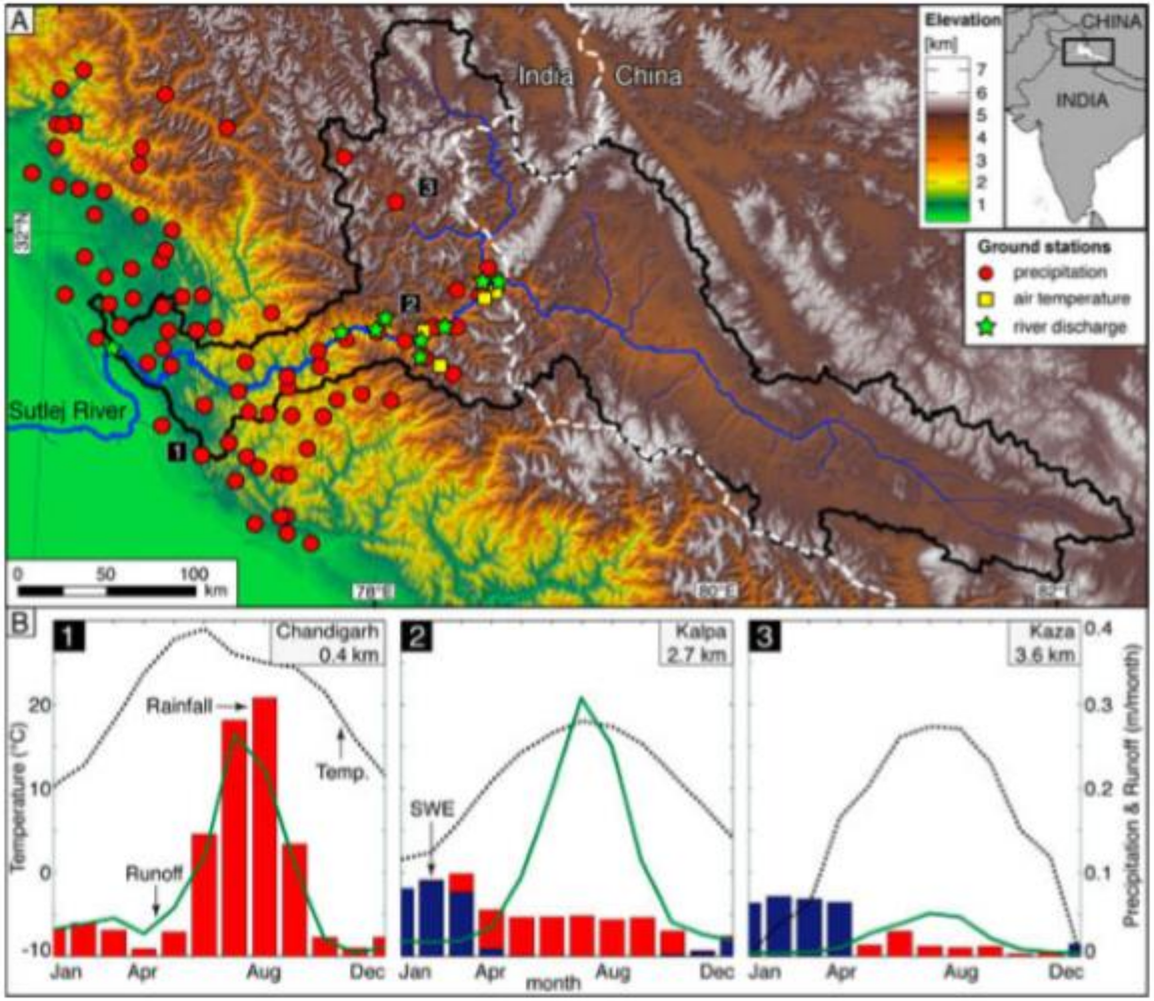


Variations in mean daily specific runoff from Din Gad & Sub-catchments

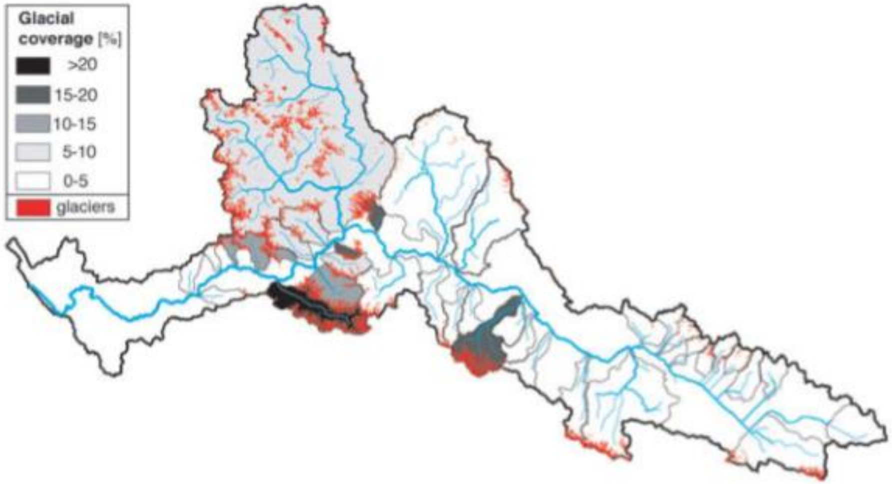


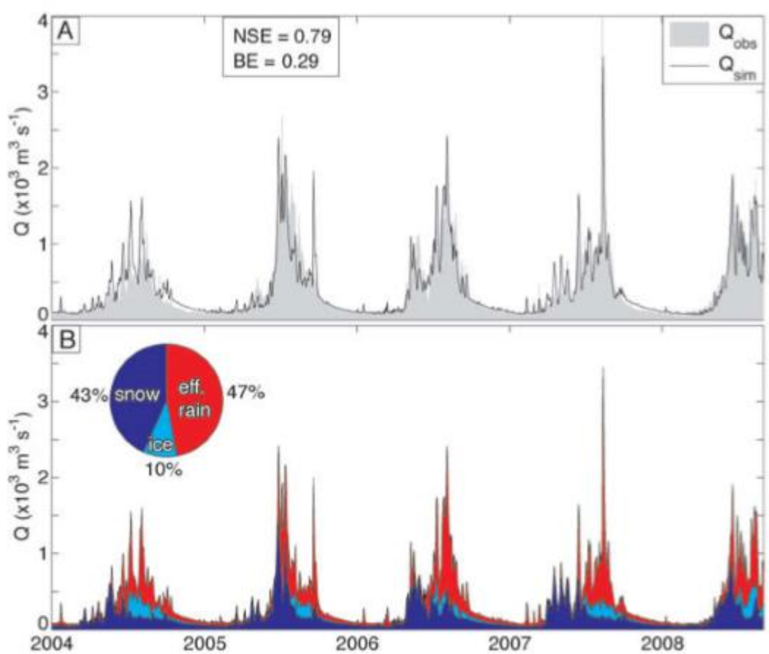
Cv	0.30	0.20	0.23
Glacier %	9.6	20.8	44.5

