Ganga Basin Water Balances - Data Extraction and Analysis using Available Hydrological Model outputs

Volume II: State Water Balance Analysis Report

INRM Consultants Pvt Ltd., New Delhi

Ganga Basin Water Balances - Data Extraction and Analysis using Available Hydrological Model outputs

Final Report

Volume II: State Water Balance Analysis Report

Contract no: 7172090

Project Funded by: The World Bank, India

INRM Consultants, New Delhi

March 2015

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

Introduction

As a key input to the World Bank lead Ganges Strategic Basin Assessment (SBA) and subsequent work on the Gangs River Basin Management Plan, hydrologic modelling of the Ganges Basin has been undertaken using the SWAT model. The modelling performed for SBA incorporated a baseline (current conditions) scenario and multiple scenarios of potential water resources development focused on hydro-power development in Nepal. Reporting from the modelling has been focused on the development scenarios and the costs and benefits stemming from these.

Objective

The main objective of this project is to construct and visualize water balance for the Ganga basin at different temporal and spatial scales.

Scope of Work

The main job of the consultant is to use data and outputs from the SWAT model to construct water balance for the Ganga basin at different spatial and temporal scales. The major tasks include:

1. On Spatial Scale: Construct water balance for:
    a. the entire Ganges Basin upstream of Farakka
    b. the Indian portion of the basin upstream of Farakka
    c. the Nepalese portion of the basin
    d. the Chinese portion of the basin
    e. each of the Indian states of the basin
    f. each of the districts (as per 2011 census) of Indian states of the basin (analysis at this spatial scale is restricted to water balance components expressed in terms of total depth of water in mm over the total district area).
2. On Temporal Scale: Water balance to be constructed at annual and calendar month level, for
    a. an average year
    b. a flood year (10^{th} percentile)
    c. a drought year (90^{th} percentile)
3. Water Balance Components: Water balance to be constructed including:
    a. Inflows to rivers of major tributaries
    b. Outflows from rivers of major tributaries
    c. Losses in river systems (Evapotranspiration, ground water recharge and conveyance loss), **however quantifying loss due to water distribution efficiency and water use efficiency at different scales may not be possible**
    d. Water Use:
        i. sectoral disaggregation (domestic, Industrial and agriculture)
        ii. major crop wise disaggregation.
4. Water Quality (model outputs for water quality parameters) of
        i. Sediment transport
        ii. BOD.
5. Indications of relative level of uncertainty
    a. wherever possible quantitatively (or qualitatively)
    b. list of additional data that would be required to reduce the uncertainty.

Analysis shall include monthly and daily flow duration curves, and descriptive statistics of monthly and annual flows (mean, 3 quartiles, temporal coefficient of variation).

Methodology

The information and the analysis provided here is the outcome of a detailed modeling exercise carried out using the SWAT hydrological model under the World Bank-led Ganges Strategic Basin Assessment (SBA) and some of the subsequent works on the hydrologic modelling of the Ganges Basin undertaken using the SWAT model. This report utilizes the following outputs:

- River water balance
  - Components: Stream Flow - FLOW_IN and FLOW_OUT
  - Units: cumecs (m^3/sec)
  - Description: Outflow = Inflow (upstream inflow+ generated in the catchment) - Use (irrigation +Domestic + Industrial) - Losses - change in storage
  - Spatial scale: At Country, State and major subbasins
  - Temporal scale: Long term average annual and monthly.
- Catchment Water balance
  - Components: Water yield - WYLD, Actual evapotranspiration - ET
  - Units: mm
  - Description: WYLD = Rainfall - ET - change in storage.
- Water Quality constituent balances
  - Components: Sediment yield, Biochemical oxygen demand (BOD)
  - Units: tons/ha, kg O2
  - Description: Load out = Load in (upstream Load in + generated in the catchment) - deposition/sinks.

Definitions of some of the key entities

- Water yield (mm) - WYLD: The net amount of water that leaves the subbasin and contributes to stream flow in the reach during the time step. (WYLD = SURQ + LATQ + GWQ – TLOSS – pond abstractions)
- Direct Surface runoff (mm - SURQ): Surface runoff contribution to stream flow during time step
- Lateral flow (mm) - LATQ: Lateral flow contribution to stream flow during the time step
- Base flow (mm) - GWQ: Groundwater contribution to stream flow (mm). Water from the shallow aquifer that returns to the reach during the time step
- Actual evapotranspiration (mm) - ET: Actual evapotranspiration from the subbasin during the time step
- Percolation (mm) - PERC: Water that percolates past the root zone during the time step (mm). There is potentially a lag between the time the water leaves the bottom of the root zone and reaches the shallow aquifer. Over a long period of time, this variable will be equal groundwater percolation. (Ground water Recharge = PERC-GWQ)
- Sediment yield (tons/ha) - SYLD: Sediment from the subbasin that is transported into the reach during the time step

- Stream In-Flow(m3/s) - FLOW_IN: Average daily stream flow into reach/stream (subbasin outlets) during the time step
- Stream Out-Flow(m3/s) - FLOW_OUT: Average daily stream flow out of reach (subbasin outlets) during the time step
- Biochemical oxygen demand-in (kg O2) - CBOD_IN: Carbonaceous biochemical oxygen demand of material transported into reach during the time step
- Biochemical oxygen demand-out (kg O2) - CBOD_OUT: Carbonaceous biochemical oxygen demand of material transported out of reach during the time step.

Spatial entities that have been defined for the study include:

- the entire Ganges Basin upstream of Farakka
- the Indian portion of the basin upstream of Farakka
- the Nepalese portion of the basin
- the Chinese portion of the basin
- each of the Indian States in the basin.

Temporal Scale include:

- at annual and calendar month level for
  - long term annual average (long term basin average)
  - a high flow year (basin 10^{th} percentile, single year)
  - a low flow year (basin 90^{th} percentile, single year).

Identification of High flow and Low flow year

Specific years are identified as year of high flow and year of low flow based on stream flow from 1975-2004. Average annual flow of 20 locations (major basins and on main Ganga at Farakka) was analysed for high flow (10^{th} percentile) and low flow (90^{th} percentile). High and Low flow years were identified as those years which had maximum number of subbasins experiencing high and low flow. Table 1 and Figure 1 show the year wise basins falling in high and low flow year category. Accordingly 1985 and 1989 were identified as basin high flow year and basin low flow year respectively.

Table 1: Count of major basins of Ganga showing High Flow and Low Flow Years

High Flow Year	No of Basins	Low Flow Year	No of Basins
1975	2	1976	2
1978	2	1977	1
1980	1	1979	1
1982	1	1981	1
1984	2	1987	2
1985	4	1989	5
1988	1	1992	1
1990	1	1994	1
1994	2	2001	1
1995	1	2004	2

High Flow Year	No of Basins	Low Flow Year	No of Basins
1996	2	2005	3
2001	1		

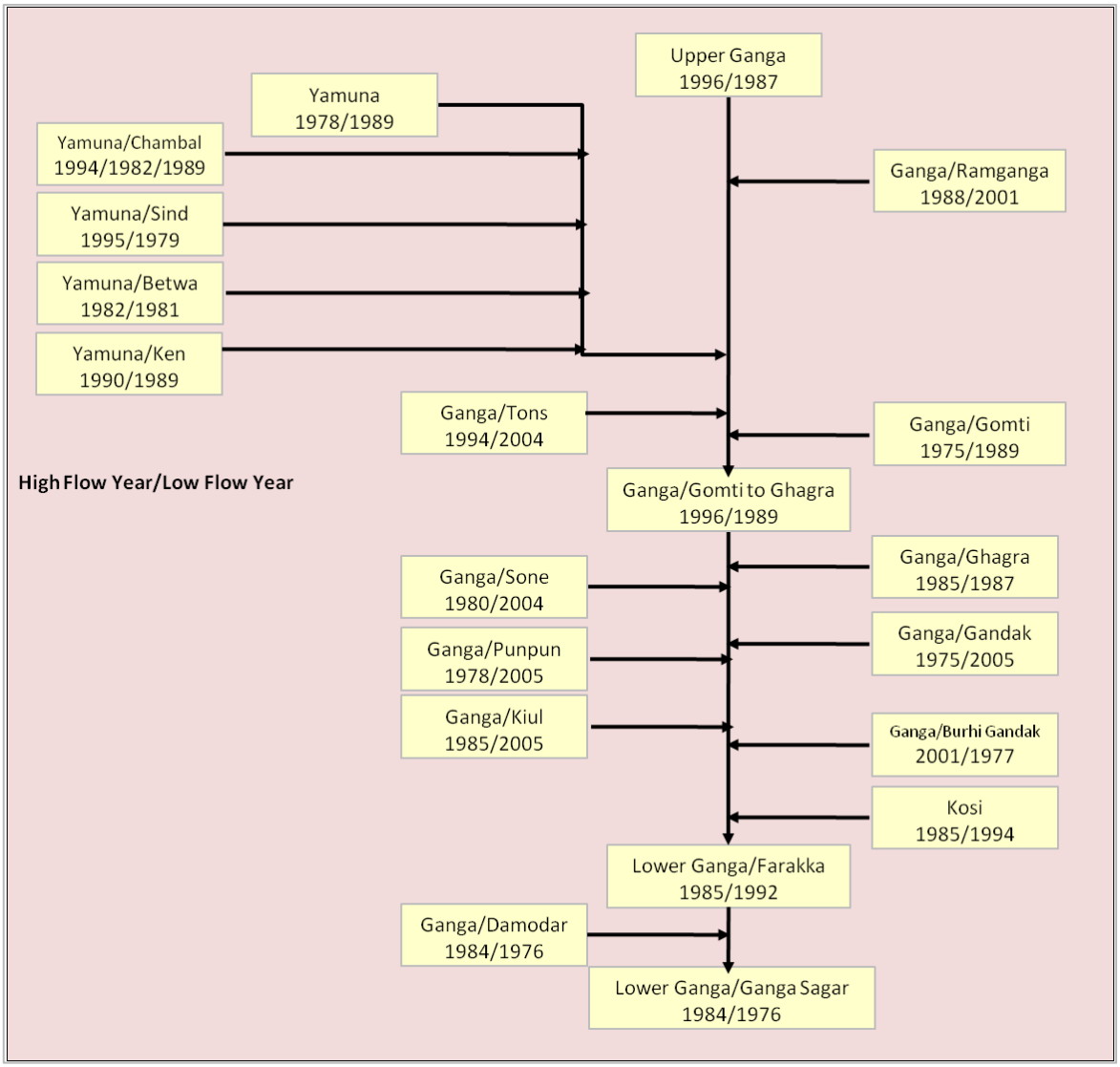


Figure 1: Flow Chart showing High and Low Flow years for major tributaries of the Ganga river basin

Scenarios for flow regime change analysis

The following two scenarios have been constructed to represent two distinct flow regimes, representing i) pre-water resources development and ii) present flow regimes.

Scenario A: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting catchment hydrology corresponding to the current landuse.

Scenario B: Current conditions:, Existing major water resources infrastructure, current management/operation practices, existing crop water demand through irrigation. Note: Current crop management practices (irrigation from Surface and Ground water) + Point source (average BOD

and the average sewage generation per capita and converting total load based on subbasin population) has been used.

Levels and Spatial Scales at which Outputs are Consolidated

Flow outputs (Inflow and outflow) in BCM (Billion Cubic Metre) are given, within States of India (Figure 2). Flow generated in terms of water balance components (Water Yield in mm, Evapotranspiration in mm and Sediment Yield in million metric tons within the spatial units as shown in Figure 2 has been analysed and aggregated.

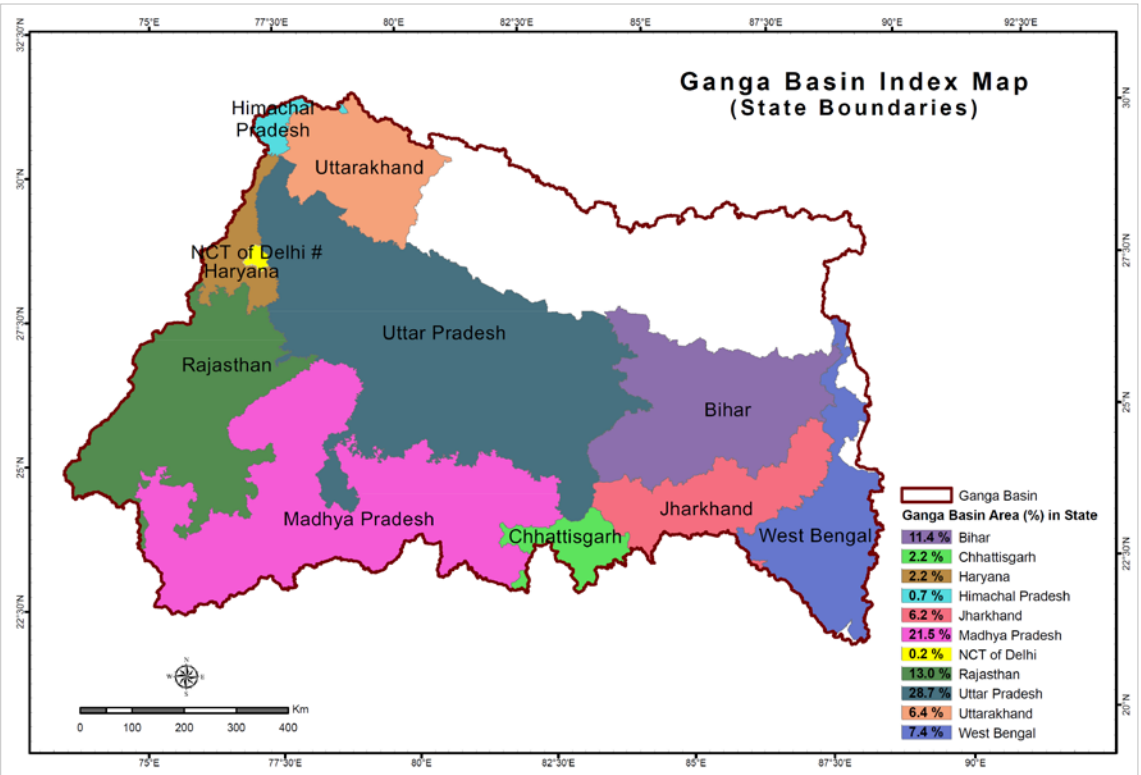


Figure 2: Index map of Ganga Basin - Output 2 at Administrative level -Indian States

