Hydrologic Inputs for Ganga Rejuvenation

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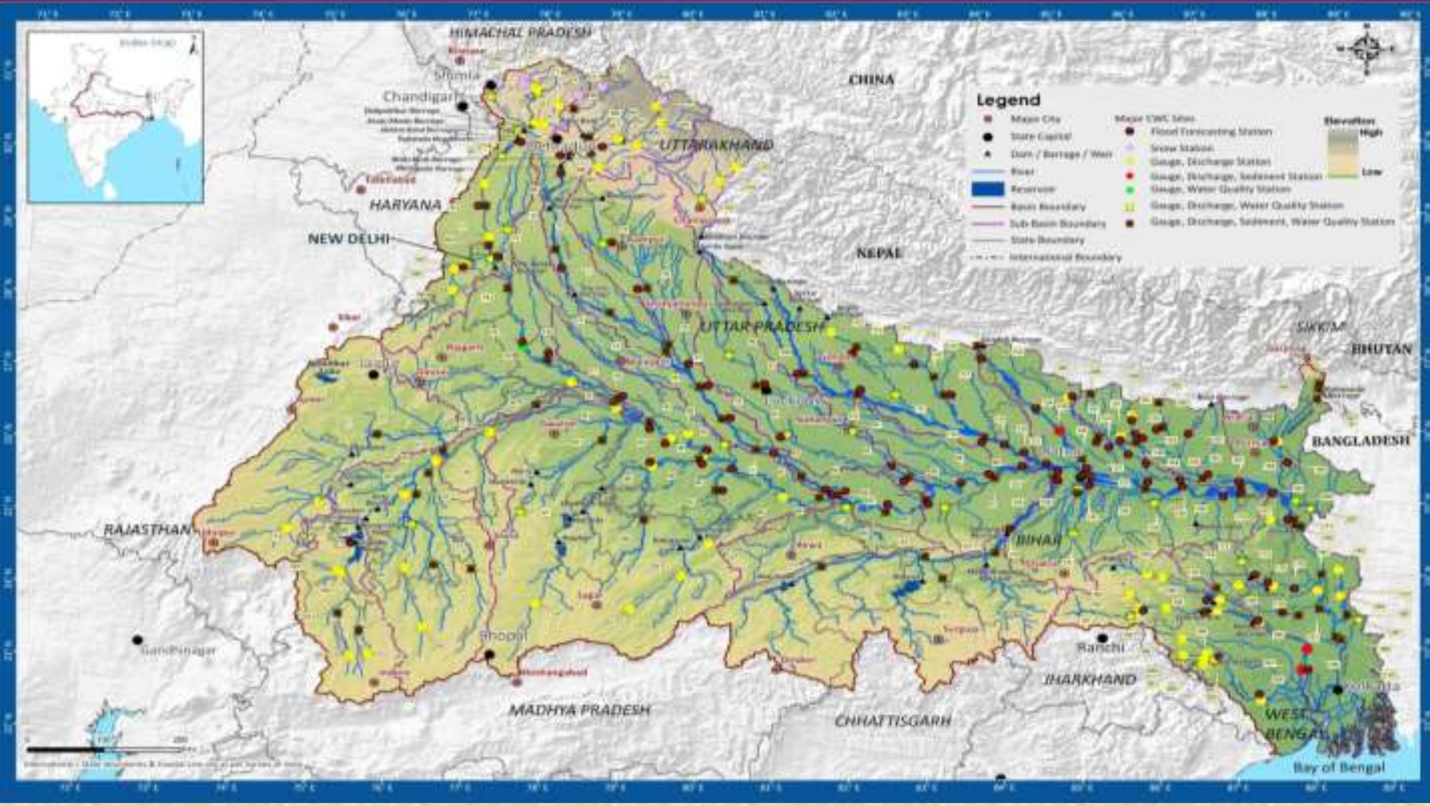
General Description - Ganga basin



Area 1.086 M sq. km;
In India 0.86 M sq. km;
UK area 0.244 M sq. km
Supports ≈ 30% of India's population and 9% of world's population.

- Extraordinary variation in altitude, geology, climate, land use ...
- Immense topographic contrasts -- elevation drops from 8848 m (Mt. Everest) to 100 m (Ganga plains) in just 150 km.
- Voluminous silt-laden flows have formed large, flat and fertile plains.
- Abundant water, fertile soil and suitable climate gave rise to a highly developed, agriculture based, densely populated civilization.