Sutlej basin –Climate regimes



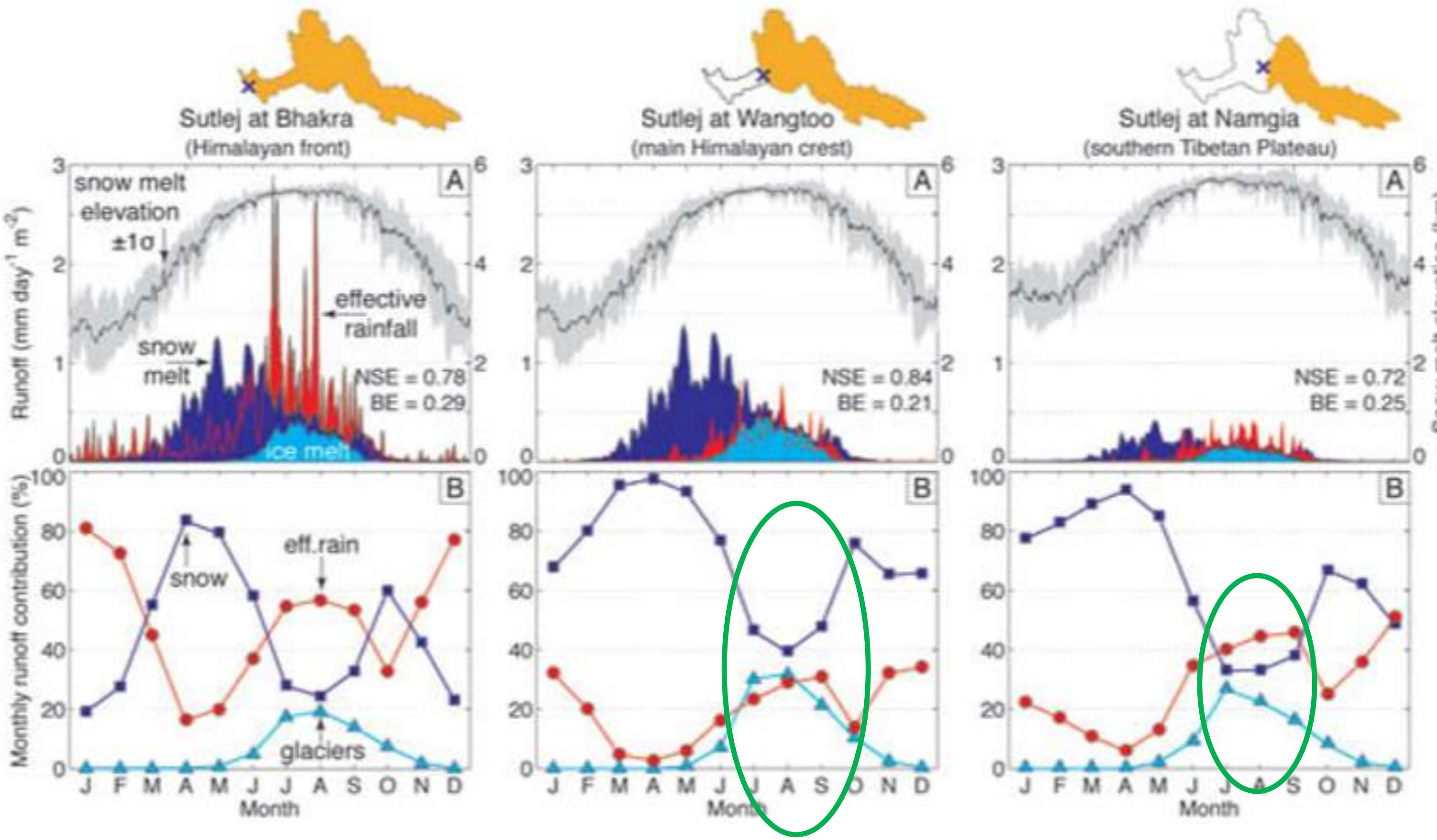
Sutlej River –Glacier contribution to downstream flow at Bhakra