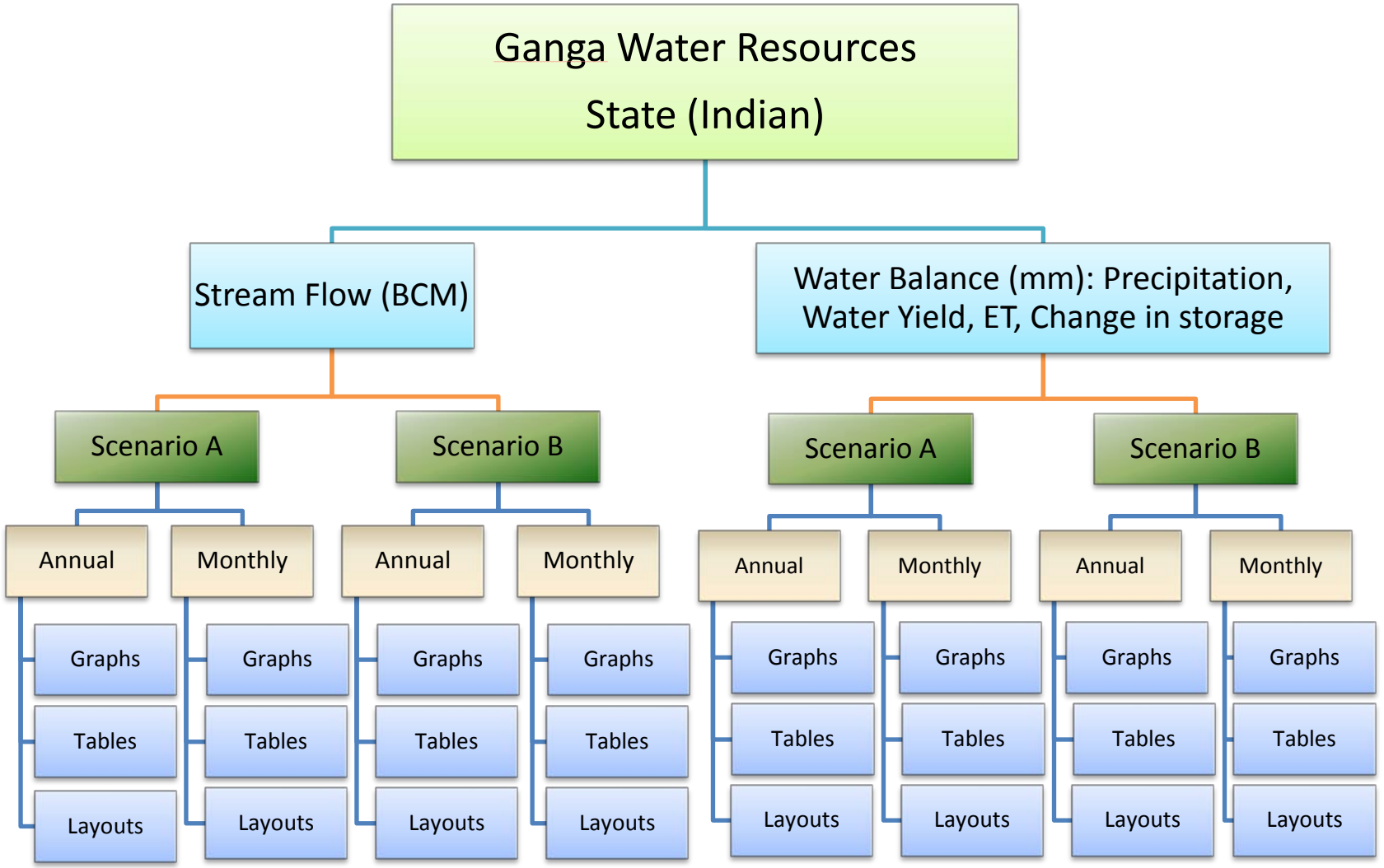


Figure 3: Flow Chart depicting Presentation of Outputs

Chapter 2

Stream Flow, Water Balance and Sediment Flow at State (India) Level

Stream Flow and Water Balance at State (India) Level

Average annual stream flow and water balance have been aggregated at state level for scenario A and scenario B.

Annual and Seasonal Stream Flow in BCM/year for Scenario A and Scenario B - State level

Table 2 shows the average annual flow for long term average year.

Table 2: Stream Flow: Annual Stream flow (BCM/year) - State Level

Country	Abbrevi-ation	Scenario A+		Scenario B++	
		Flow In	Flow Out	Flow In	Flow Out
Long-term Average Year: Stream Flow (BCM/year)					
Himachal Pradesh	HP	0.0	4.4	0.0	3.9
Haryana	HAR	5.1	7.9	4.4	4.6
NCT of Delhi	DEL	6.4	6.7	5.0	4.8
Madhya Pradesh	MP	0.0	97.0	0.0	43.9
Rajasthan	RAJ	25.5	52.3	11.4	20.0
Uttarakhand	UK	0.0	56.8	0.0	49.5
Chhattisgarh	CHG	0.0	14.7	0.0	8.7
Uttar Pradesh	UP	265.7	373.3	157.5	197.7
Jharkhand	JHK	0.0	38.0	0.0	19.3
Bihar	BIH	503.1	560.1	291.4	307.5
West Bengal	WB	586.3	638.4	322.0	341.2

* India at Farakka

+ Scenario A: Pre-development flow in the absence of water resources infrastructure and water diversionsbut reflecting catchment hydrology corresponding to the current landuse

++ Scenario B: Current conditions: Existing major water resources infrastructures, current management/operation practices, existing crop water demand with irrigation wherever applicable.

Change in flow in Scenario B with respect to Scenario A along with percentage reduction in flow is shown in Figure 4. Figure 5 and Figure 6 show the graphical representation.

Figure 7, Figure 8 and Figure 9 depict annual, monsoon and non monsoon flows in BCM at state level for Scenario B and the ratio of Scenario B to Scenario A.

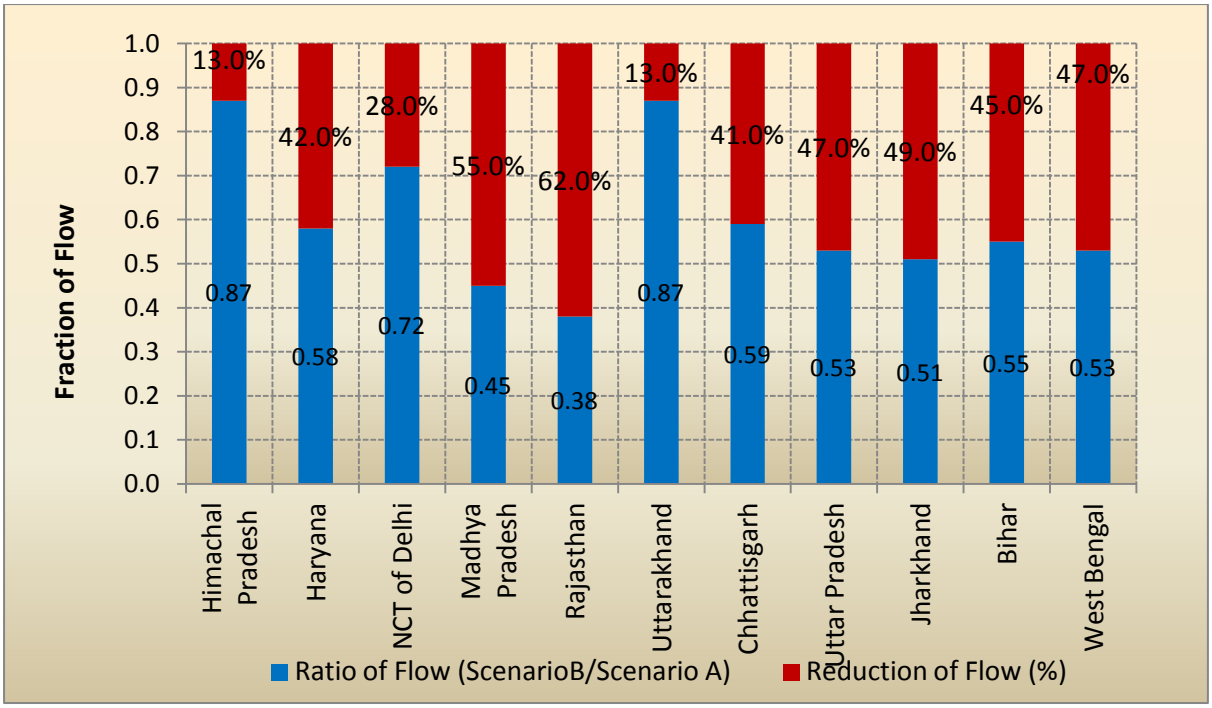
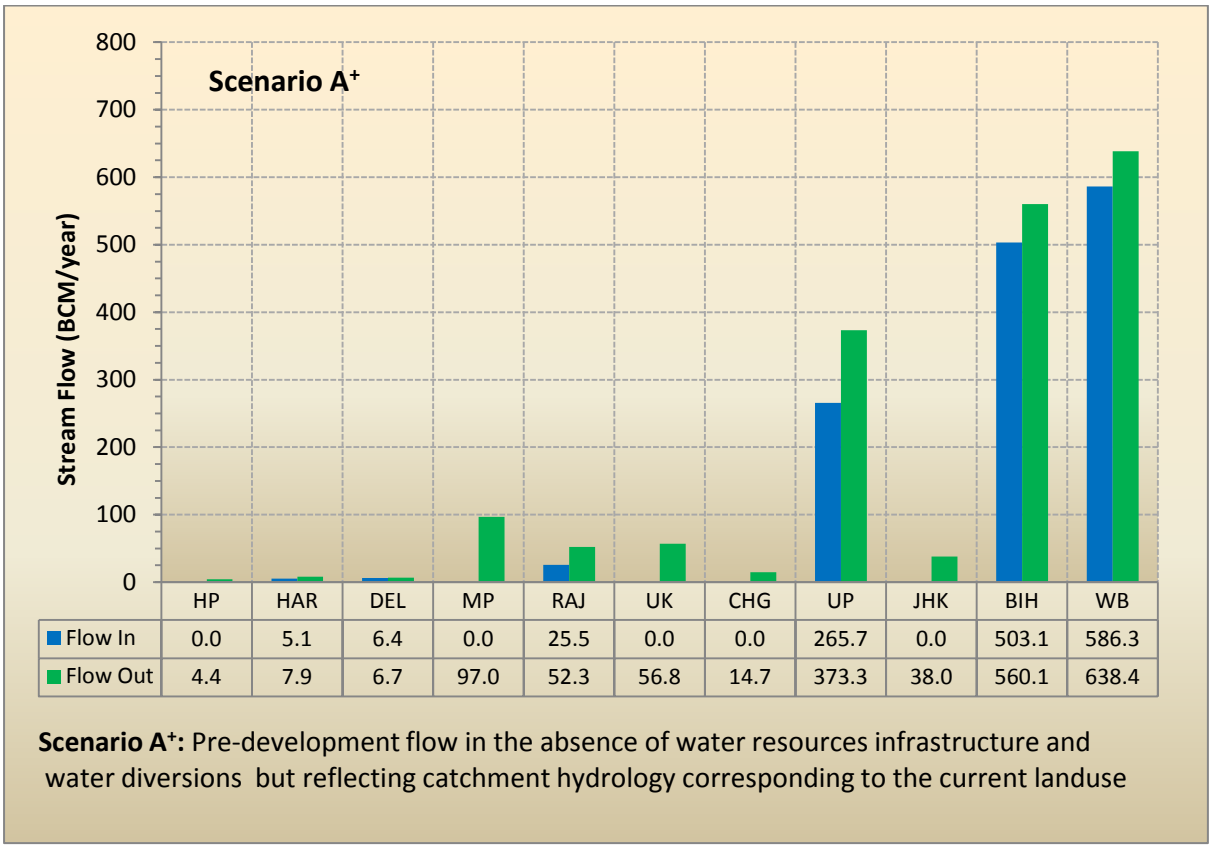


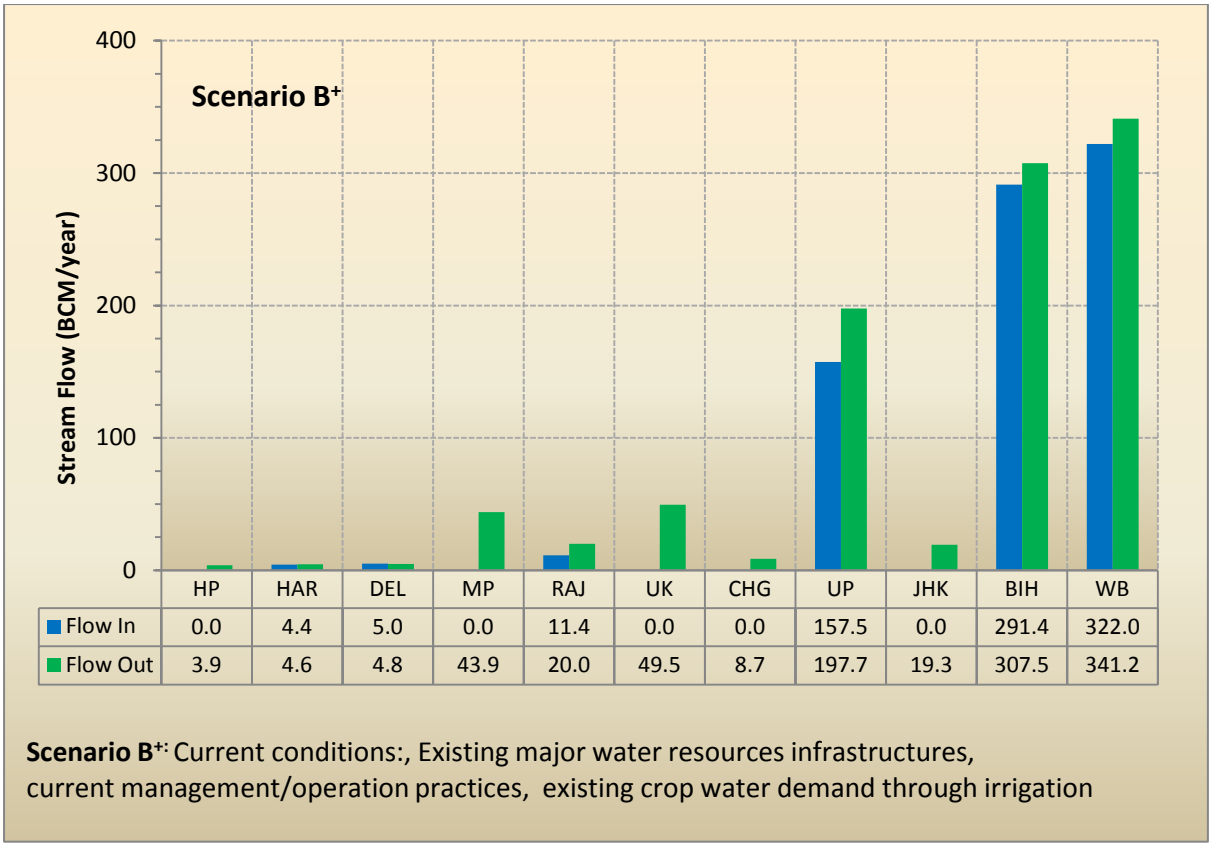
Figure 4: Graph : Change in flow w.r.t. Scenario A and percentage reduction in flow - State Level



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.0	5.1	6.4	0.0	25.5	0.0	0.0	265.7	0.0	503.1	586.3
Flow Out	4.4	7.9	6.7	97.0	52.3	56.8	14.7	373.3	38.0	560.1	638.4

Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting catchment hydrology corresponding to the current landuse

Figure 5: Graph: Annual Stream flow (BCM/year) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.0	4.4	5.0	0.0	11.4	0.0	0.0	157.5	0.0	291.4	322.0
Flow Out	3.9	4.6	4.8	43.9	20.0	49.5	8.7	197.7	19.3	307.5	341.2

Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 6: Graph: Annual Stream flow (BCM/year) - State Level - Scenario