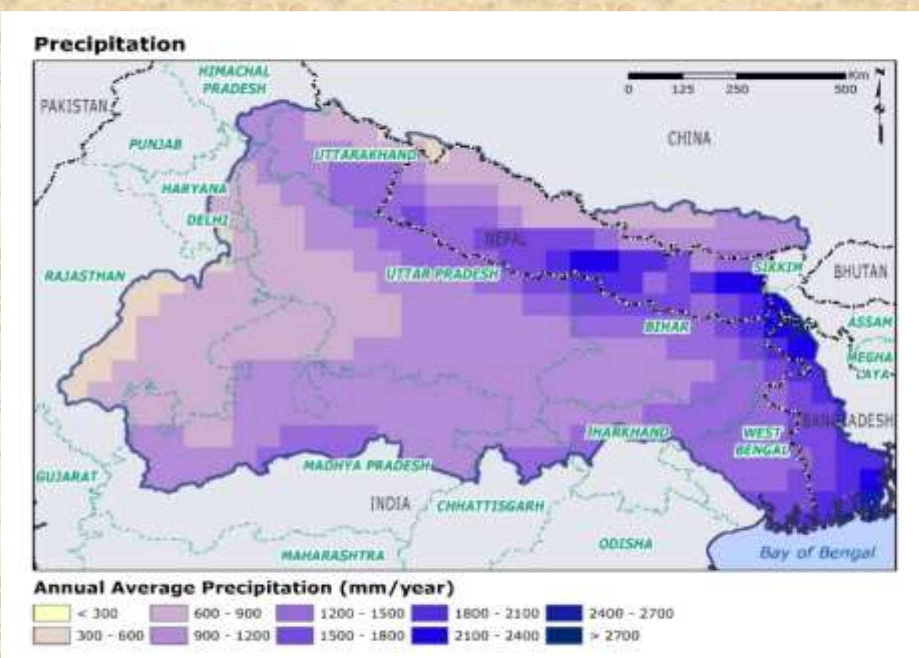
Hydro-Met Observation Networks in Ganga Basin

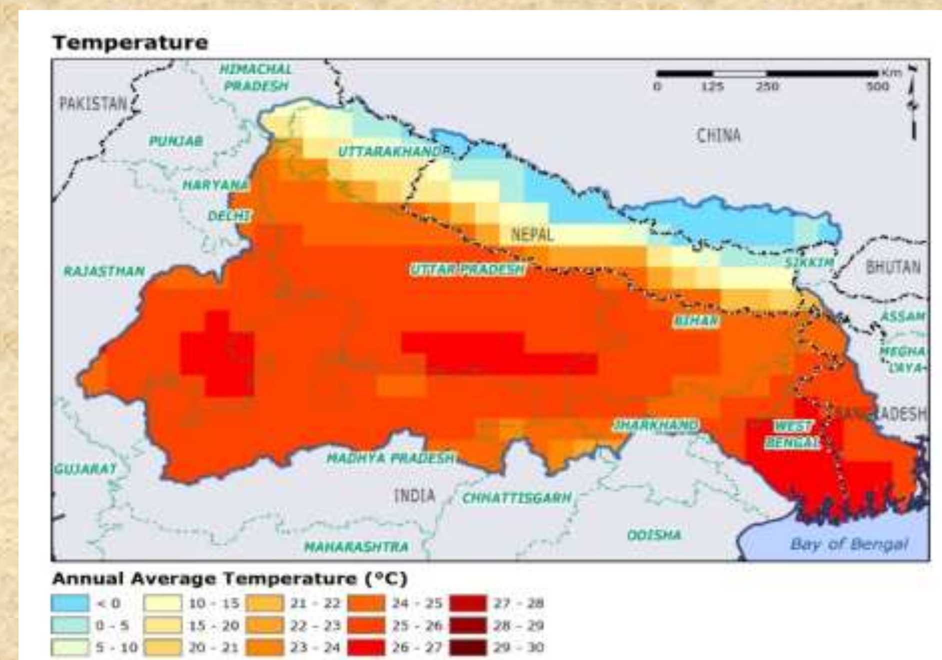
- CWC river gauging: 111 sites for water levels, 75 for discharge, 87 flood forecasting stations, sediment and WQ parameters at 8 and 27 stations.
- River flow is also measured by state governments.

- IMD has 703 district monitoring stations in Ganga basin to measure ppt, temp, humidity, and other met data -- can be purchased. ISRO has a network of 133 AWS.
- Streamflow data of Ganga basin is treated as classified by Govt. of India. This restriction is preventing wider hydrologic research on Ganga.

Important Hydrological Characteristics of Basin

- Precipitation patterns are variable in space as well as time: RF is highest in eastern Himalayan belt and delta areas (>2000 mm annually), and lowest in deserts of Rajasthan in the west (<250 mm annually).
- Average annual temp are high in basin except high elevation Himalaya areas.