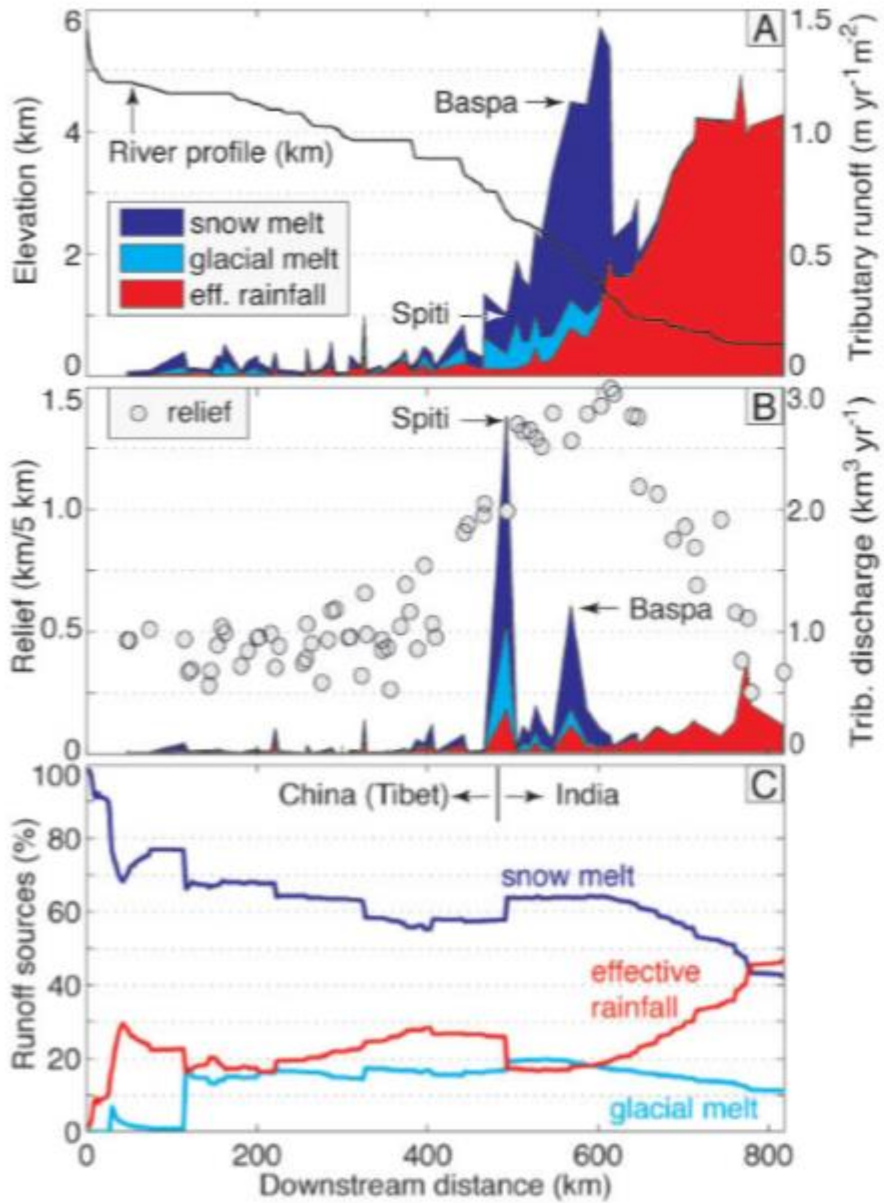


Wulf, 2010

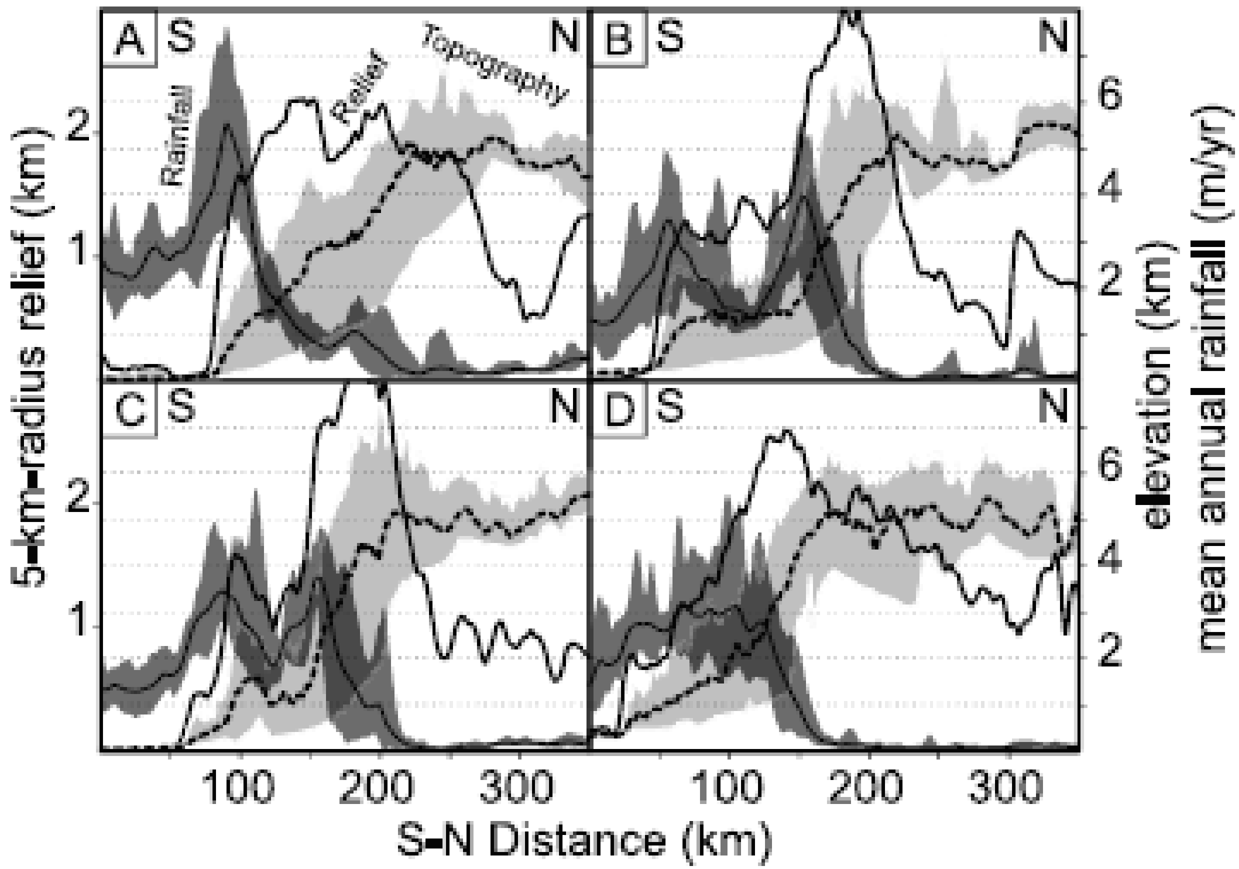
Runoff components at different regimes of the basin



Runoff components: variation from headwater to downstream



Mountain relief and precipitation--Monsoon

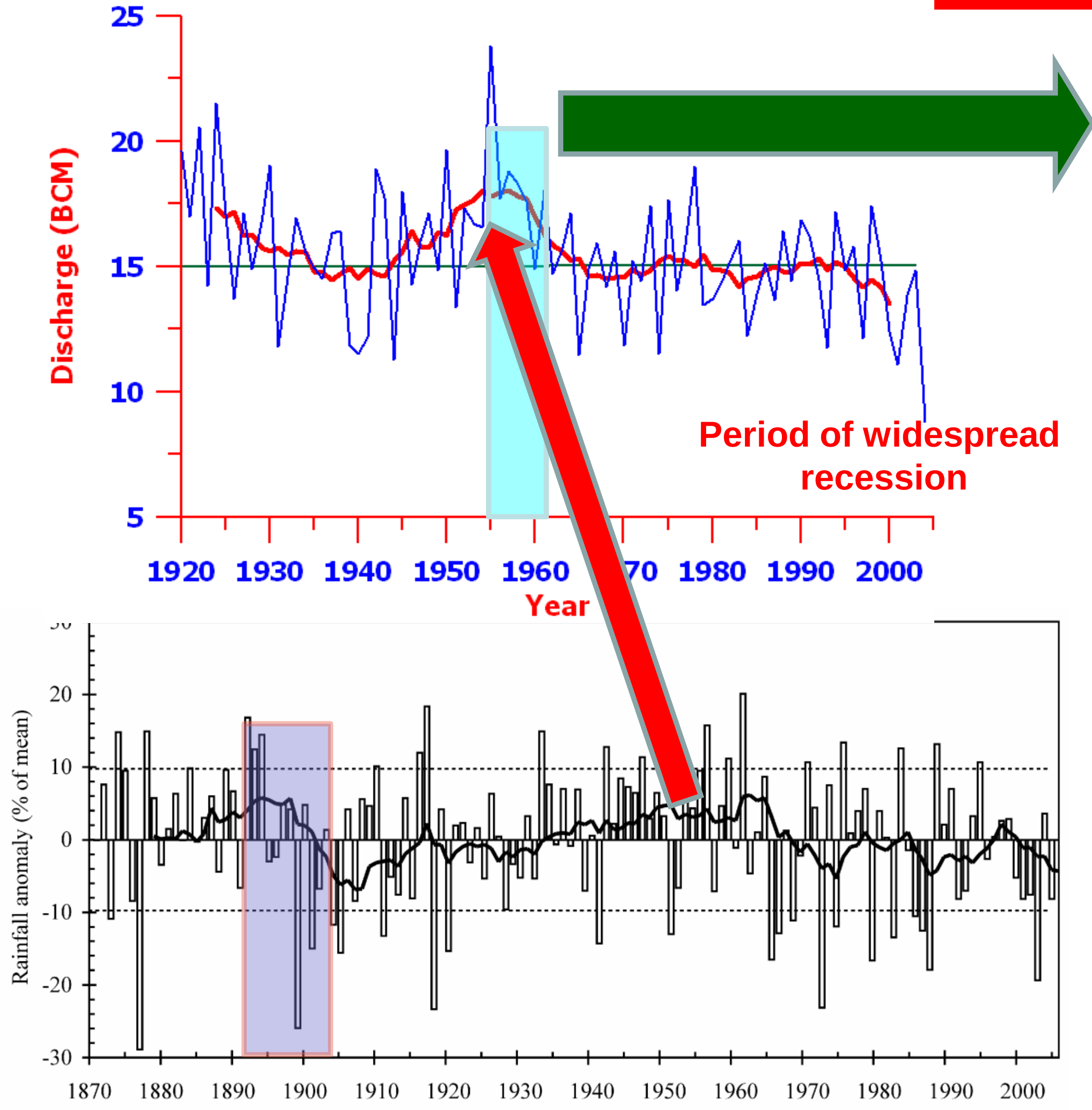


Swath profile running from South (S) to North (N) from A. Northwestern, B. CentralB&C Central and D) eastern Himalaya

Zone of highest rainfall are offset to 10s km south of the highest topography and relief

Bookhagen et al 2006

Runoff trends: Sutlej basin



Many Himalayan glaciers were either stationery or advancing in 1950's (Vohra,1993, Mayewski et al.,1980, Sharma&Owen, 1996)

All-India summer monsoon rainfall anomalies (1871–2004).