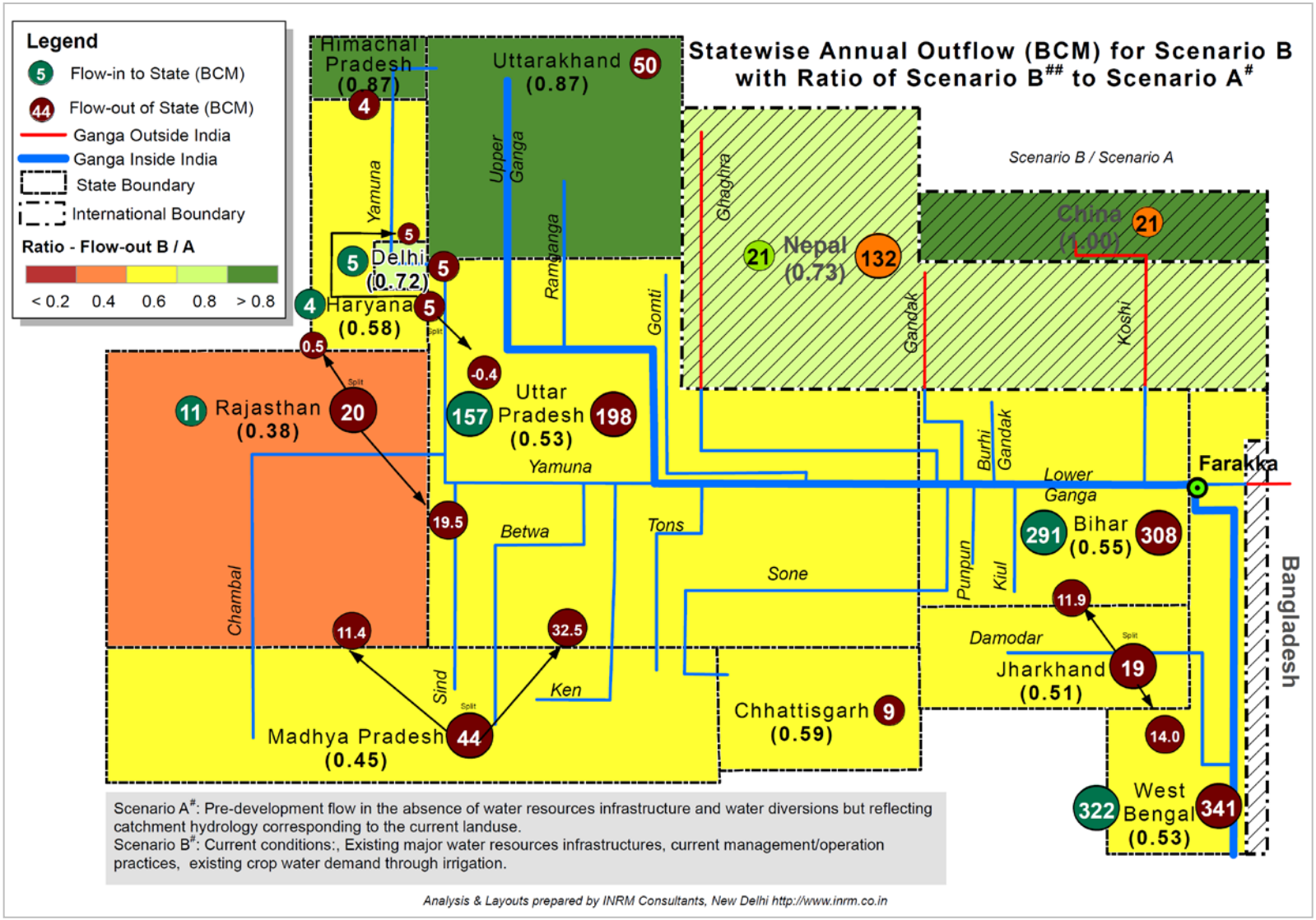


Figure 7: Conceptual Diagram: Annual Stream flow (BCM/year) - State Level - Scenario B and Ration of Scenario B to Scenario A

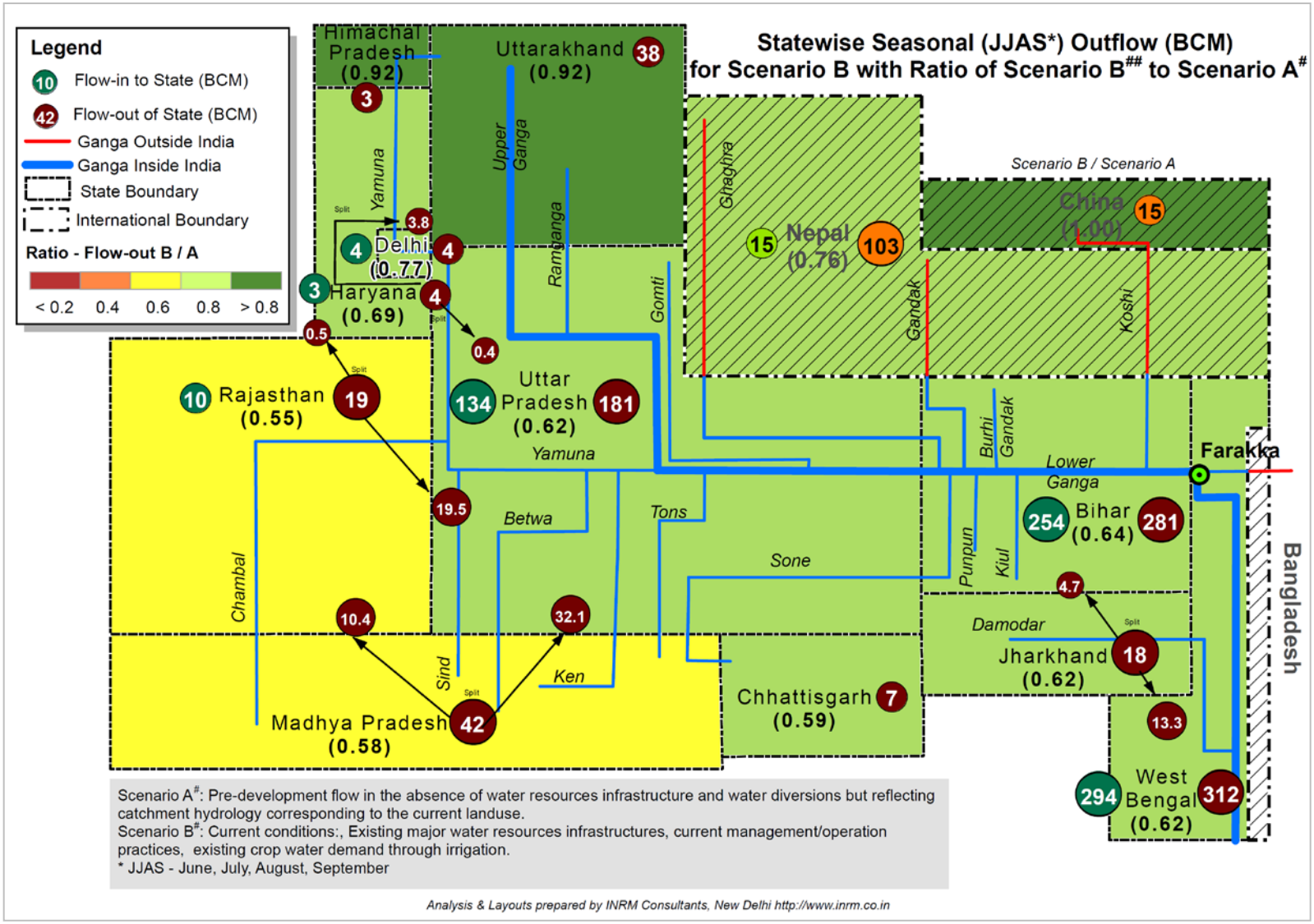


Figure 8: Conceptual Diagram: Monsoon Stream flow (BCM/season) - State Level - Scenario B and Ration of Scenario B to Scenario A

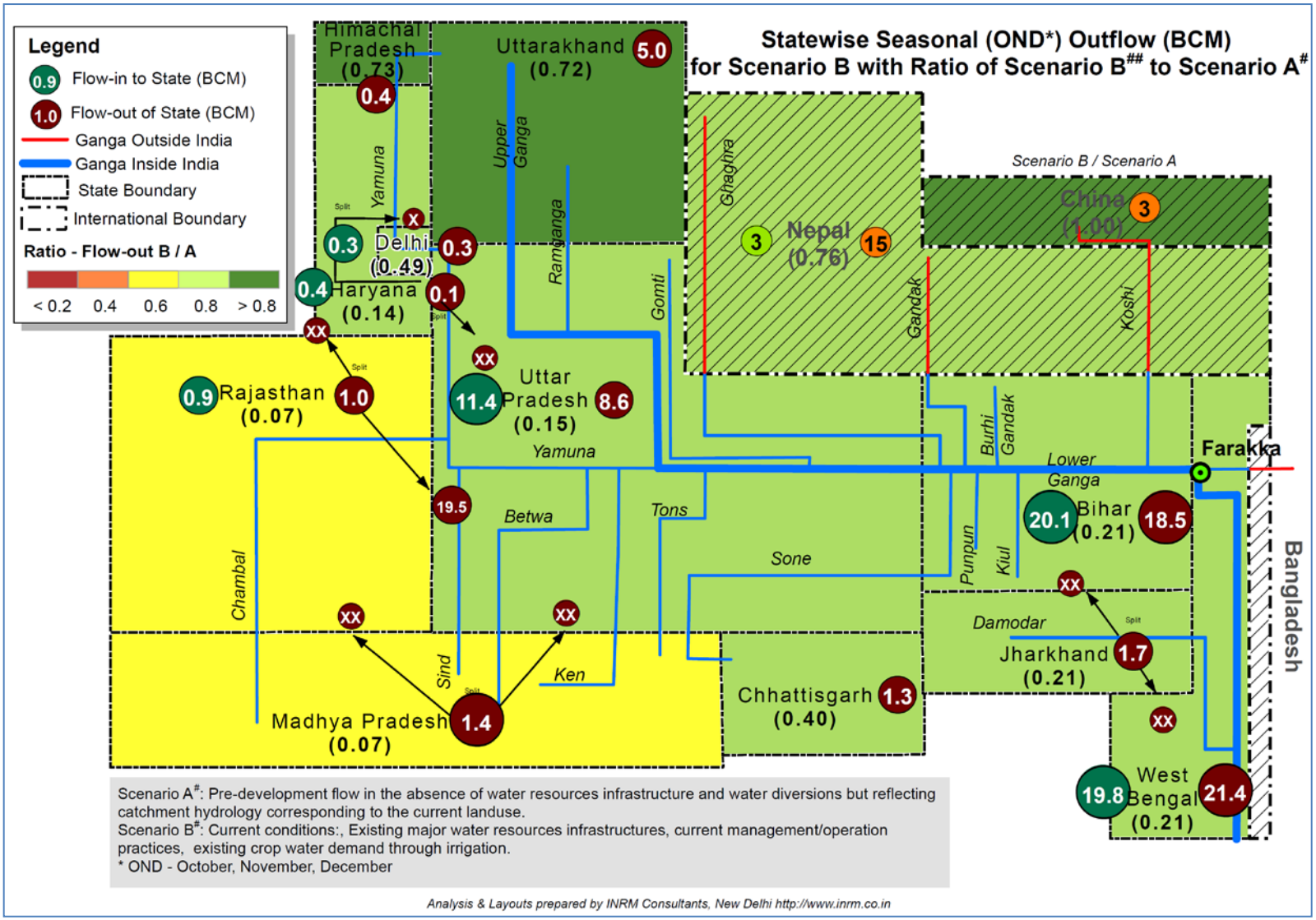
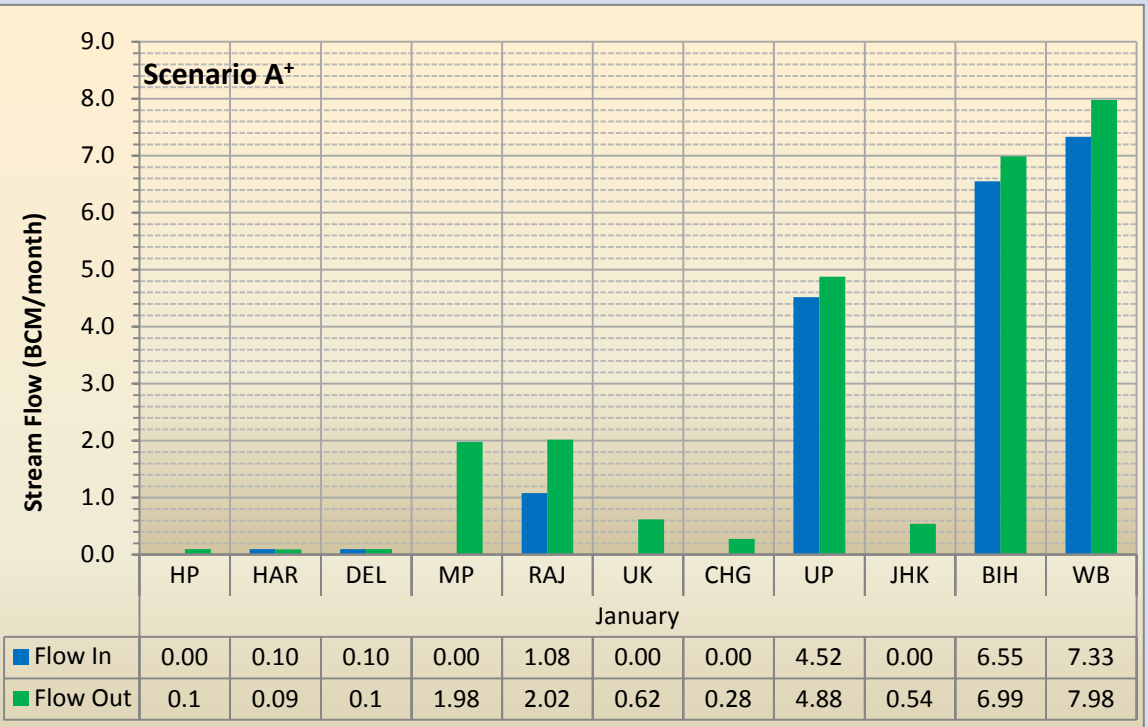


Figure 9: Conceptual Diagram: Non Monsoon Stream flow (BCM/season) - State Level - Scenario B and Ration of Scenario B to Scenario A

Monthly Stream Flow in BCM/year - Scenario A - State (India) Level

Long term average monthly stream flow has been aggregated at state level for scenario A. Figure 10 shows graphical representation of the long term monthly values of stream flow at state level.