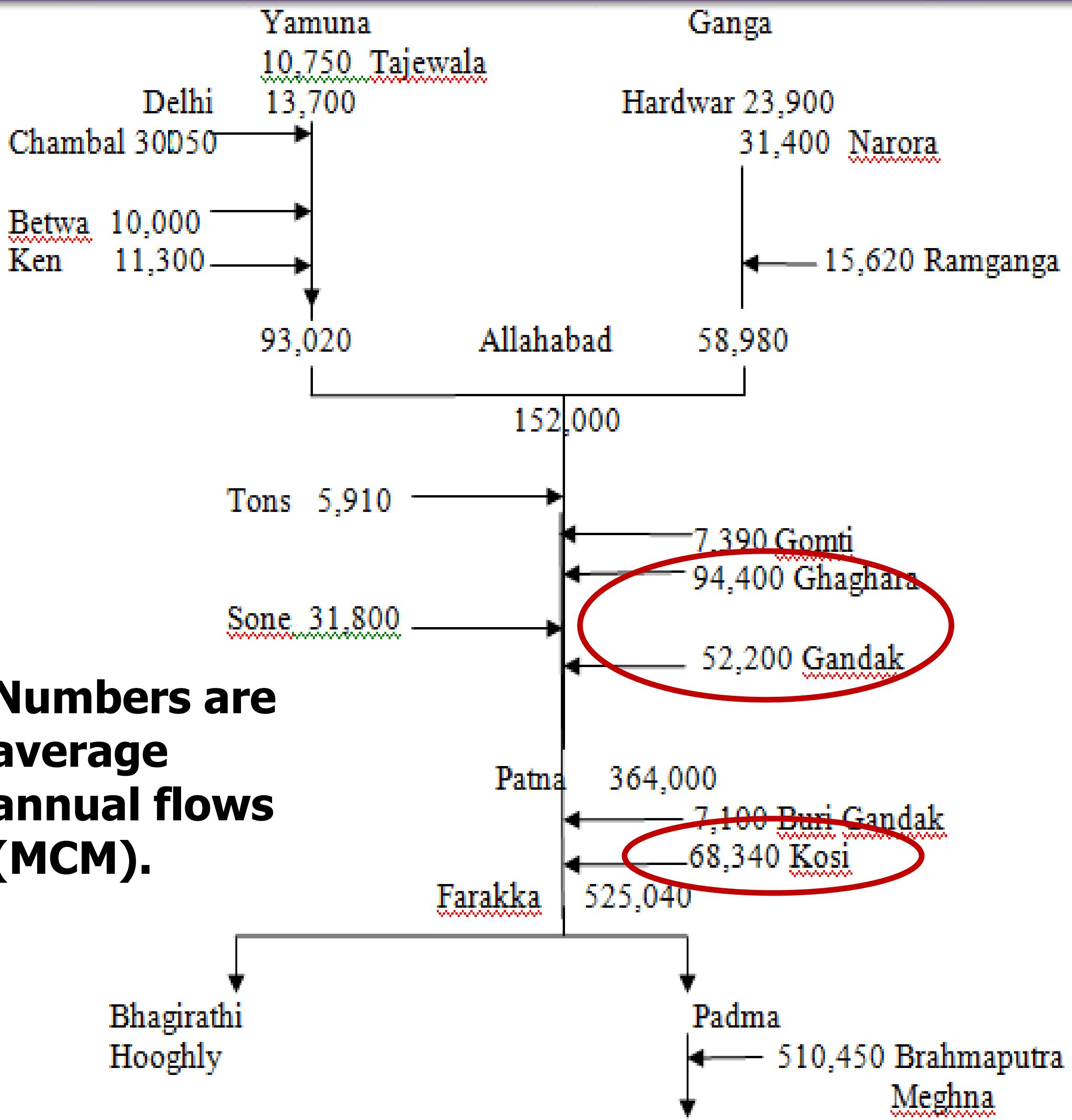


Historical average temperature and precipitation in Ganges (Source Jeuland et al. (2013) using CRU TS 3.0 1901–2006).

Important Hydrological Characteristics of Basin (Contd..)

- Snow and ice melt contribute about 9% (2/3 from snow) of annual flows in Ganga; contribute much more in some tributaries.
- Glaciers contribute about 2% of total flow in Ganga; most glacier melt occurs in early monsoon when RF is already heavy.
- Glaciers and snow storage ensures perennial flow of Himalayan tributaries and enhance dry season flows. Snow and ice melt contribution ranges between 12 and 38% low flows (March-May) at Farakka.
- GW contributions to base flows are significant.

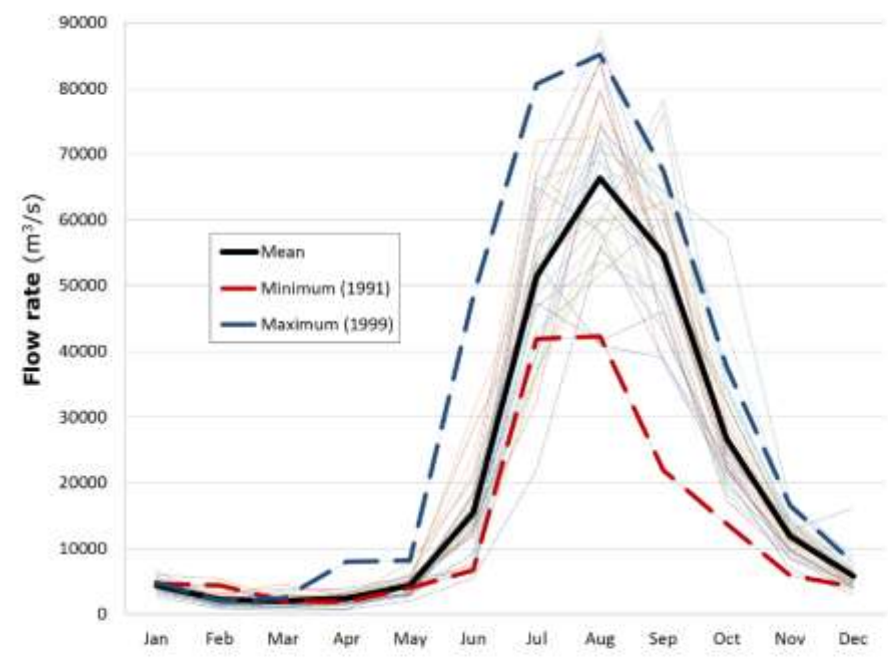
Important Hydrological Characteristics of Basin (Contd..)