Sutlej Basin

Total area – 22 305 km2
Seasonal snow cover – 65%
Glaciers - 12%

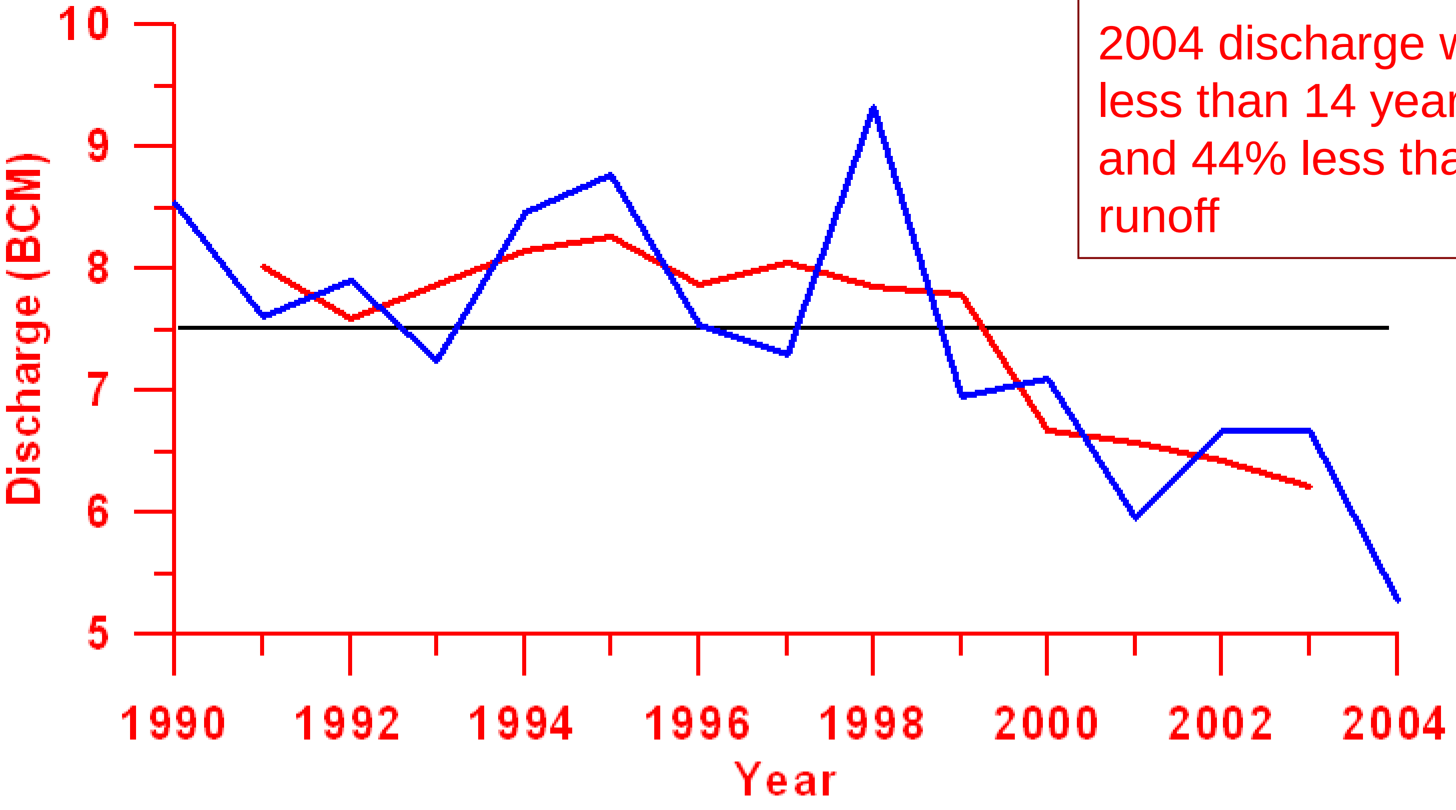
2004 discharge was % less than 84 year normal and 50% less than 1998 runoff