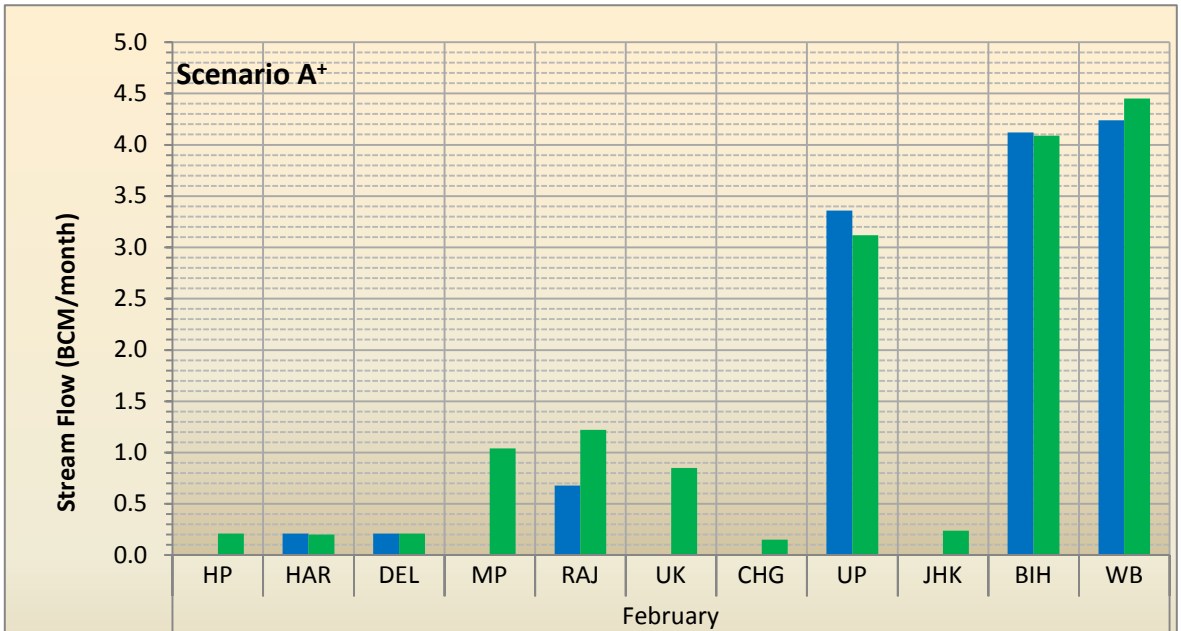
Figure 10: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.10	0.10	0.00	1.08	0.00	0.00	4.52	0.00	6.55	7.33
Flow Out	0.1	0.09	0.1	1.98	2.02	0.62	0.28	4.88	0.54	6.99	7.98

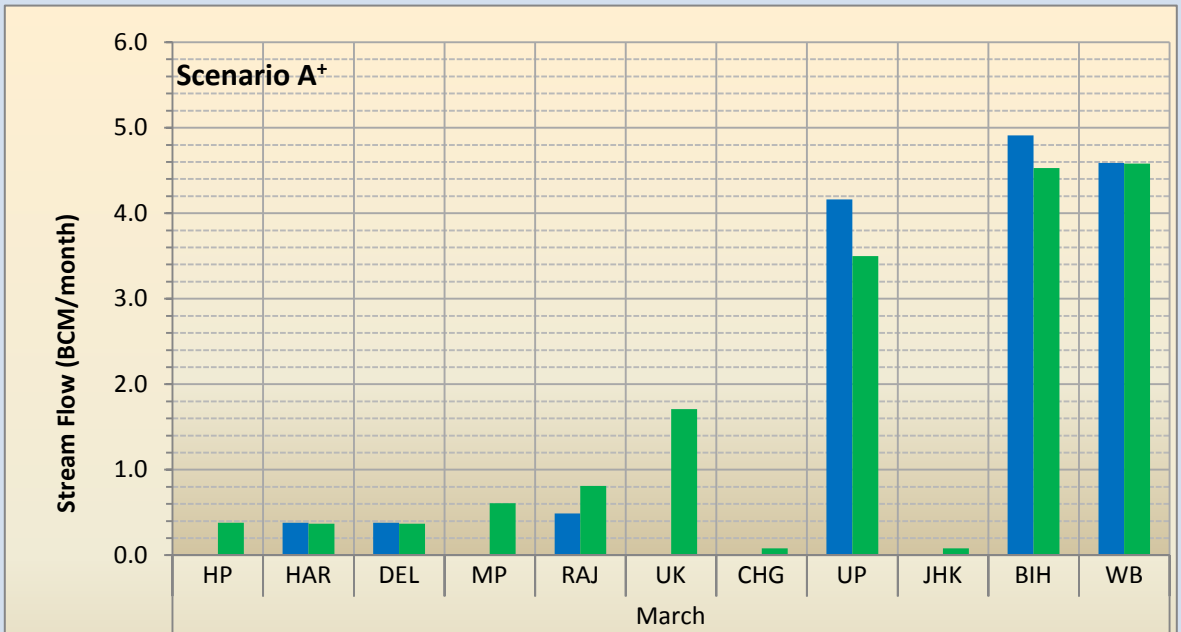
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 10: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.21	0.21	0.00	0.68	0.00	0.00	3.36	0.00	4.12	4.24
Flow Out	0.21	0.2	0.21	1.04	1.22	0.85	0.15	3.12	0.24	4.09	4.45

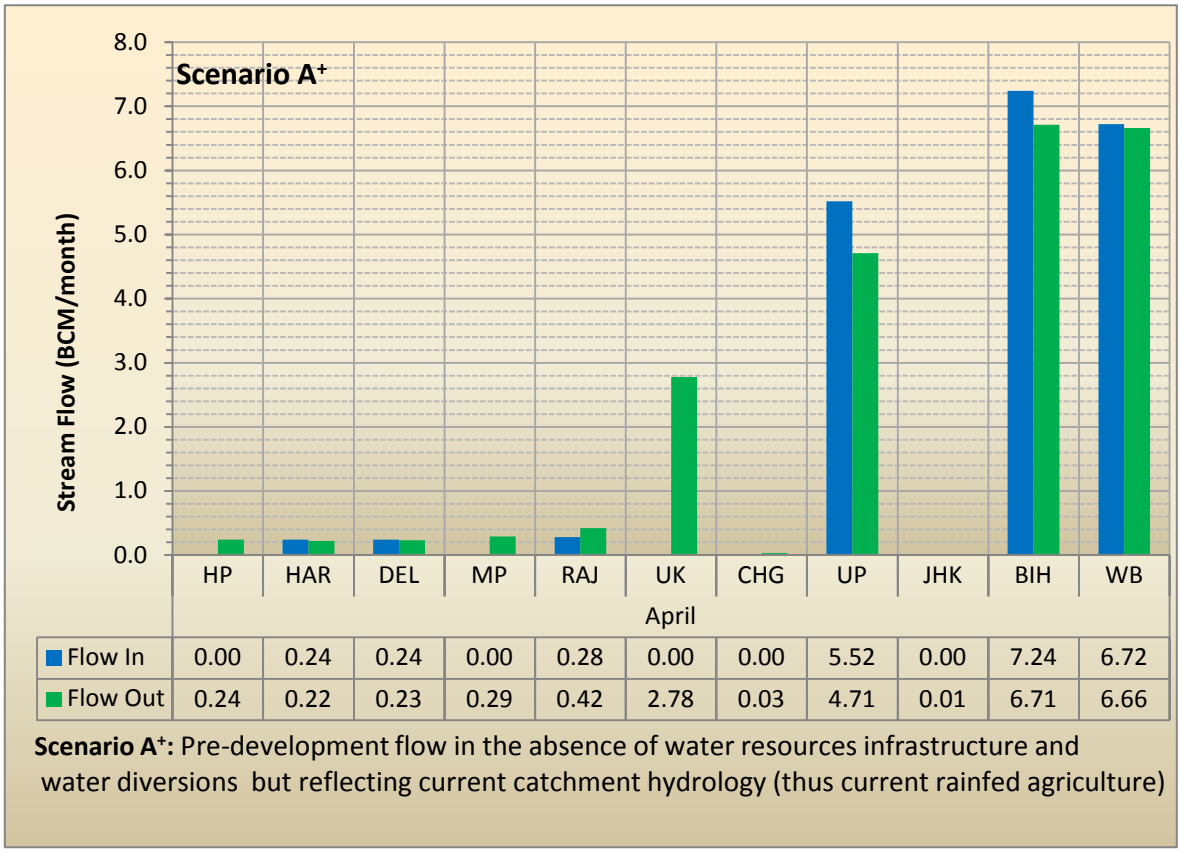
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.38	0.38	0.00	0.49	0.00	0.00	4.16	0.00	4.91	4.59
Flow Out	0.38	0.37	0.37	0.61	0.81	1.71	0.08	3.5	0.08	4.53	4.58

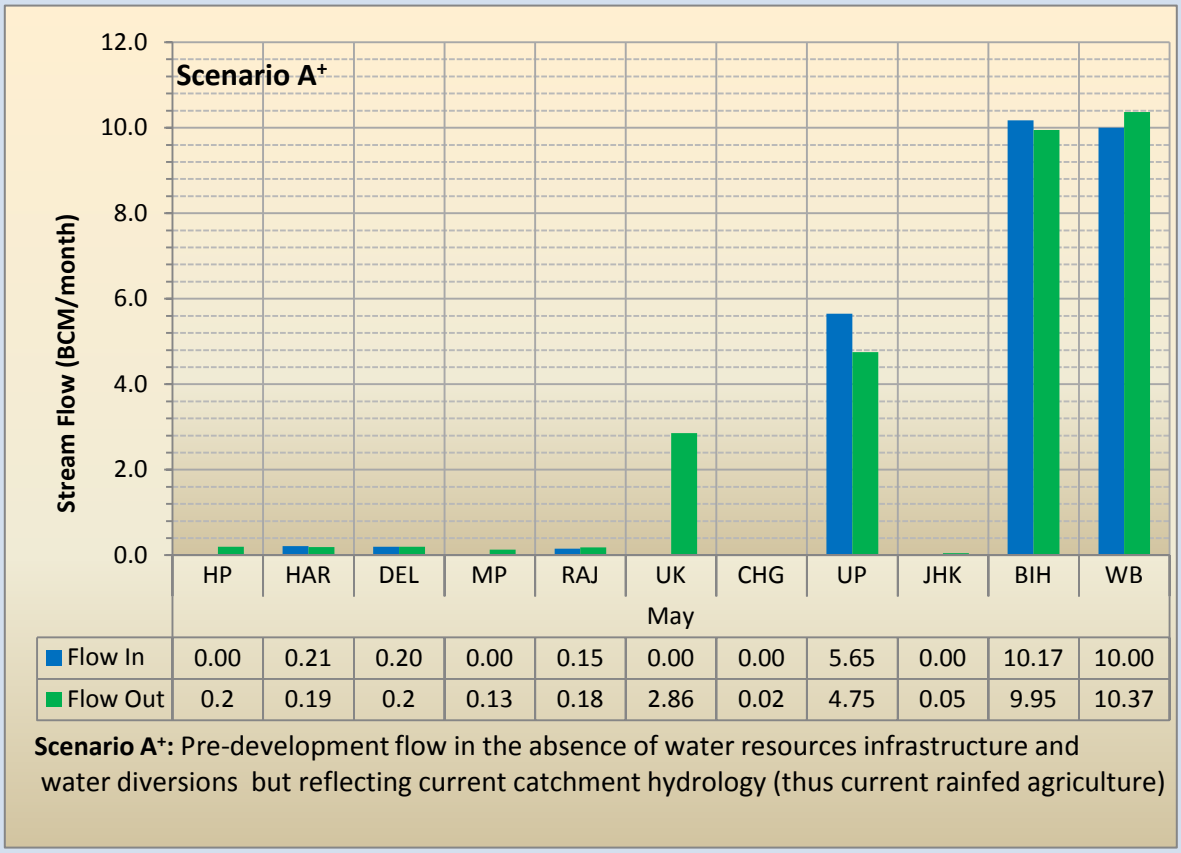
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 10: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.24	0.24	0.00	0.28	0.00	0.00	5.52	0.00	7.24	6.72
Flow Out	0.24	0.22	0.23	0.29	0.42	2.78	0.03	4.71	0.01	6.71	6.66

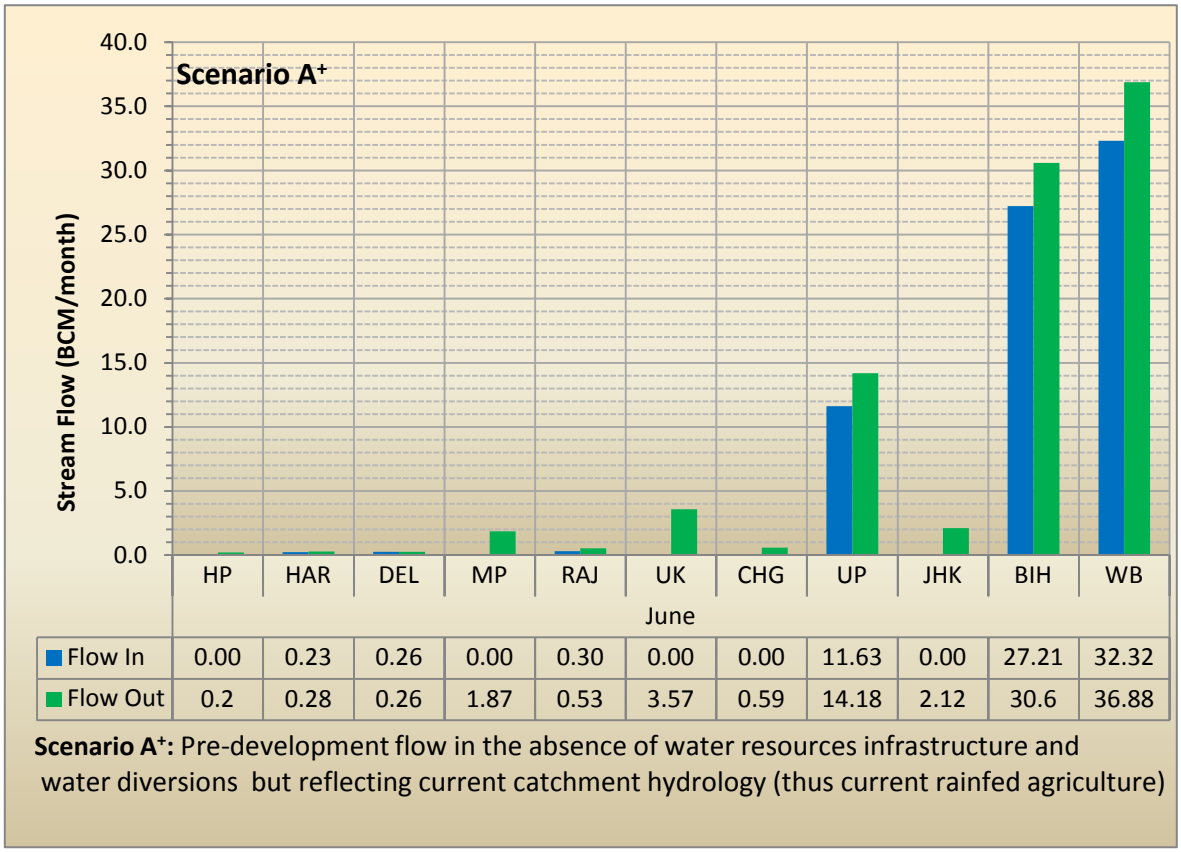
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.21	0.20	0.00	0.15	0.00	0.00	5.65	0.00	10.17	10.00
Flow Out	0.2	0.19	0.2	0.13	0.18	2.86	0.02	4.75	0.05	9.95	10.37