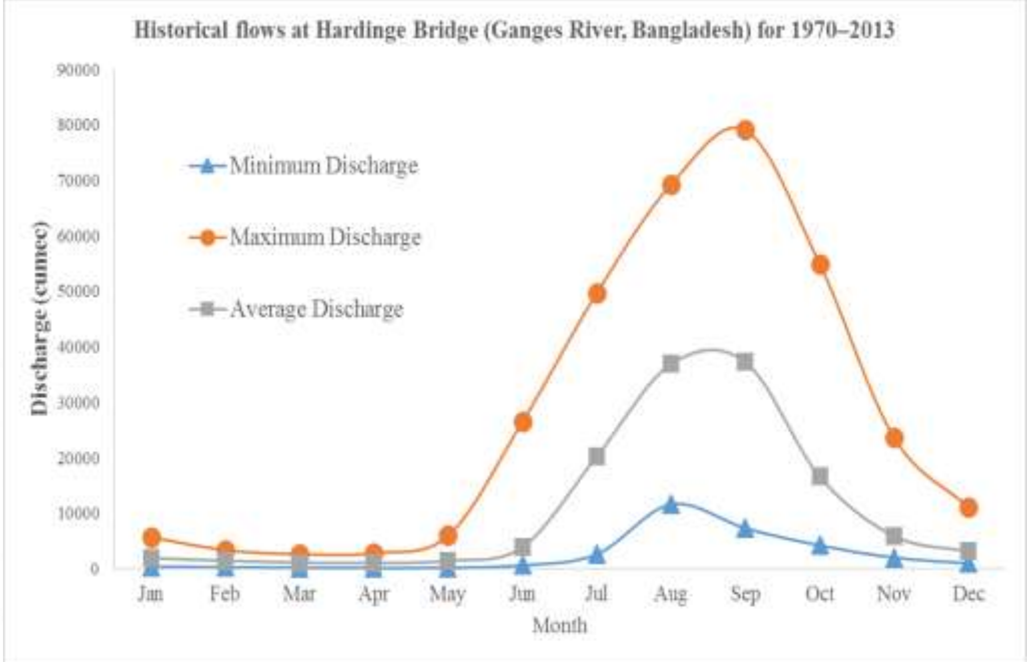
Numbers are average annual flows (MCM).

- Average water potential of Ganga basin at Farakka is 525 BCM (IRWR-SW 143, IRWR-GW 172, INF 210). Total utilizable SW in Ganga basin in India is 250 BCM.
- Nearly 60% of flow in Ganga comes from north rivers; have more power potential.

Important Hydrological Characteristics of Basin (Contd..)



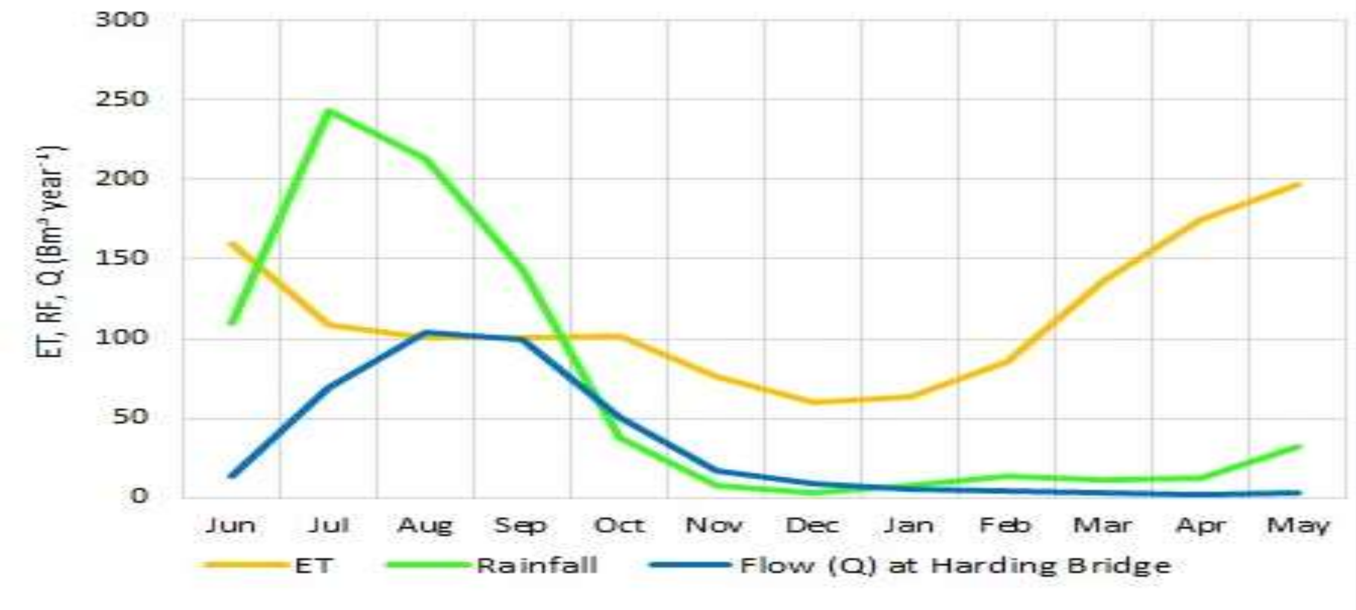
Flows @ Farakka (1969–2001), from Jeuland et al. (2013), WB (2013), data from CRU, Univ of East Anglia.