Runoff trends : Beas basin

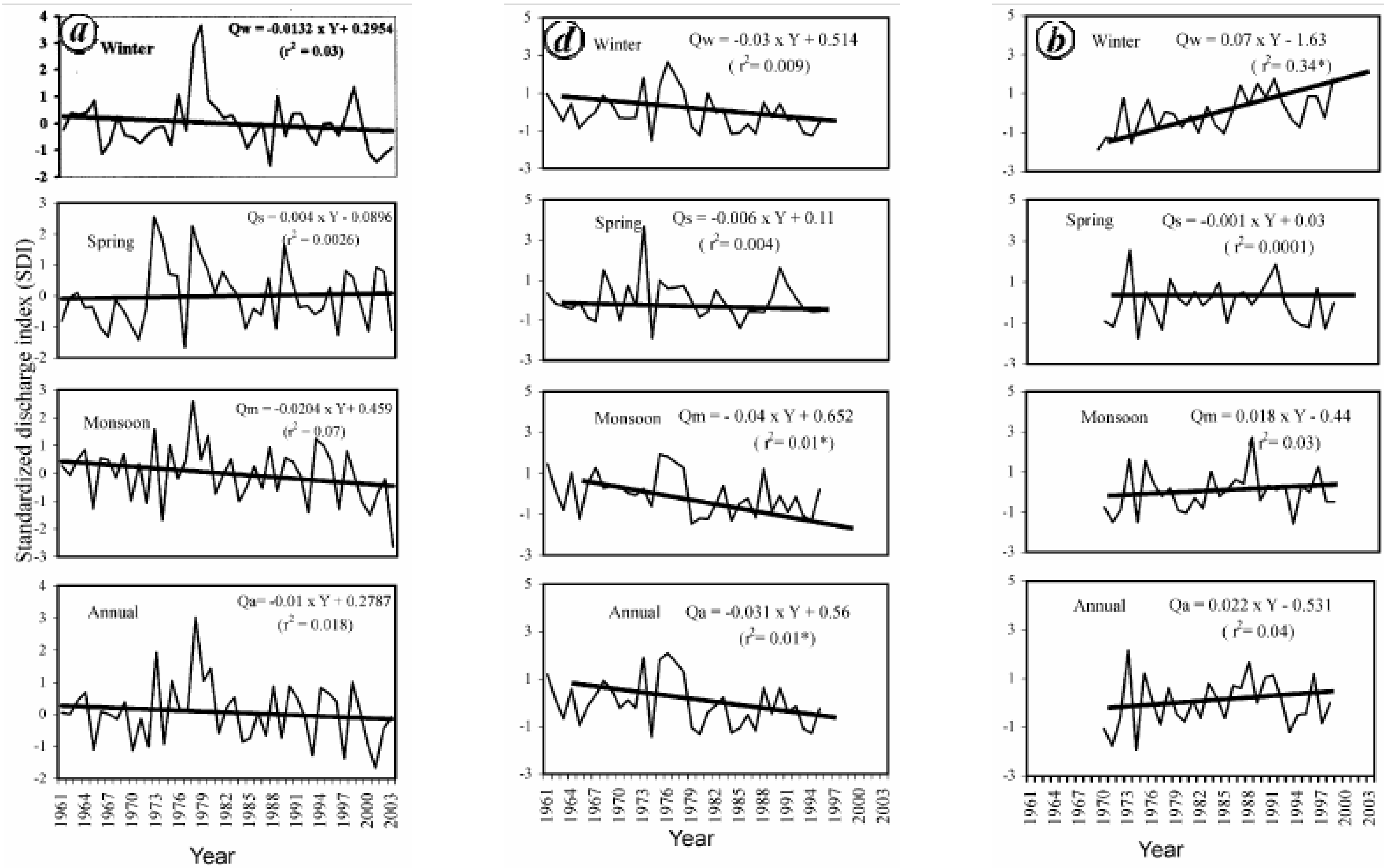
Beas basin

Total area – 5278 km2
Snow cover – 45%
Glaciers – 14.7%

2004 discharge was 29% less than 14 year normal and 44% less than 1998 runoff



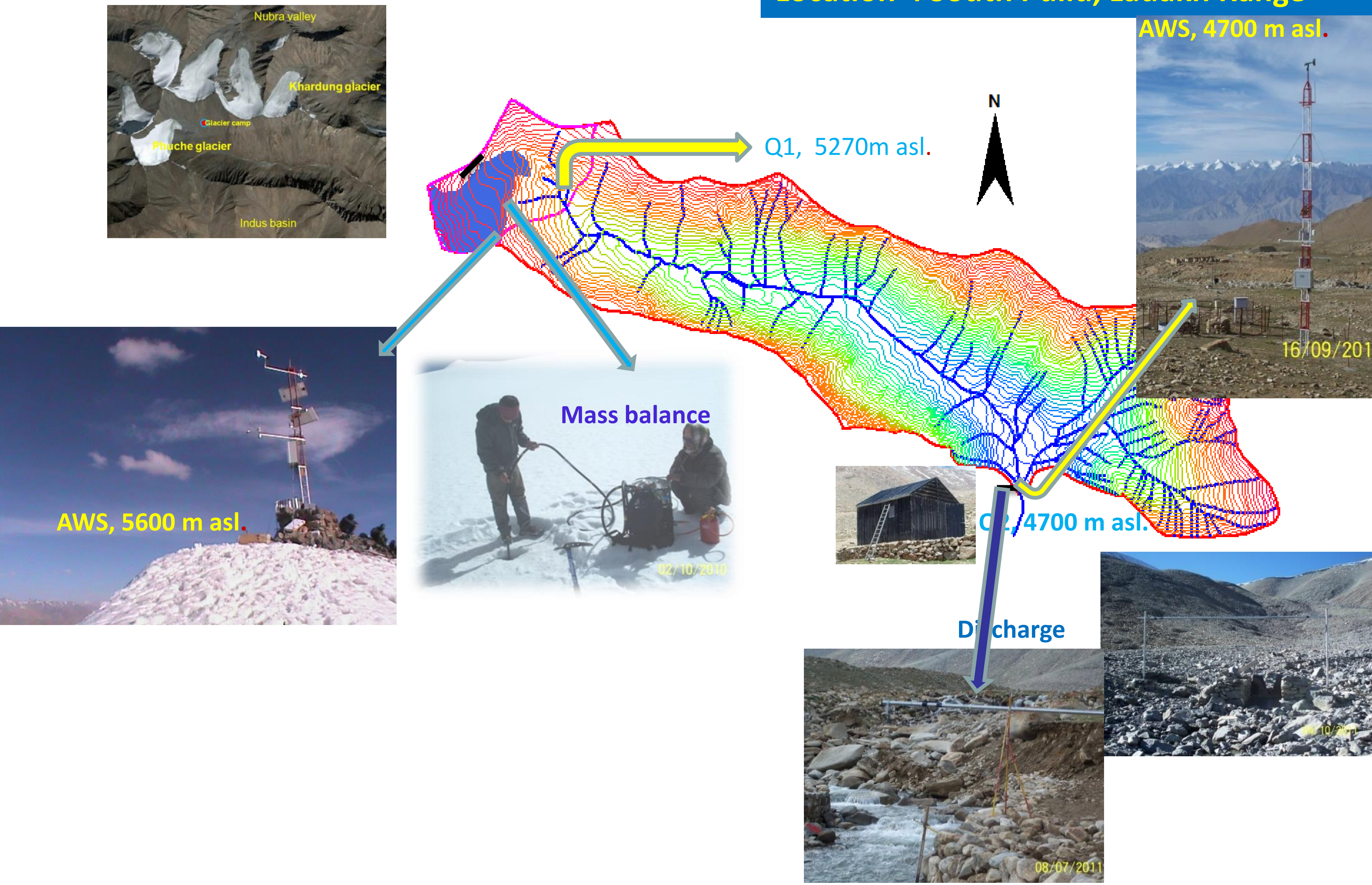
Varying trend in discharge of some Himalayan Rivers