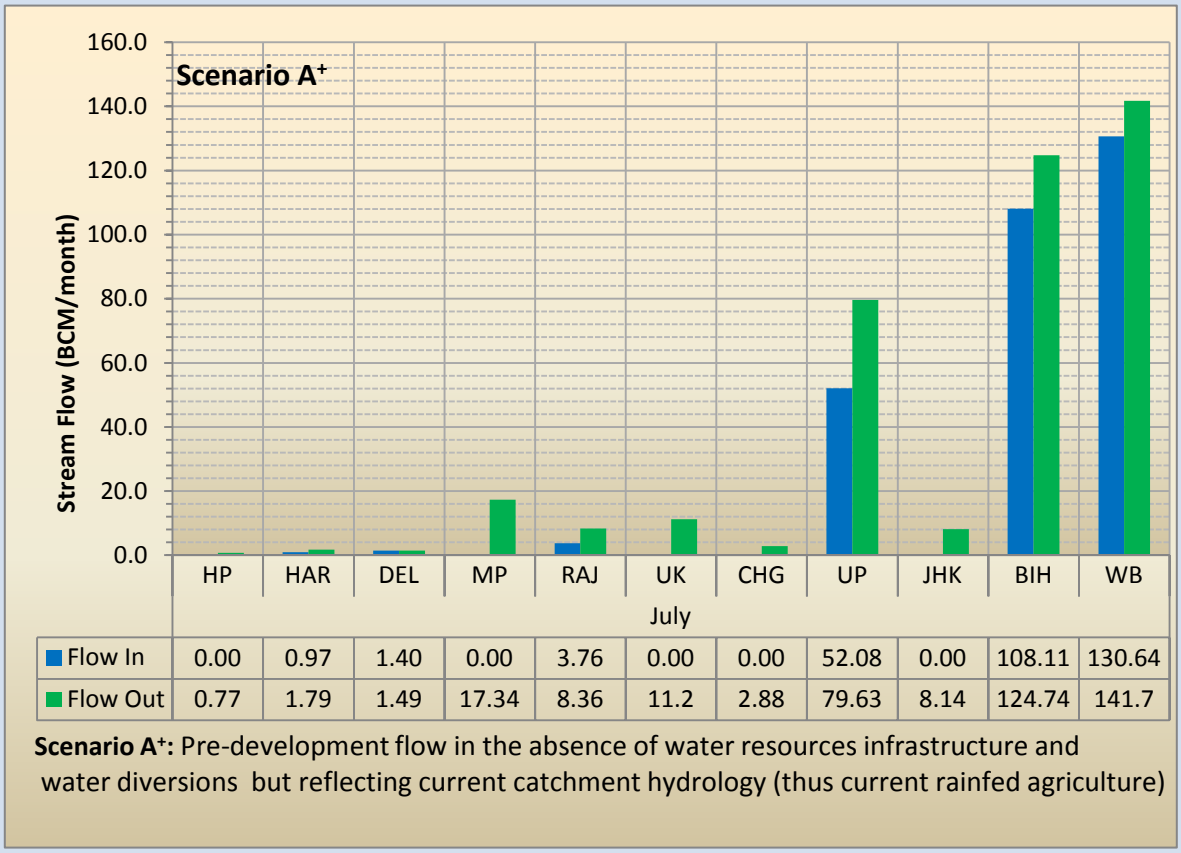
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 10: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.23	0.26	0.00	0.30	0.00	0.00	11.63	0.00	27.21	32.32
Flow Out	0.2	0.28	0.26	1.87	0.53	3.57	0.59	14.18	2.12	30.6	36.88

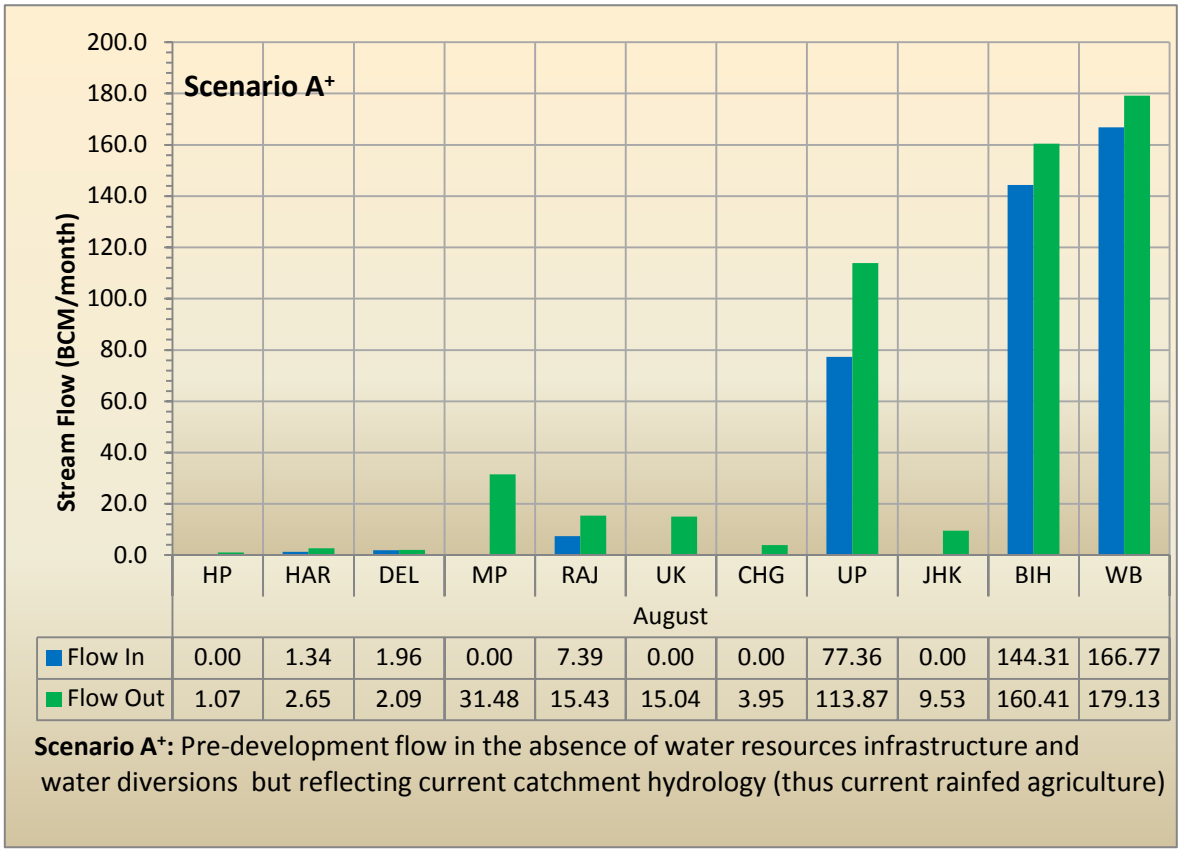
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.97	1.40	0.00	3.76	0.00	0.00	52.08	0.00	108.11	130.64
Flow Out	0.77	1.79	1.49	17.34	8.36	11.2	2.88	79.63	8.14	124.74	141.7

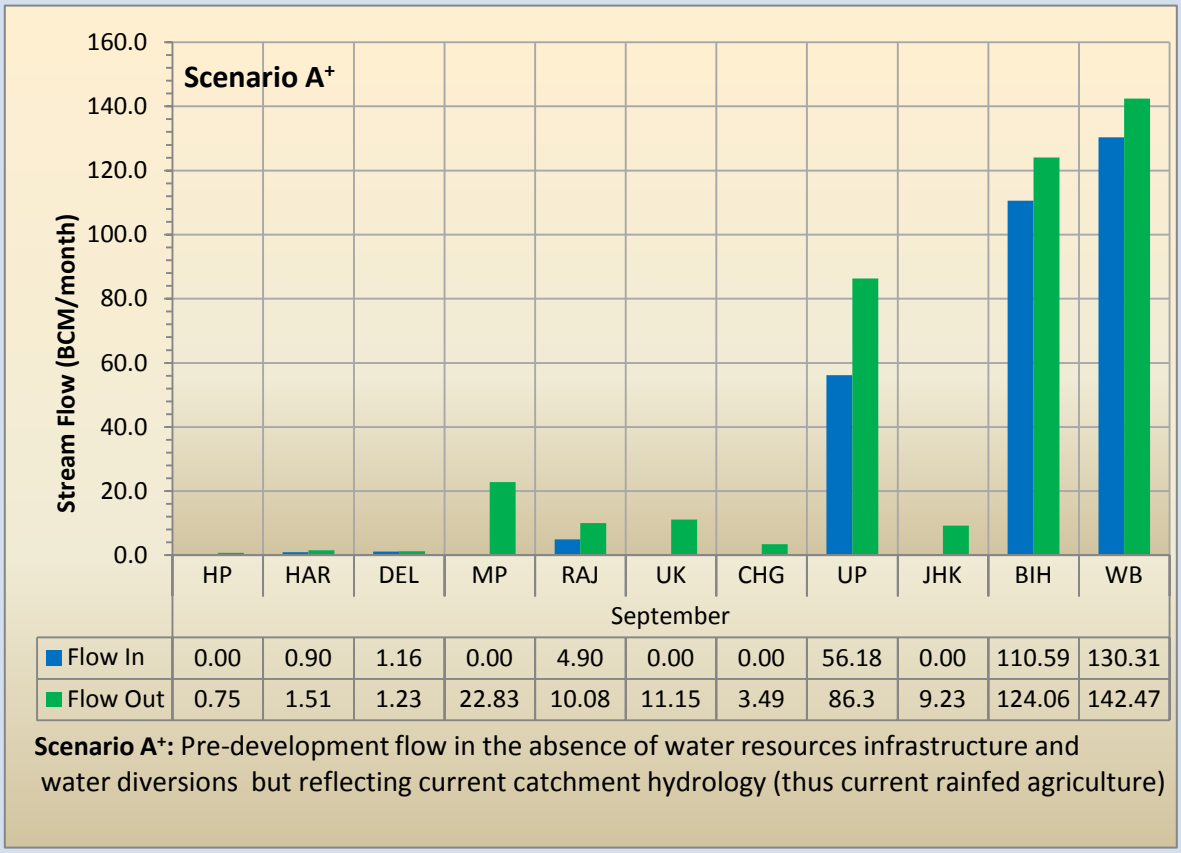
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 10: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	1.34	1.96	0.00	7.39	0.00	0.00	77.36	0.00	144.31	166.77
Flow Out	1.07	2.65	2.09	31.48	15.43	15.04	3.95	113.87	9.53	160.41	179.13

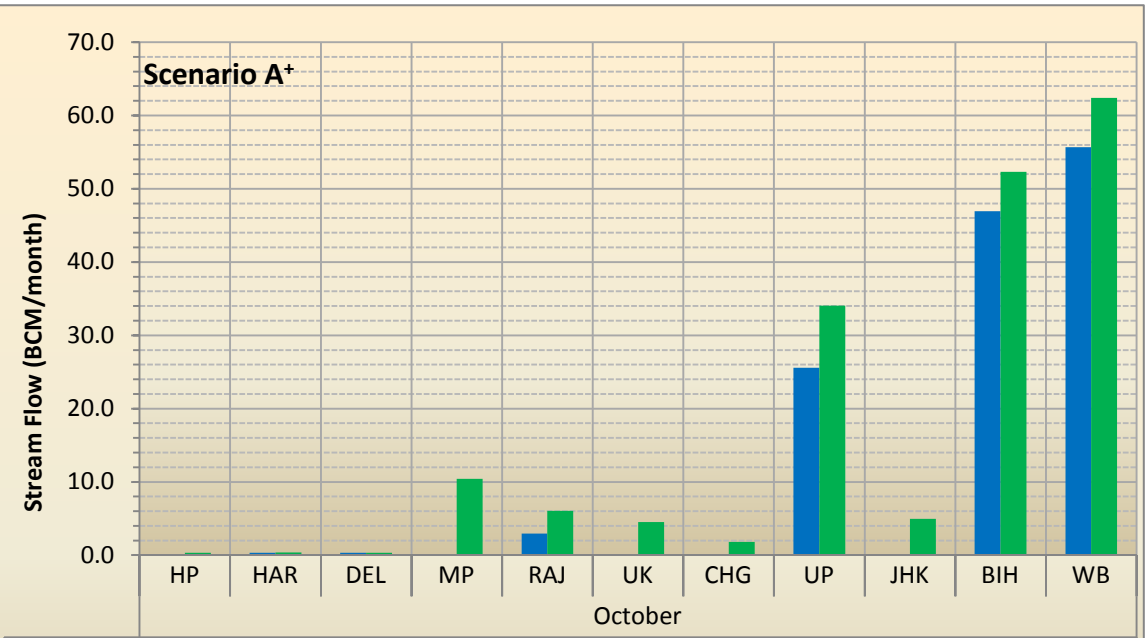
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.90	1.16	0.00	4.90	0.00	0.00	56.18	0.00	110.59	130.31
Flow Out	0.75	1.51	1.23	22.83	10.08	11.15	3.49	86.3	9.23	124.06	142.47

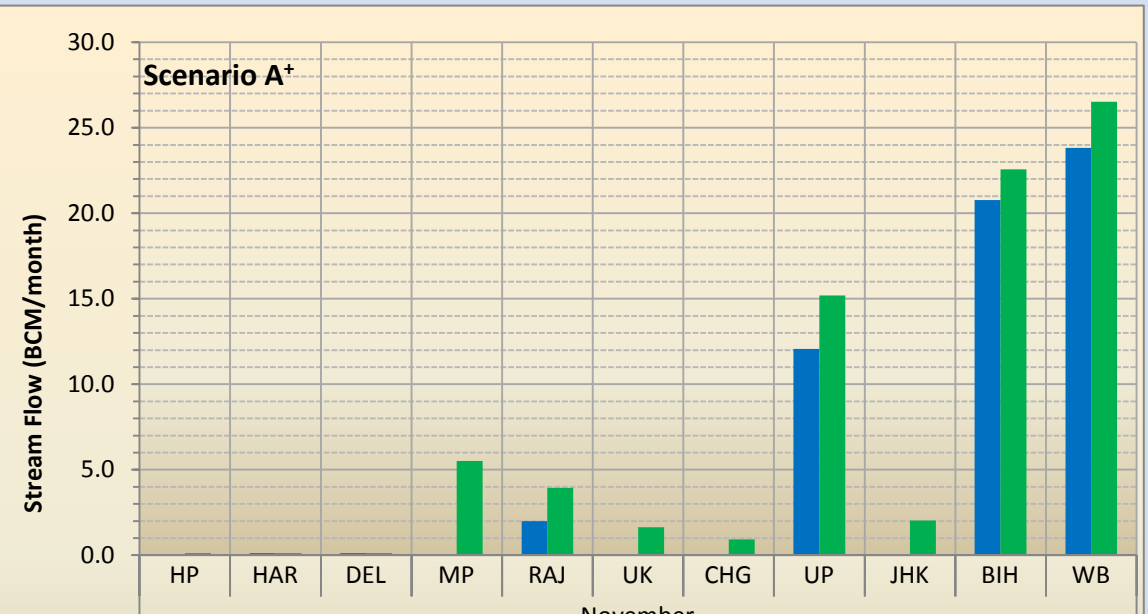
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 10: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.31	0.32	0.00	2.96	0.00	0.00	25.57	0.00	46.94	55.68
Flow Out	0.31	0.37	0.33	10.42	6.03	4.53	1.82	34.03	4.97	52.31	62.41