Historical flows (min, max, mean) of Ganga River at Hardinge Bridge (IWM-2014)

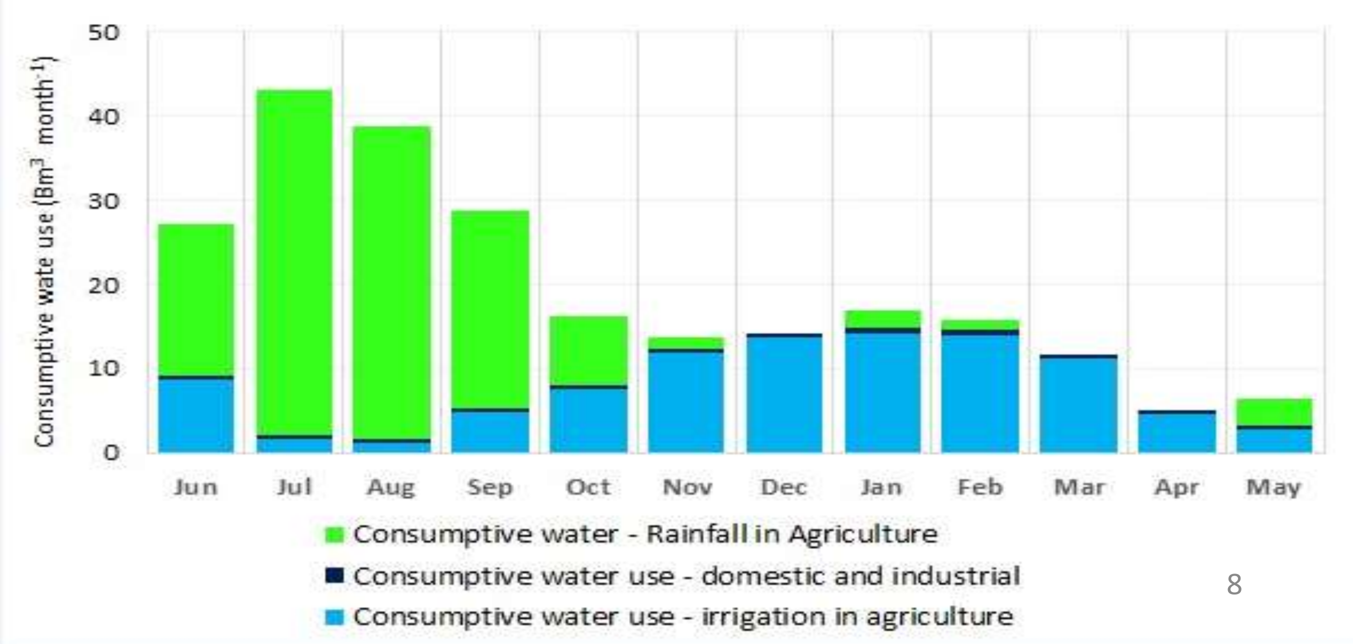
- About 80% of annual flows come during July-Oct.
- Monthly variation across years is very high. Peak flow in max flow year > 2*peak flow in min flow year.
- In historical low flow year (1991), flow was 153 BCM (38% lower than mean); historical high year (1999) 369 BCM (49% higher than mean).
- Large differences in two figures -- partly due to different time periods. Note difficulties in reconciling data for this large transboundary river.