Satluj **Beas** **Chenab**

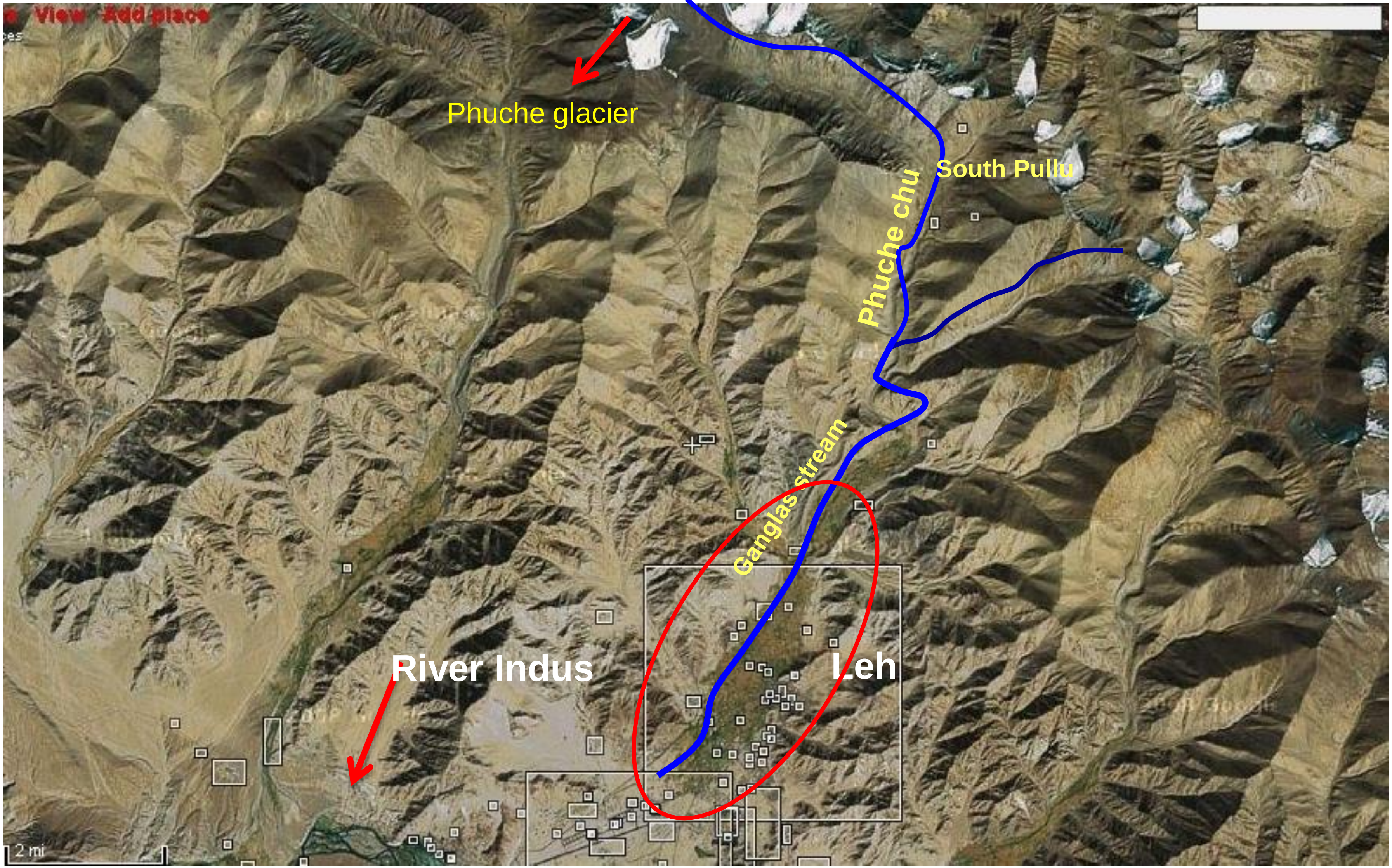
Case Study-2 Cold-arid systems

Location : South Pullu, Ladakh Range

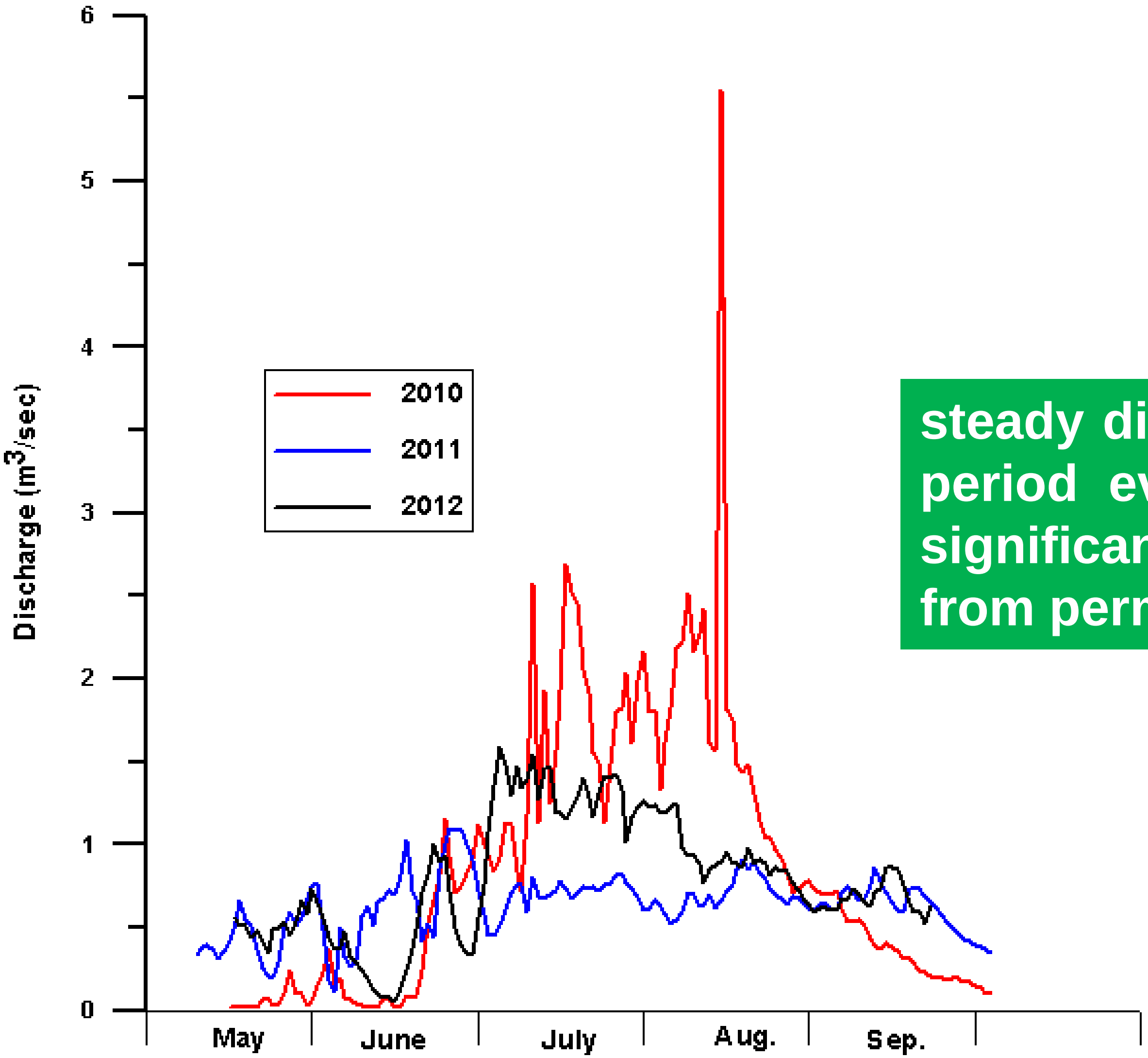


Cold-Arid system, very high societal dependency on cryospheric systems

Ganglass Catchment

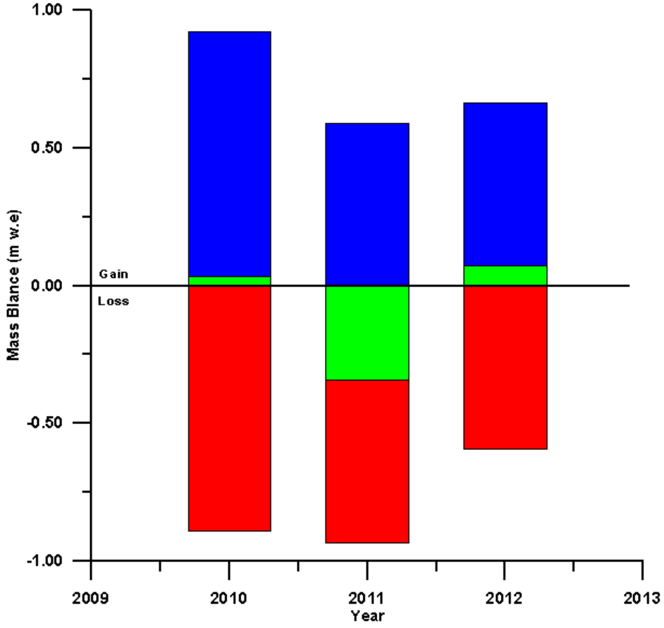


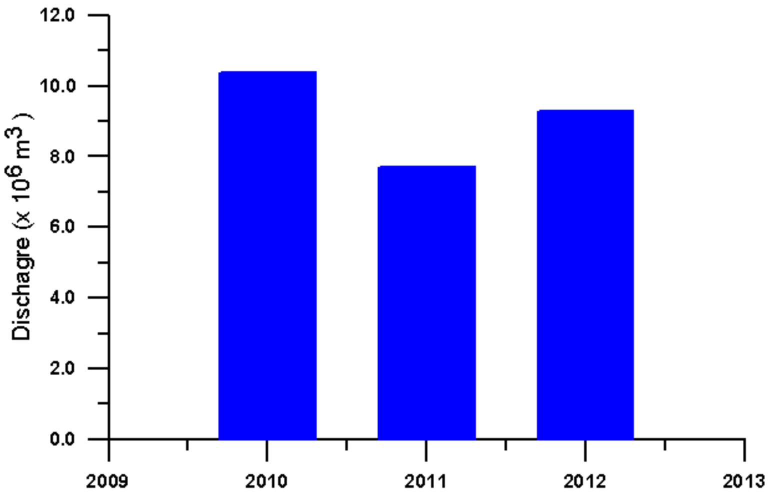
Factors influencing the Catchment Runoff variations – Cold-Arid system



steady discharge for prolonged period even in the absence of significant snow cover could be from permafrost melting

Glacier mass balance & Stream flow response Cold-Arid systems





South Pullu station 4700 m asl.
Catchment area 15.7 km2

Glacier cover 4%

Glacier contribution 4 - 7.5 %

1. **Study suggests higher catchment runoff during positive mass balance years in cold-arid system similar to the monsoon dominated system (Thayyen & Gergan 2010).**