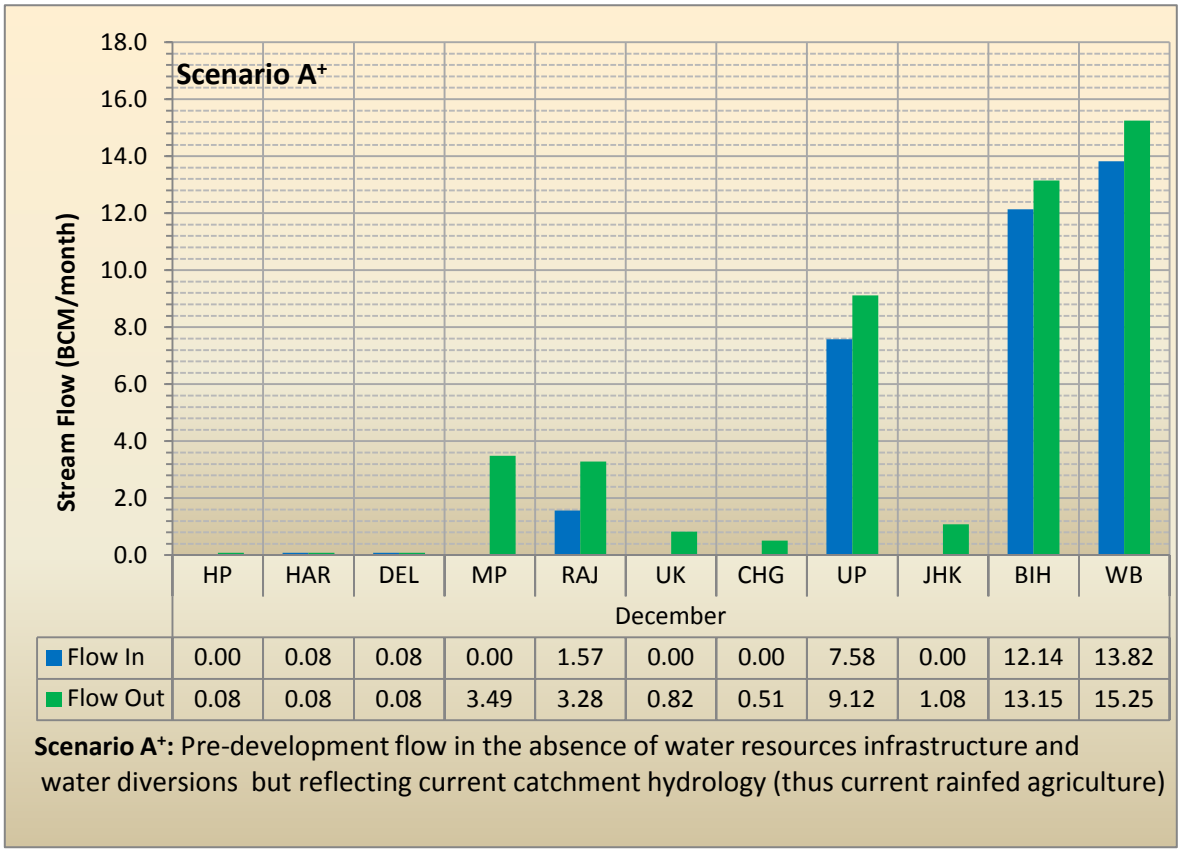
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.12	0.12	0.00	1.99	0.00	0.00	12.06	0.00	20.77	23.83
Flow Out	0.12	0.13	0.12	5.52	3.94	1.63	0.92	15.2	2.03	22.57	26.51

Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 10: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario A



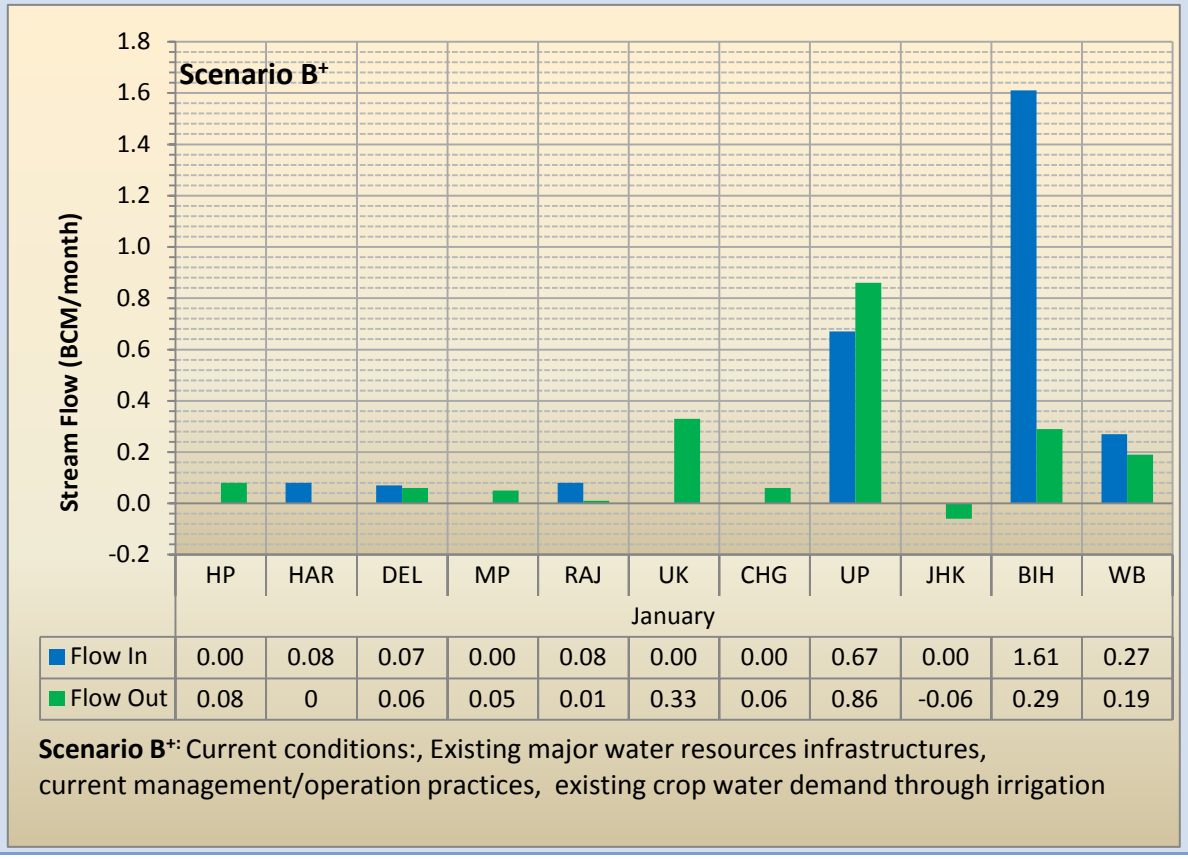
	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.08	0.08	0.00	1.57	0.00	0.00	7.58	0.00	12.14	13.82
Flow Out	0.08	0.08	0.08	3.49	3.28	0.82	0.51	9.12	1.08	13.15	15.25

Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Monthly Stream Flow in BCM/year - Scenario B - State (India) Level

Long term average monthly stream flow has been aggregated at state level for scenario B. Figure 11 shows graphical representation of long term monthly values of stream flow at state level.

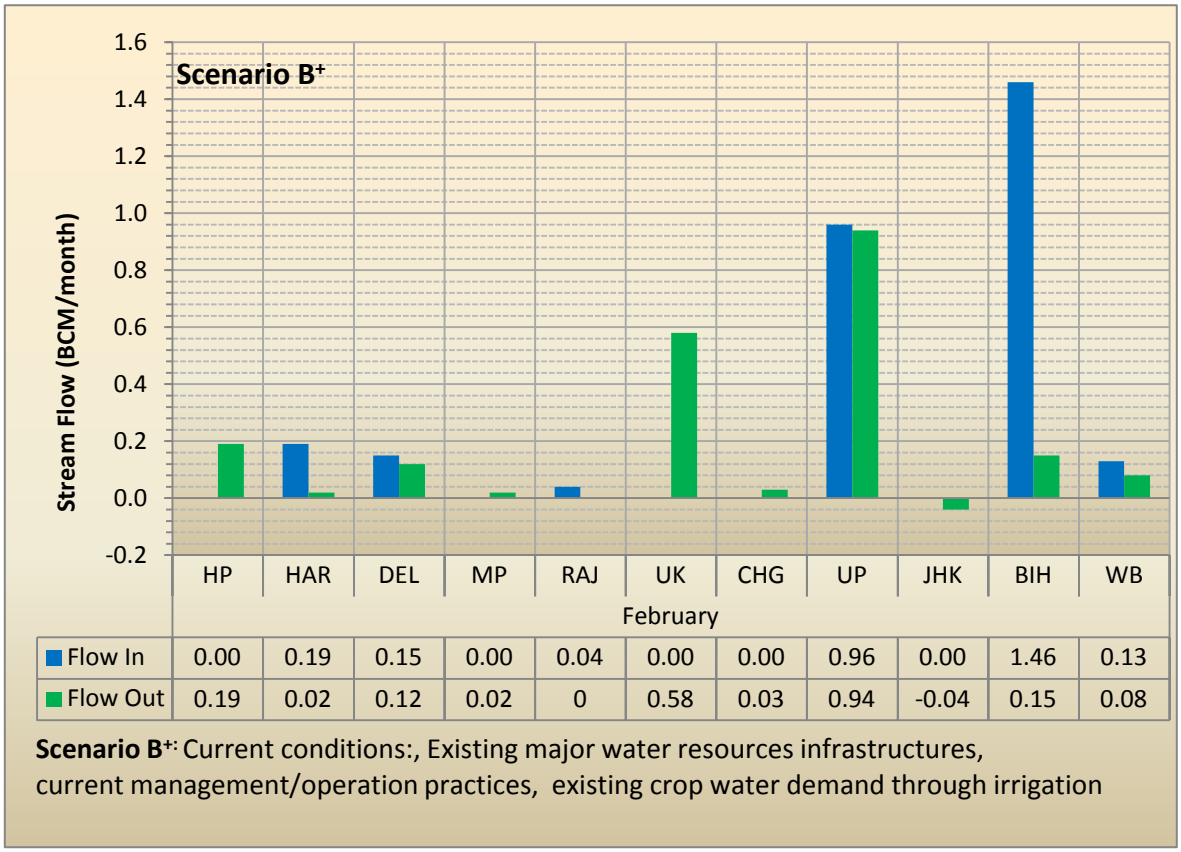
Figure 11: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.08	0.07	0.00	0.08	0.00	0.00	0.67	0.00	1.61	0.27
Flow Out	0.08	0	0.06	0.05	0.01	0.33	0.06	0.86	-0.06	0.29	0.19

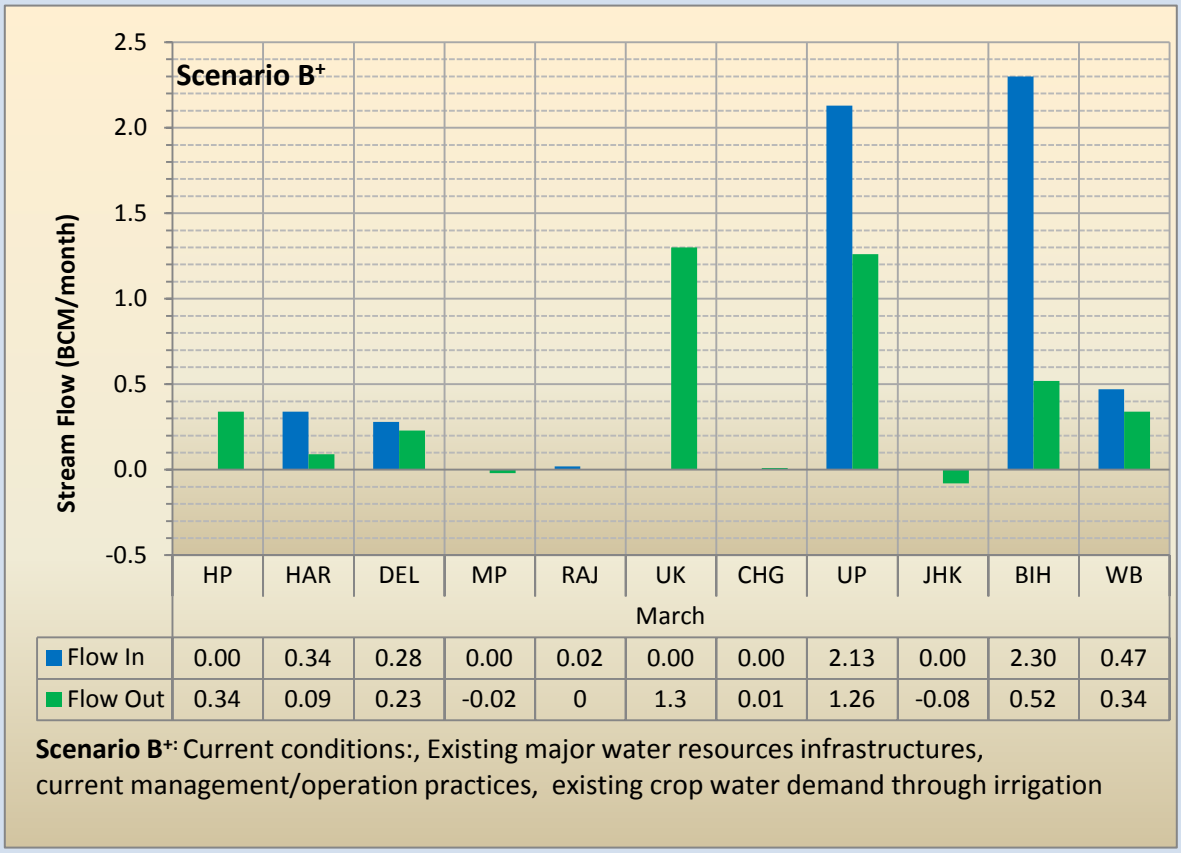
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 11: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.19	0.15	0.00	0.04	0.00	0.00	0.96	0.00	1.46	0.13
Flow Out	0.19	0.02	0.12	0.02	0	0.58	0.03	0.94	-0.04	0.15	0.08