Water Uses and Demands

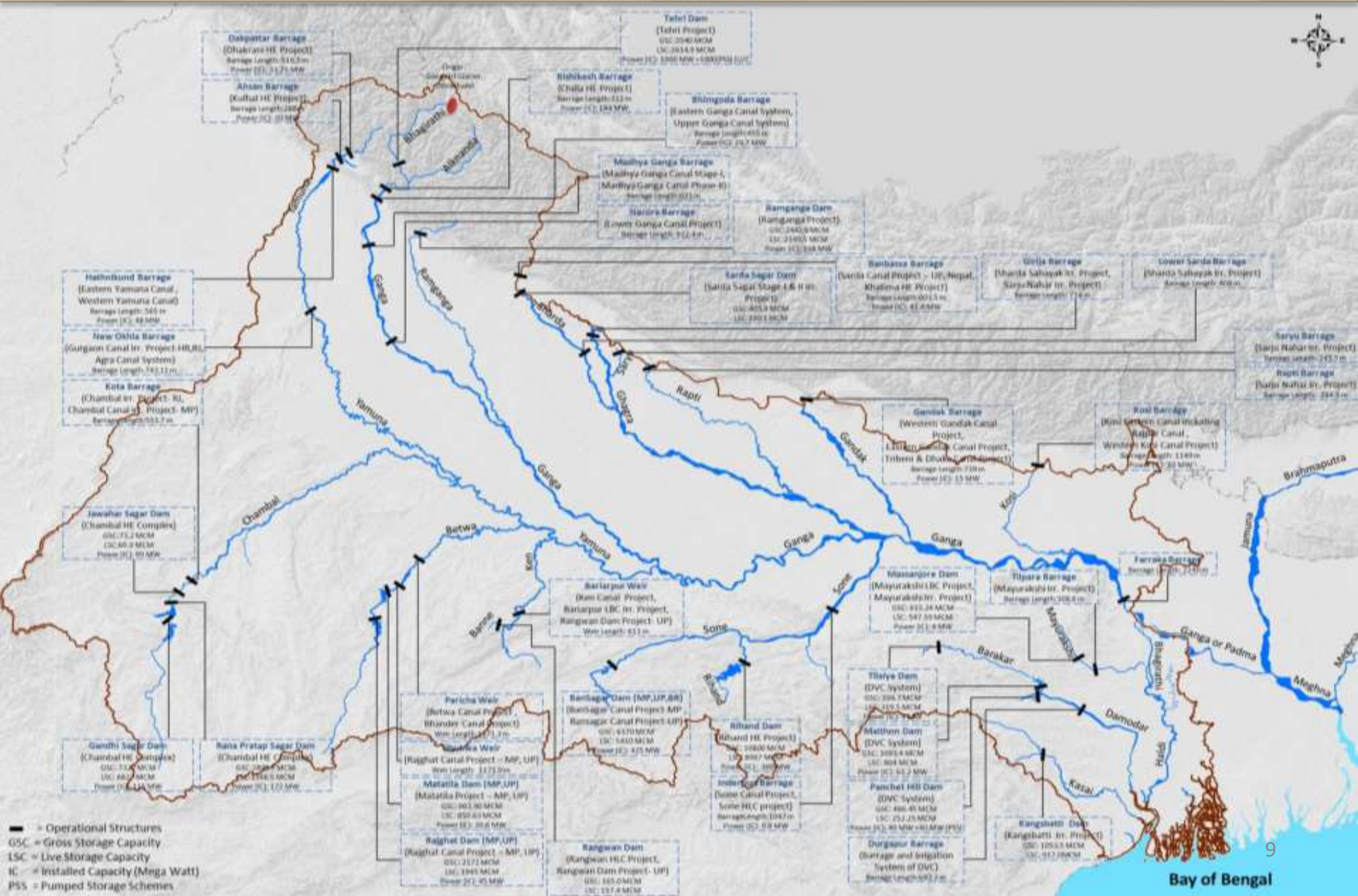


Average monthly RF, ET, and SF at Farakka

Average monthly CWU 1999-2011. Courtesy: U.Amarsinghe



Major water resources projects



Water Use and Infrastructure

- WRD in earlier times was focused on diverting river flows for irrigation through canals. UGC – MGC - LGC system.
- Agriculture accounts for about 90% of all of consumptive water abstractions.
- Use of Ganga waters for irrigation is critical for coping with uncertain RF as well as during dry months.
- Productivity in all but westernmost parts of basin (in Haryana and West UP) is low.
- GW pumping provides a critically important supply; GW irrigated areas are more productive. SW and GW are highly interconnected; canal seepage recharges aquifers.
- **Storage capacity in system is only about 55 BCM, active storage about 40 BCM, < 10% of annual flow; lowest among major rivers of world.**
- Most reservoirs are modest sized. Many dams are in relatively flat areas – less storage, high losses.

Water Use and Infrastructure (Contd..)

- Tehri multipurpose project (261 m, 3540 MCM) is largest and only storage on main stem. Ramganga: 2,190 MCM; cascade of storages (Gandhisagar, Jawaharsagar and Rana Pratapsagar) in Chambal Basin have a live storage of 8,500 MCM. Rihand Dam impounds 10608 MCM of water; its reservoir water is mainly used to cool 5 thermal power stations with IC of 8000 MW located at periphery.
- Some large tributaries originating in Nepal have almost no storage.
- Existing capacity to regulate flows, generate storage-backed hydropower, control flood, and augment low flows is limited.
- Significant potential for HP and multipurpose dams in Nepal. Kosi, Karnali (Chisapani) and Pancheshwar proposed mega-projects in Nepal would multiply current HP IC by a factor of 30.

Hydrological Extremes: Floods and Droughts

- **Large variation in spatial and temporal distribution of water availability leads to recurrent floods and droughts.**
- **Floods are common and frequent in Ganga Basin. An intense storm in Mandakini valley in Alaknanda basin caused much devastation and loss of life in June 2013.**
- **Bihar state is affected by floods almost every year.**
- **Average bed slope of Ganga from Allahabad to Farakka (960 km) is 1:15,795 and from Farakka to Nabadwip (230 km) is 1:23,000.**
- **Slow movement of flood water + intense local RF → upstream dams alone can't control lowland flooding – with information-backed flood management will be more effective.**
- **Large areas of basin are also affected by drought.**

Hydrological Variabilities Extremes

- Natural cycle of inundation and drying due to seasonal hydrology and high interannual and spatial variation has beneficial aspects also.
- High RFs → more crop production in Rabi; short periods of inundation connect river & flood plains, move sediments.
- Estimates of sediment transport by Ganga vary from 329 to 794 million tonnes/year.
- Transfer of surplus water through inter-linking of rivers will help mitigate drought in affected areas of Haryana, and Rajasthan.
- U/s dams (also a part of river linking) would enhance low flows season and help in drought mitigation.
- Aquifers could provide space for water storage to partly tame floods.