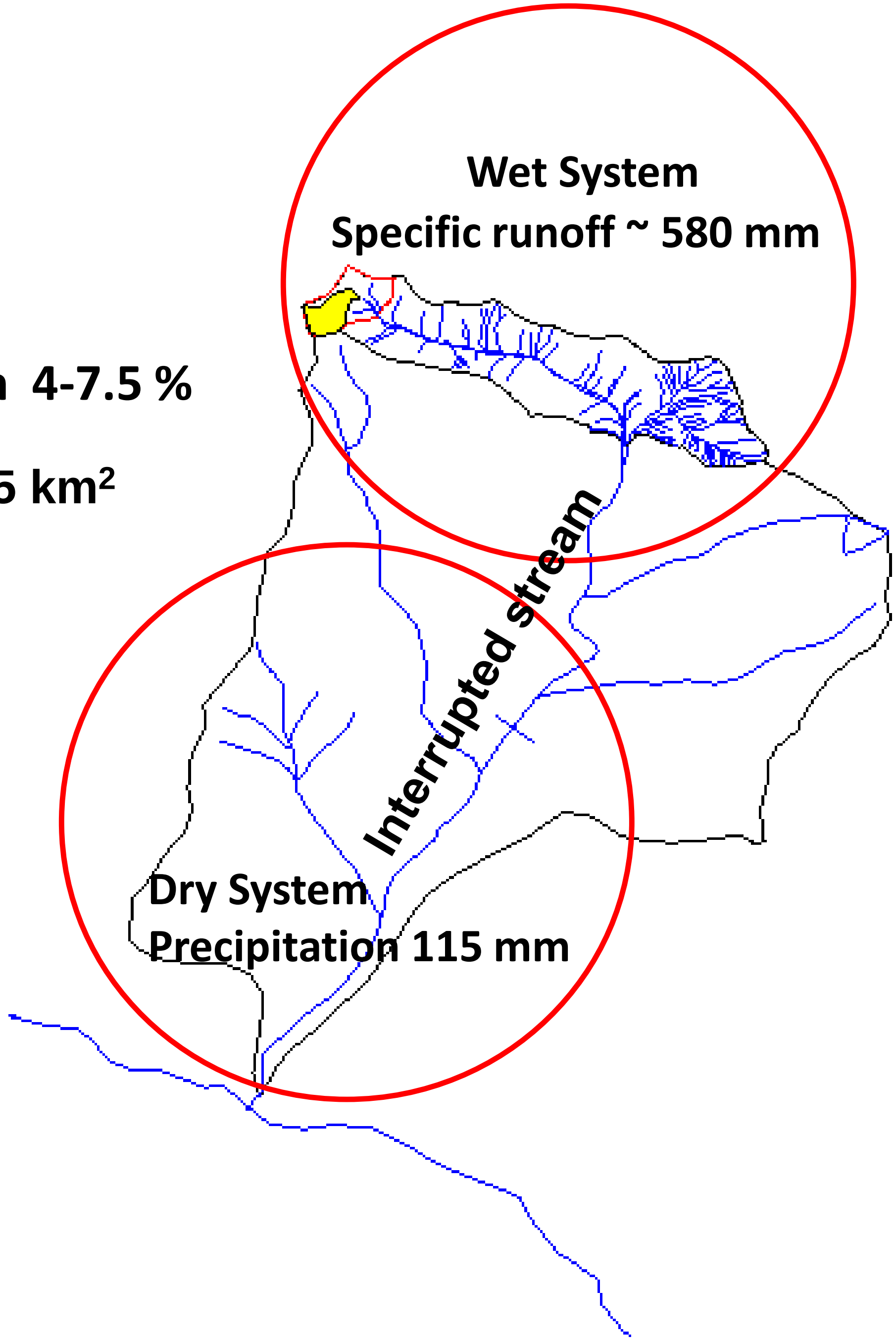
2. **Results suggests that heavy melting of one negative mass balance year is capable of obliterating many years of accumulation in cold-arid systems.**

Cold-Arid System Hydrology

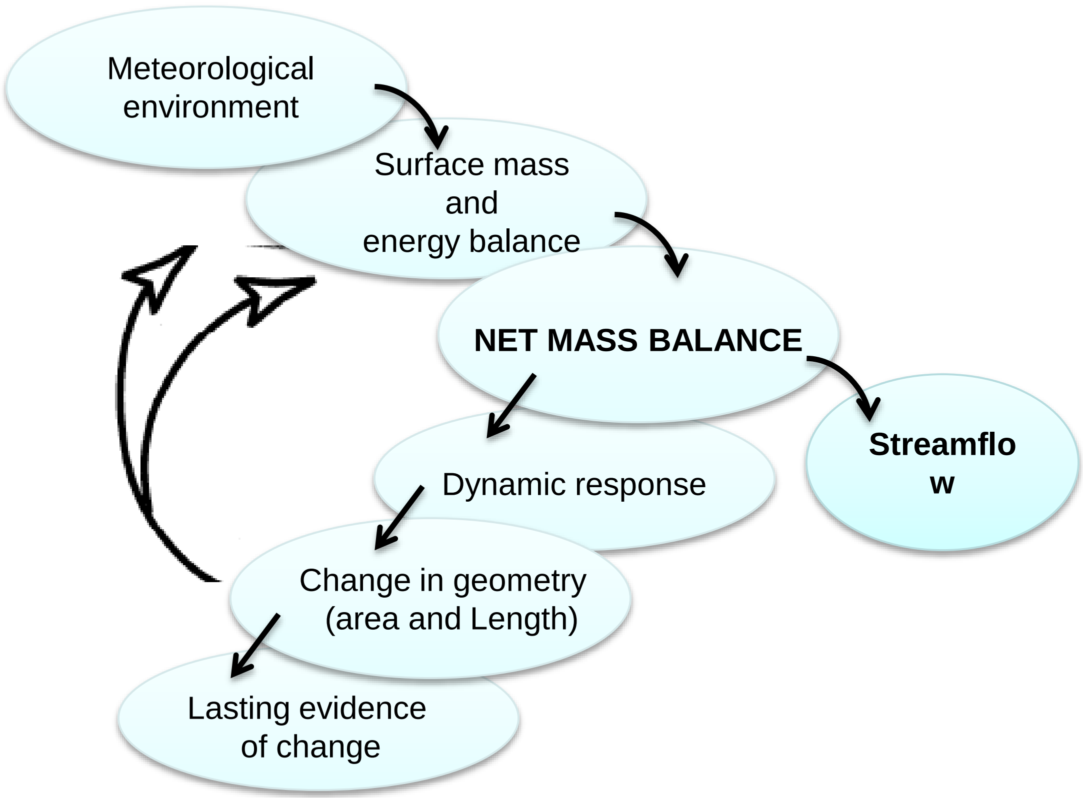
Glacier cover 4%

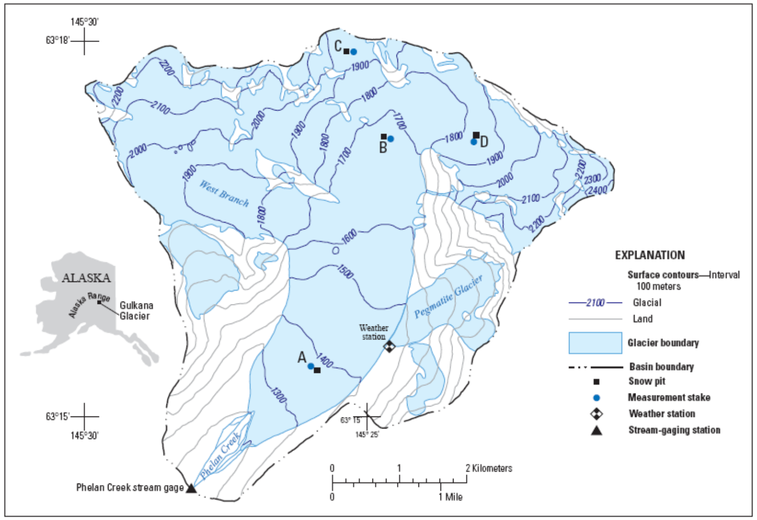
Glacier contribution 4-7.5 %

Catchment area =15 km²

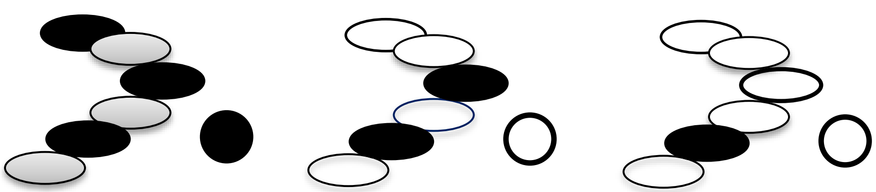


Is present research model appropriate ???
Benchmark glacier strategy, USGS,1997 (Modified after Meier, 1965)