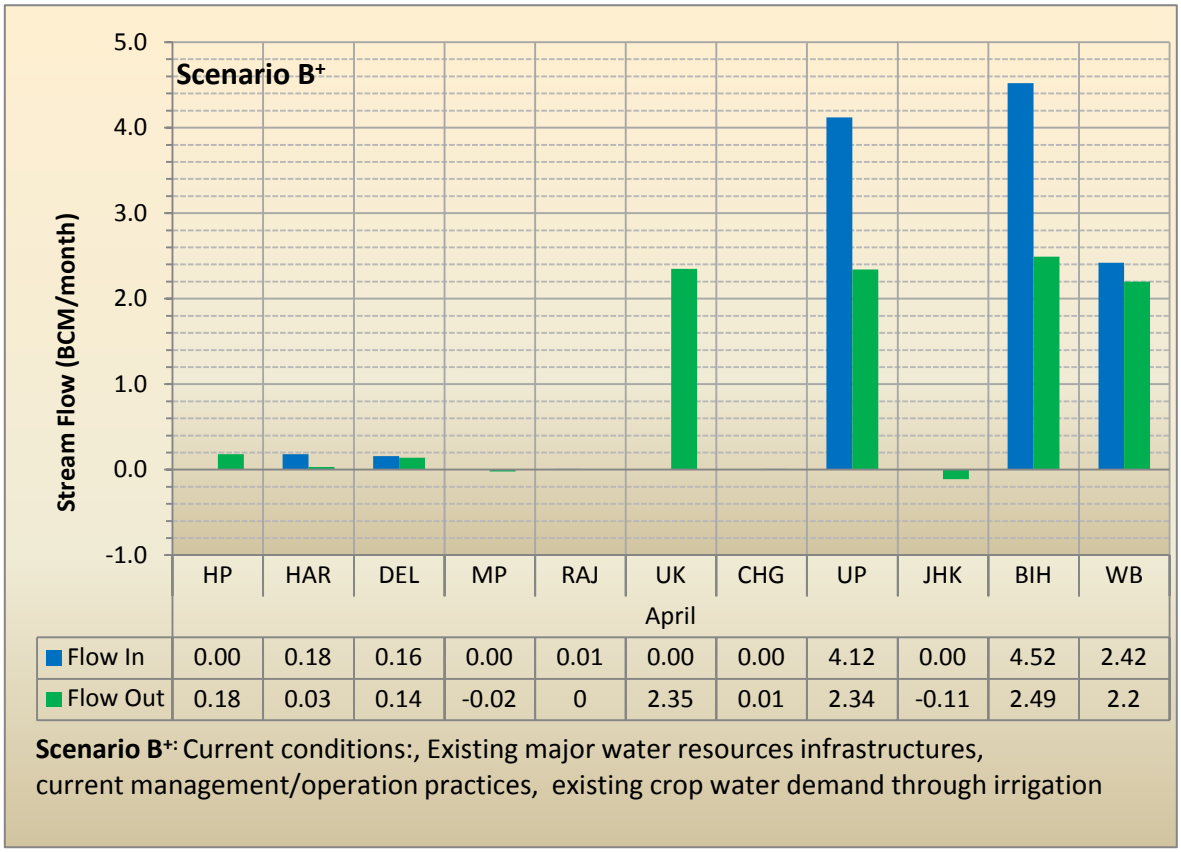
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.34	0.28	0.00	0.02	0.00	0.00	2.13	0.00	2.30	0.47
Flow Out	0.34	0.09	0.23	-0.02	0	1.3	0.01	1.26	-0.08	0.52	0.34

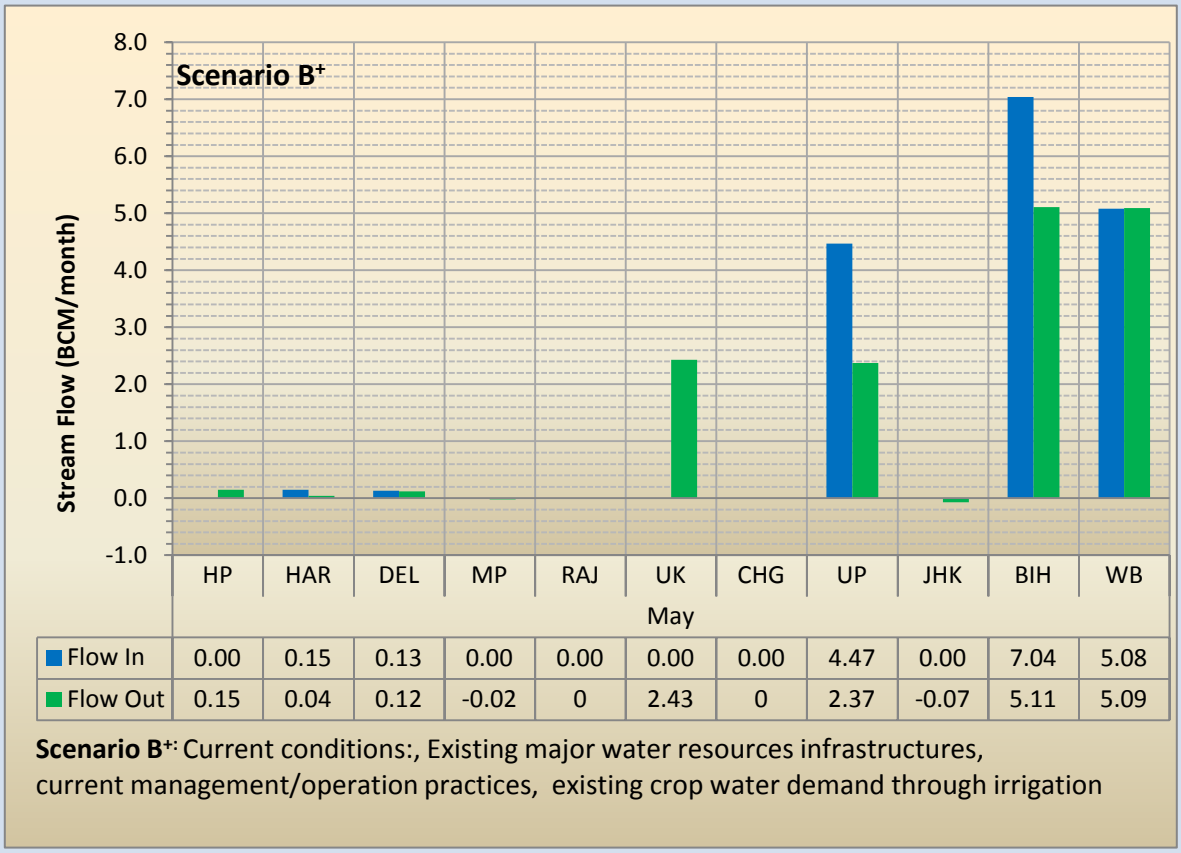
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 11: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.18	0.16	0.00	0.01	0.00	0.00	4.12	0.00	4.52	2.42
Flow Out	0.18	0.03	0.14	-0.02	0	2.35	0.01	2.34	-0.11	2.49	2.2

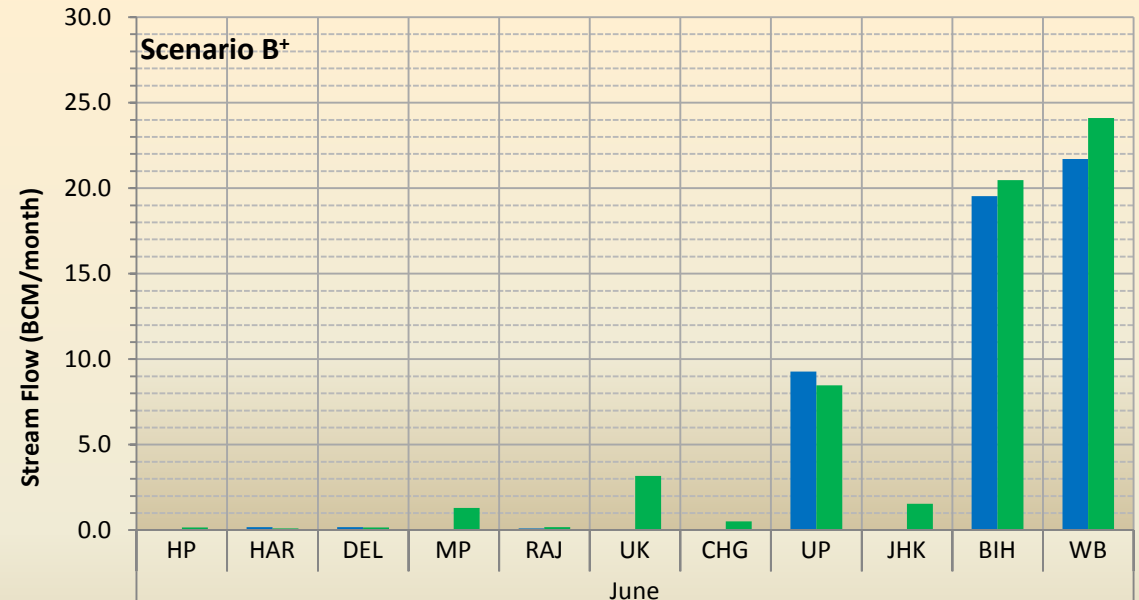
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.15	0.13	0.00	0.00	0.00	0.00	4.47	0.00	7.04	5.08
Flow Out	0.15	0.04	0.12	-0.02	0	2.43	0	2.37	-0.07	5.11	5.09

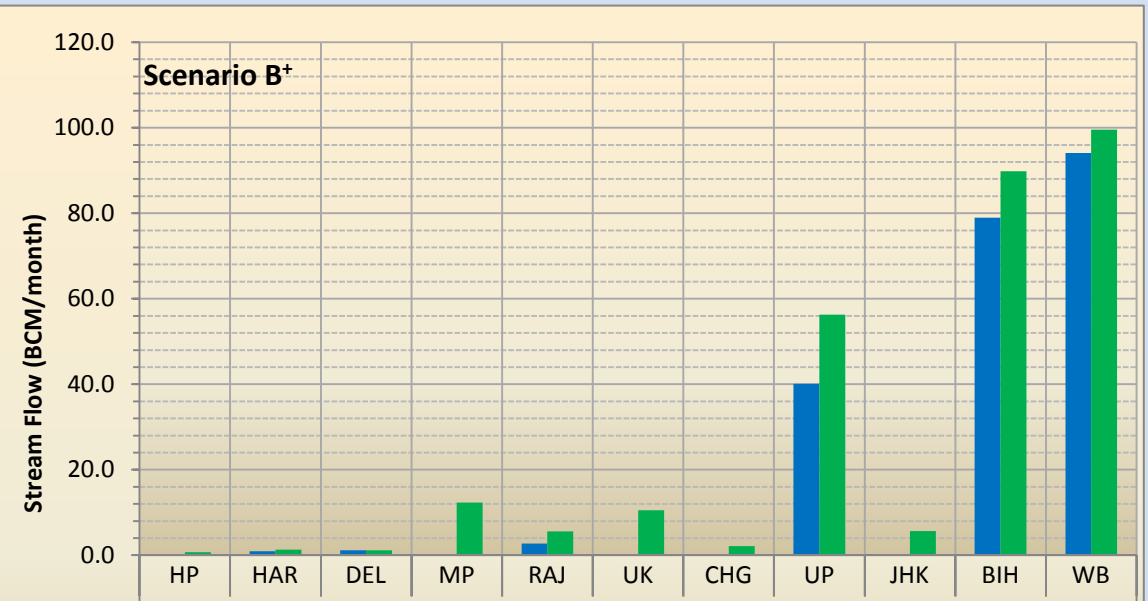
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 11: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.18	0.18	0.00	0.11	0.00	0.00	9.27	0.00	19.53	21.70
Flow Out	0.16	0.1	0.16	1.3	0.18	3.17	0.52	8.48	1.54	20.48	24.11

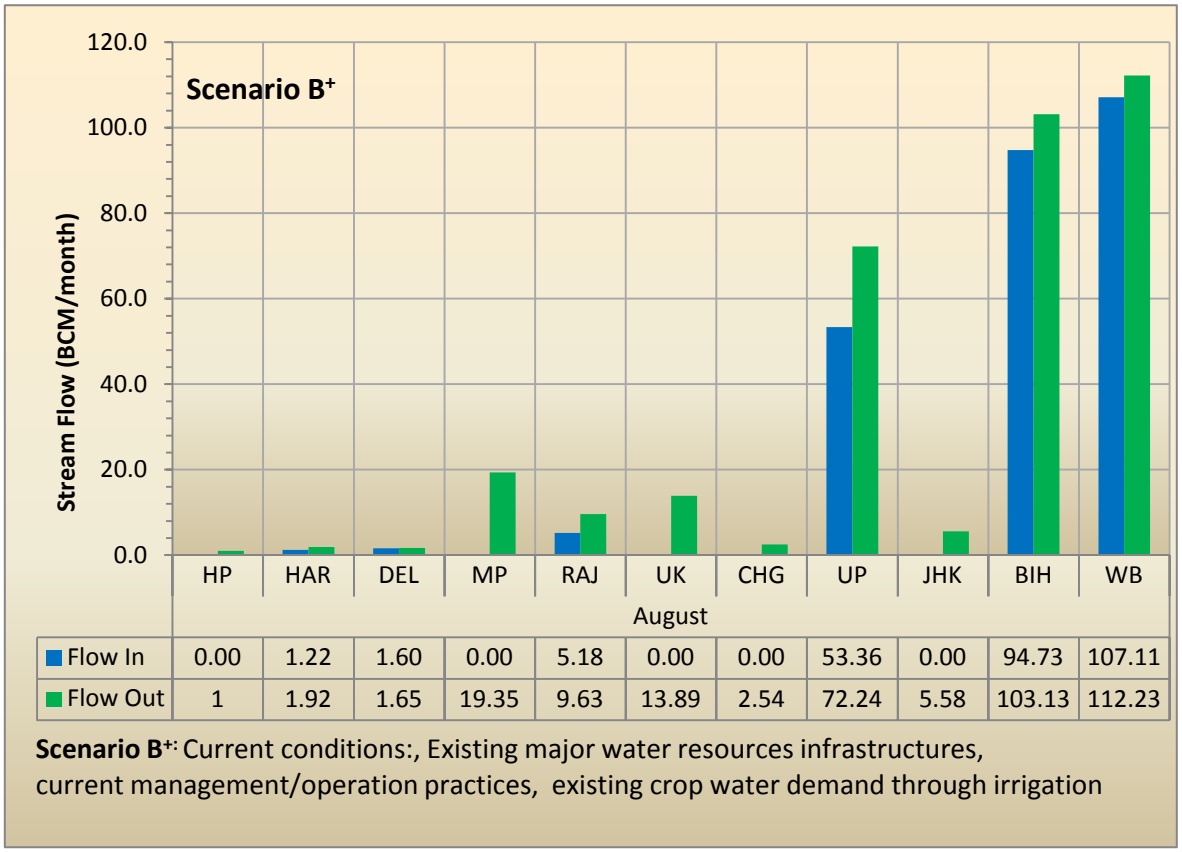
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.90	1.15	0.00	2.71	0.00	0.00	40.09	0.00	79.00	94.07
Flow Out	0.73	1.3	1.18	12.29	5.6	10.49	2.13	56.24	5.67	89.84	99.58