Water Quality Aspects

- Increasing extraction of river and GW to meet domestic, industrial, and agricultural needs. Estimates show that water demand in India will increase by 30% by 2050.
- Monotonic and rapid rise in population → increasing waste and sewage generation without commensurate increase in treatment capacity.
- Increasing use of fertilizers, insecticides and pesticides.
- Rapid rise in industries without increase in treatment capacity; poor enforcement.
- Land use, cropping, food choices, and water use patterns are changing, due to changing demographics and consumption patterns. All these have important implications for basin water management.

Religious and Social Aspects

- Ganga has central role in many social, religious customs and rituals such as marriage, worshipping, and cremation.
- Ganga is worshipped as a mother.
- On auspicious occasions such as Full Moon and No-moon days, melas (fairs, e.g. Kumbh) are held on river banks; millions of pilgrims gather for baths - physical + spiritual.
- Bathing requires clean flowing water with sufficient depth; has transient impact on river water quality.
- Loads of human waste is generated in a small area in these events. Carrying capacity is exceeded manifold during a brief period.
- Popular belief: Ganga has immense cleaning power – waste can't harm it. This mindset is to be changed.

Challenges

- **Considerable amounts of data are collected but basin is data-deficient due to lack of sufficient & reliable data and sharing → hinders Plg and Mgmt, inconsistent hydrologic appraisals.**
- **Big challenge is to manage intra-annual variability in water availability.**
- **Water quality in some river stretches and aquifers at some places is poor and degrading. This needs to be addressed with quantity.**
- **GW in many locations in eastern parts contains Arsenic which is causing serious health problems.**
- **Basin is currently experiencing strong economic and income growth, with substantial implications for future water and food requirements.**

Constraints

- **Flow regulation has affected hydrology of Ganga basin. Due to diversions for irrigation, downstream flows are considerably reduced in lean season.**
- **Intense ground water pumping is lowering water tables in the basin which is contributing to reduced lean season flows.**
- **Vertical fragmentation of habitat and ecosystems due to dams is also affecting aquatic species in river as well as riverine and riparian ecology.**
- **Water is a state subject: State Govts. deal with water supplies, irrigation and canals, drainage and embankments, storage and hydro-power projects.**
- **Centre deals with regulation and development of inter-state rivers subject to legislation passed by Parliament.**

Environmental Flows

- Necessary for maintenance of aquatic ecosystem
- Uttarakhand: 10% of lean season flow has been specified for e-flows.
- UJVNL: specifies e-flows as 10% of minimum discharge observed or 0.3 cumec, whichever is higher.
- No clear guidelines in some States.

IMG Recommendations for Alaknanda & Bhagirathi river Basins

E-flows in 'Fish zone' should be fixed in terms of percentage of daily uninterrupted inflows at following levels:

April – May & Oct. – Nov.	25%
June - September	20%
December – March	30%

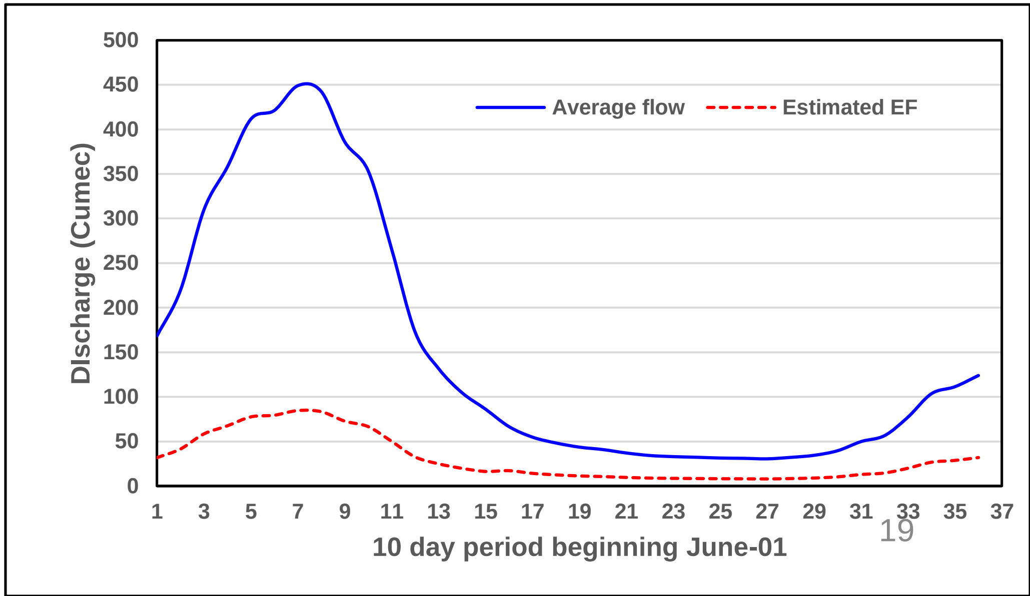
E-flows for 'No Fish Zone' should be fixed in terms of percentage of daily inflows at following levels:

April – September	20%
October – March	30%

ASSESSMENT OF E-FLOWS FOR UPPER GANGA BASIN

G&D Sites	Min flow requirements in lean period (Nov-May)			Min flow requirements in spawning period (June-Oct)		
	Depth (m)	Velocity (m/s)	Discharge (cumecs)	Depth (m)	Velocity (m/s)	Discharge (cumecs)
	D	V	Q	D	V	Q
Alaknanda (Joshimath)	0.25	0.87	5.98	1.00	1.75	51.25
Alaknanda (Rudraprayag)	0.50	2.06	29.20	1.00	3.12	41.36
Bhagirathi (Uttarkashi)	0.50	1.99	7.98	1.00	2.70	131.45
Bhagirathi (Tehri)	0.50	1.73	41.96	1.00	3.11	89.49
Ganga (Devprayag)	0.50	0.88	18.25	1.00	4.55	136.40
Ganga (Rishikesh)	0.50	2.08	43.88	1.00	1.75	51.25

- **Tehri live storage = 2600 MCM**
- **Alaknanda Yield @ Rudraprayag = 9600 MCM, Monsoon 7300 MCM**
- **Reservoir(s) in Alaknanda valley storing ≈ 3500 MCM can increase lean season flow and supply enough water to meet Eflow needs**



Environmental Flows and Energy

Tarrif scenarios for various Eflows (20-25-30% , 30 - 50 % E Flows)									
Impact of E Flows on Energy Generation (1971-72)									
Case	1	2	3	4	5	6	7	**8**	**9**
E flows %	3 cumecs (i.e. As in DPR)	15.65 Cumecs (Suggested)	Eflow @ 10%	20%	30%	40%	50%	IMG 30, 25 & 20 %*	IMG with 50 & 30 %^
Installed Capacity (MW)	444	444	444	444	444	444	444	444	444
Energy in Moonsoon (June to Sep)	1092.29	1074.63	1075.44	996.84	872.23	747.63	623.02	872.23	623.02
Energy in Non- Moonsoon (Oct to May)	720.73	577.02	679.33	603.85	528.37	452.89	377.41	582.72	528.37
Annual Energy (GWh)	1813.03	1651.64	1754.77	1600.69	1400.60	1200.52	1000.43	1454.95	1151.39
Design Energy (GWh)	1797.24	1635.86	1738.99	1600.69	1400.60	1200.52	1000.43	1454.95	1151.39
First Year Tariff	424.88	466.79	439.11	477.05	545.20	636.06	763.28	524.83	663.20

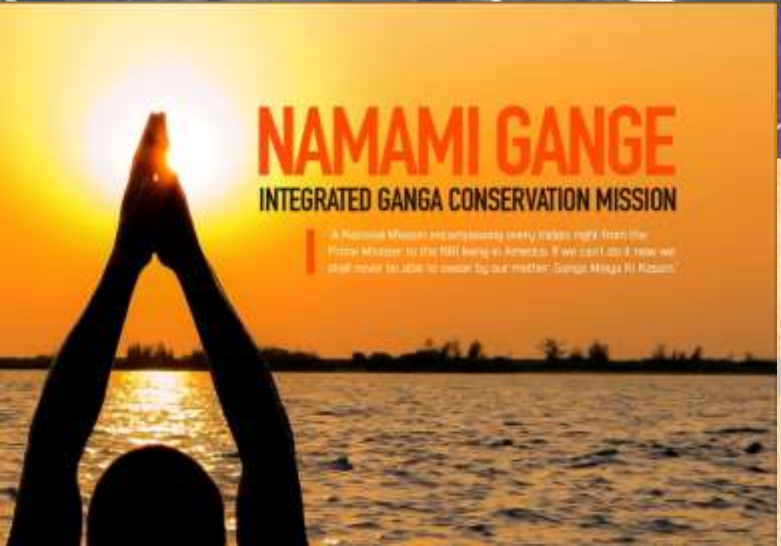
- **Uttarakhand: Hydropower potential = 20,000 MW**
- **Harnessed = 3200 MW**
- **Abandoned = 1500 MW**
- **Under review = 1800 MW**

Action Plan

- River rejuvenation approach has to be basin- not river-centric.
- A comprehensive solution to Ganga rejuvenation requires assured Eflows, innovative ways to treat sewage, regulated use of fertilizers & pesticides, and check disposal of untreated sewage into rivers.
- About 90% of water demand in basin is for irrigation with some of the lowest productivity levels in world. Improving agricultural use efficiency would free some water for river ecosystem.
- Distributed river basin modeling considering water quantity, quality, and sediment is needed to develop management plans considering:
  - Landuse/ cover changes
  - Demographic changes
  - Scenarios of new infrastructure
  - Impacts of climate change
  - …

Ideas for Discussion

- **Monitoring: strengthening of networks in terms of stations, variables, and frequency**
  - **Poor network above 1000 m elevations – presently studying valley hydrology only**
- **Drivers for change: Population growth, life style changes**
  - **Urbanization and peri-urban settlements,**
  - **Land-use land cover,**
  - **Climate changes – warming and snow/glacier melt; extreme events in mountains**
- **Changes in Hydrology in Future**
  - **Higher diversions, more surface storages,**
  - **More groundwater withdrawals and sand mining,**
  - **Reduced lean flows,**
- **Likely status in 2050**
  - **More storages on tributaries**
  - **More awareness and regulation, cleaner water, more water for Eflows.**



THANKS