Gulkana Glacier, Alaska (USGS)



BENCHMARK NETWORK

SECONDARY NETWORK

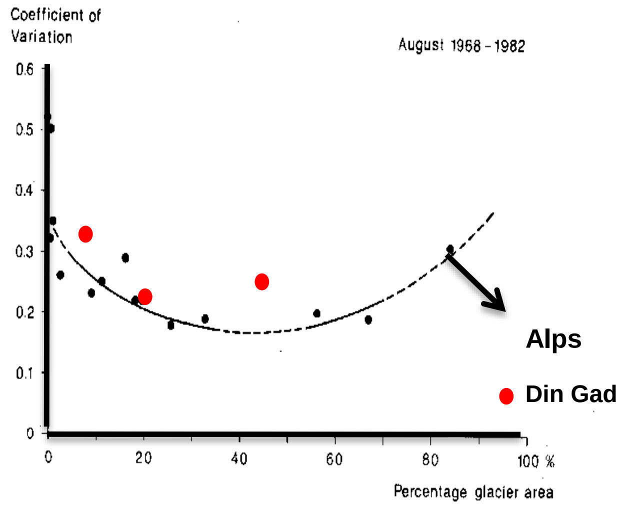
REMOTE-SENSING NETWORK

Limitations of benchmark glacier research strategy in Himalayan context

- No insight on impact of glacier runoff and glacier discharge dividend in a warming climate to the downstream flow and river ecology.

- No insight on orographic forcing on glacier & climate change impact on orographic forcing

- Not capable of providing actionable knowledge for developing policy & adaptive strategies

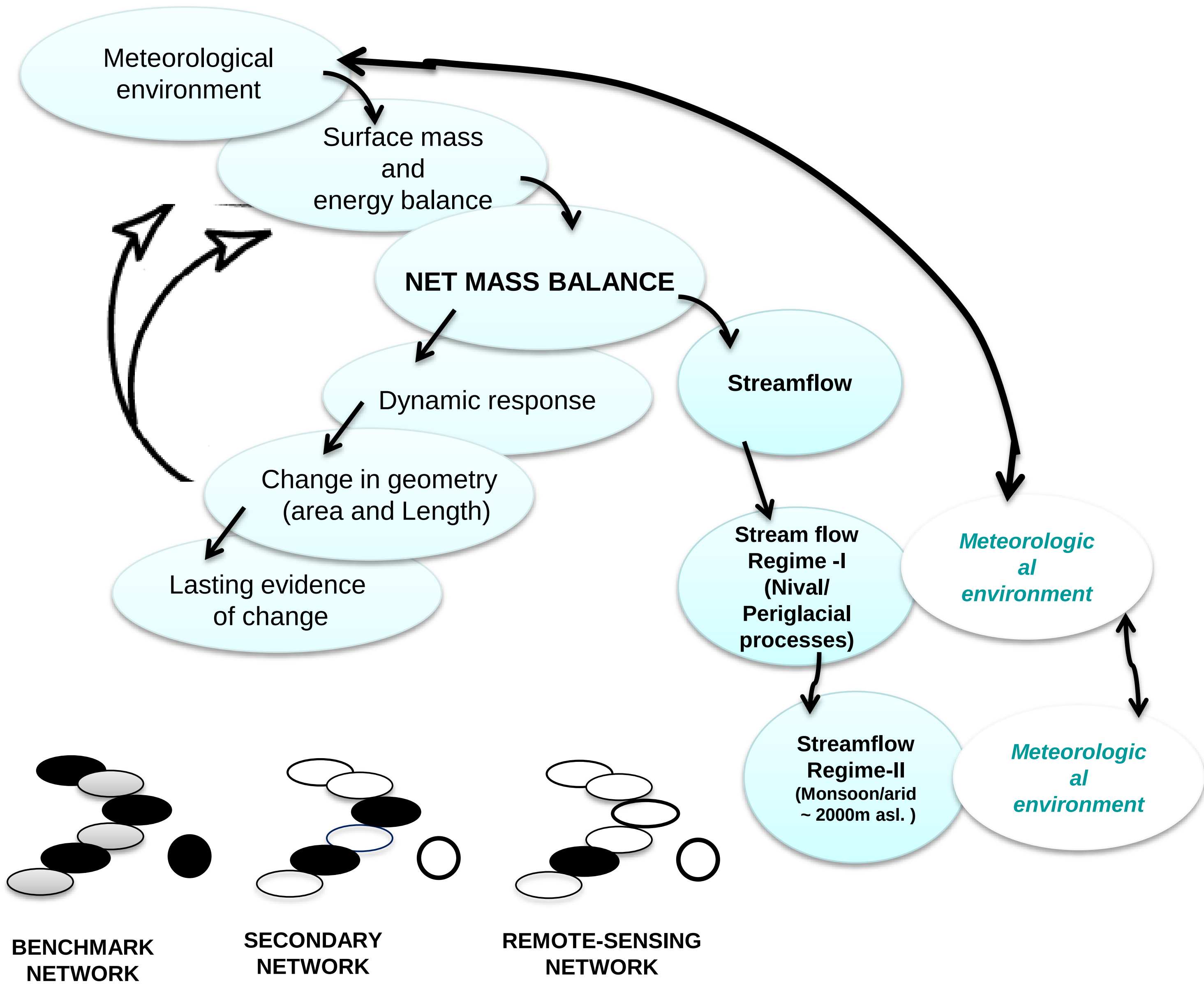


Orographic forcing on precipitation & Temperature

- Himalayan region, Weather and climate of the glacier system is highly influenced by the orographic processes

- Climate change signals are modified & delivered to the glacier through orographic processes.

Benchmark Glacier to Benchmark glacier catchment strategy



Present understanding vis a vis with Himalayan systems

- Glacier melt contribution is an add on component of annual high flows generated by melting of seasonal snow and monsoon precipitation in the major part of the Himalayan region and the role of glacier contribution is distinctly different in “Alpine” & “ Himalayan” catchments.

- Changes in the flow regime of glacier fed rivers are mainly due to changes in the precipitation characteristics; amount , extent, duration & altitudinal distribution , as it influence the hydrology of large area as compared to ~ 10% glacier cover. Contribution of other cryospheric components like permafrost also needs to be investigated.

- Higher moisture influx into the glacier system either from western disturbances or from monsoon leads to lesser glacier degradation and higher discharge leading to a situation where periods of positive mass balance of glaciers experiences higher stream discharge and vice versa.

- Melt water from glaciers critically influence the headwater river discharge regime during the years of lower summer runoff.


Wishing you all an excellent career in
Cryosphere Research