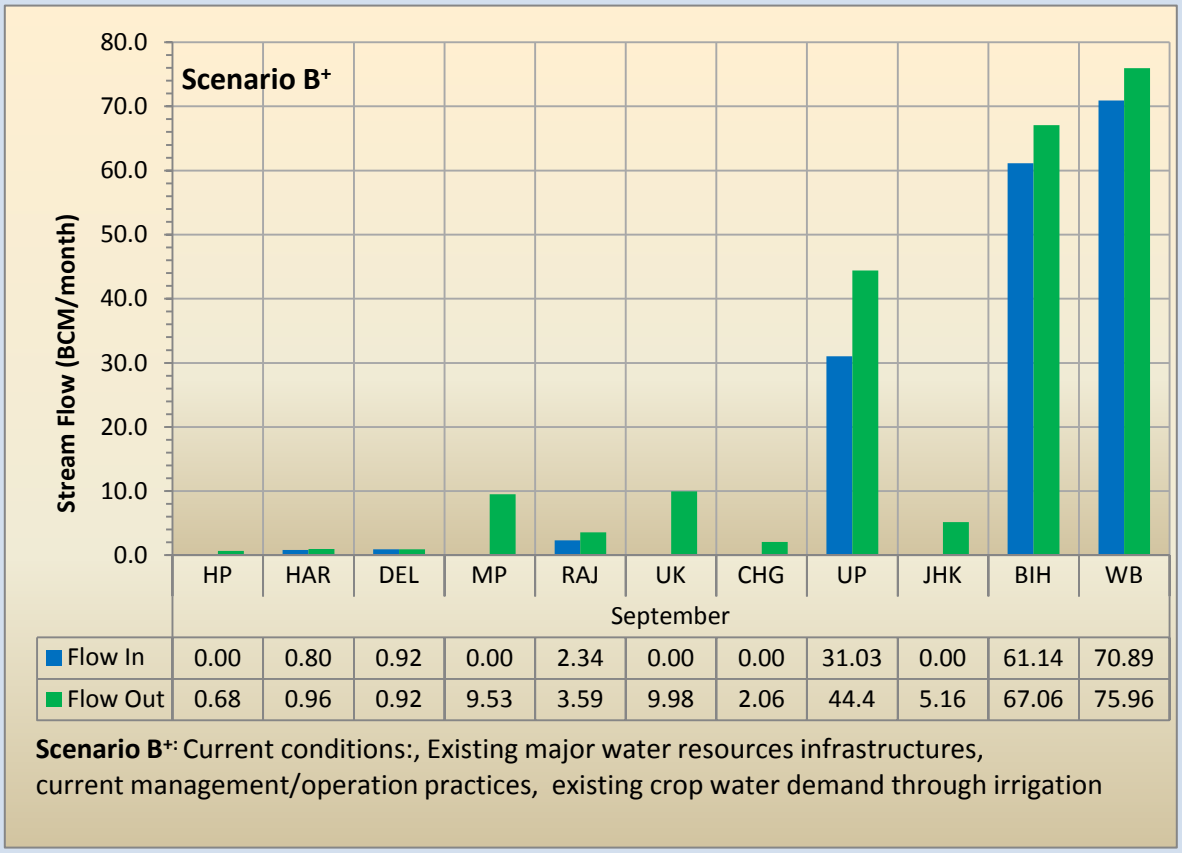
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 11: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	1.22	1.60	0.00	5.18	0.00	0.00	53.36	0.00	94.73	107.11
Flow Out	1	1.92	1.65	19.35	9.63	13.89	2.54	72.24	5.58	103.13	112.23

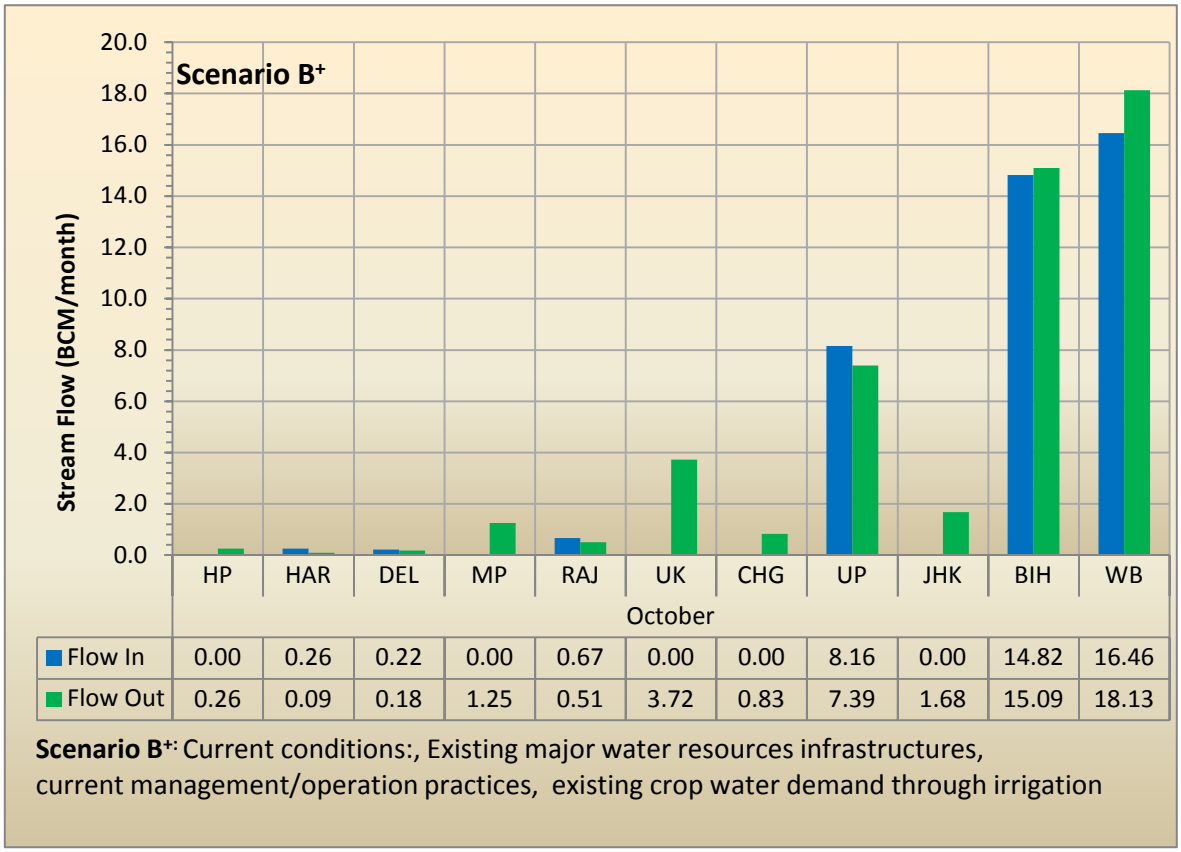
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.80	0.92	0.00	2.34	0.00	0.00	31.03	0.00	61.14	70.89
Flow Out	0.68	0.96	0.92	9.53	3.59	9.98	2.06	44.4	5.16	67.06	75.96

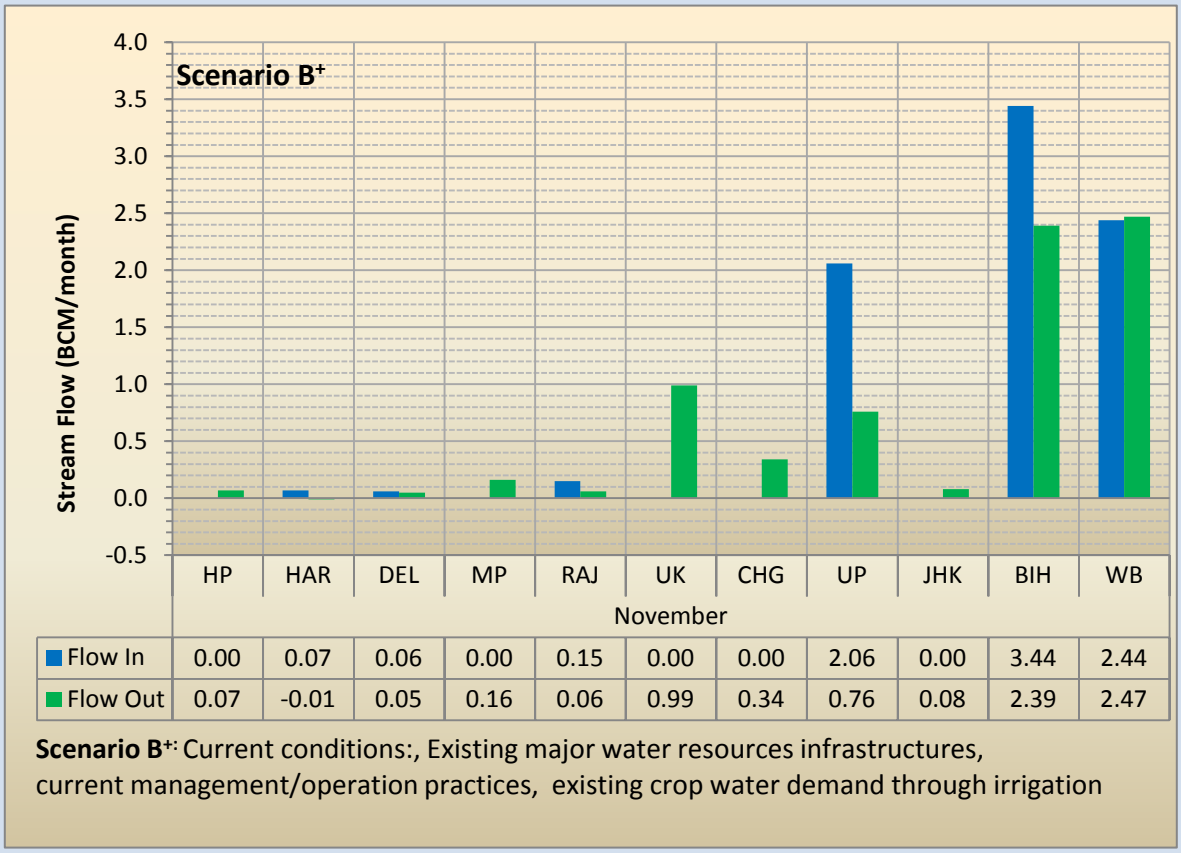
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 11: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.26	0.22	0.00	0.67	0.00	0.00	8.16	0.00	14.82	16.46
Flow Out	0.26	0.09	0.18	1.25	0.51	3.72	0.83	7.39	1.68	15.09	18.13

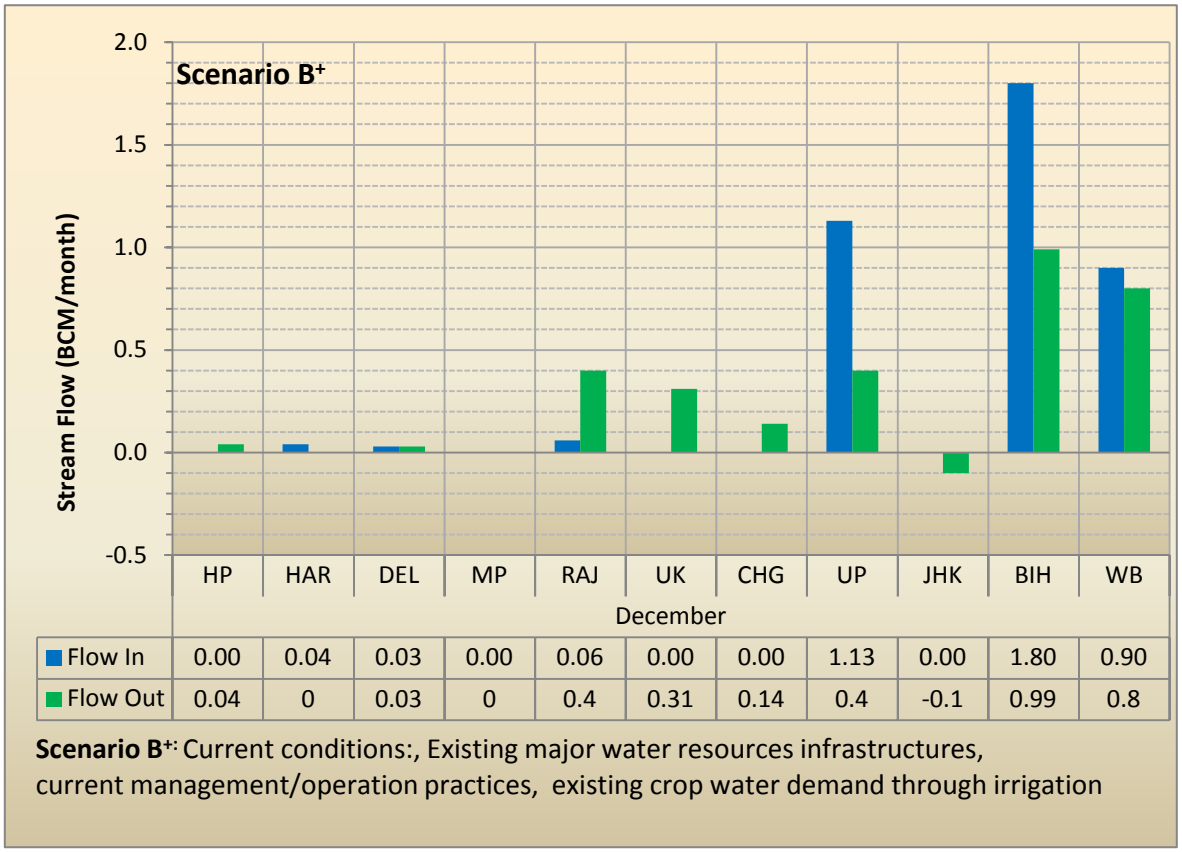
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.07	0.06	0.00	0.15	0.00	0.00	2.06	0.00	3.44	2.44
Flow Out	0.07	-0.01	0.05	0.16	0.06	0.99	0.34	0.76	0.08	2.39	2.47

Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 11: Graph: Average Monthly Stream flow (BCM/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Flow In	0.00	0.04	0.03	0.00	0.06	0.00	0.00	1.13	0.00	1.80	0.90
Flow Out	0.04	0	0.03	0	0.4	0.31	0.14	0.4	-0.1	0.99	0.8

Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Annual Water Balance BCM/year - Scenario A and Scenario B - State (India) Level

Average annual water balance components namely water yield and evapotranspiration in mm/year have been aggregated at state level for Scenario A and Scenario B.

Table 3 shows the average annual water balance components for Scenario A and Scenario B at state level.

Table 3: Catchment Water balance: Long term Average Annual Water Balance components - State (India) Level

Country	Precipitation	Scenario A+			Scenario B++		
		Water Yield	Evapo-transpiration	Change in Storage	Water Yield	Evapo-transpiration	Change in Storage
Long-term Annual Average : Water Balance (mm/year)							
Bihar	1184.5	653.8	535.0	-4.3	451.6	589.9	143.0
Chhattisgarh	1239.8	806.7	415.4	17.7	539.1	430.4	270.3
Haryana	587.5	163.5	405.5	18.5	140.8	438.8	7.9
Himachal Pradesh	1178.0	784.8	404.5	-11.3	788.0	420.7	-30.8
Jharkhand	1256.4	753.9	490.0	12.5	455.5	503.9	297.1
Madhya Pradesh	985.5	555.8	424.3	5.3	332.8	444.7	208.0
NCT of Delhi #	651.6	219.4	445.5	-13.3	172.9	525.3	-46.5
Rajasthan	658.1	274.5	382.0	1.6	139.9	395.1	123.1
Uttar Pradesh	970.1	489.9	484.2	-4.0	369.8	519.3	81.0
Uttarakhand	1347.4	1070.4	384.7	-107.6	1030.0	402.5	-85.1
West Bengal	1413.9	887.0	567.5	-40.6	514.5	593.5	305.8

* India at Farakka
Change in Storage = Change in Snowpack (snowfall-snowmelt) + Change in Shallow ground water storage + Change in Deep ground water storage
+ Scenario A: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting catchment hydrology corresponding to the current landuse.
++ Scenario B: Current conditions: Existing major water resources infrastructures, current management/operation practices, existing crop water demand with irrigation wherever applicable.

Spatial depiction of the average annual water balance components for Scenario A and Scenario B at state level is shown in Figure 12.

Monthly Water Balance mm/month - Scenario A and Scenario B

Average long term monthly water balance components namely water yield and evapotranspiration in mm/month have been aggregated at state level for Scenario A and Scenario B. Appendix XX gives the table of long term monthly water balance components.

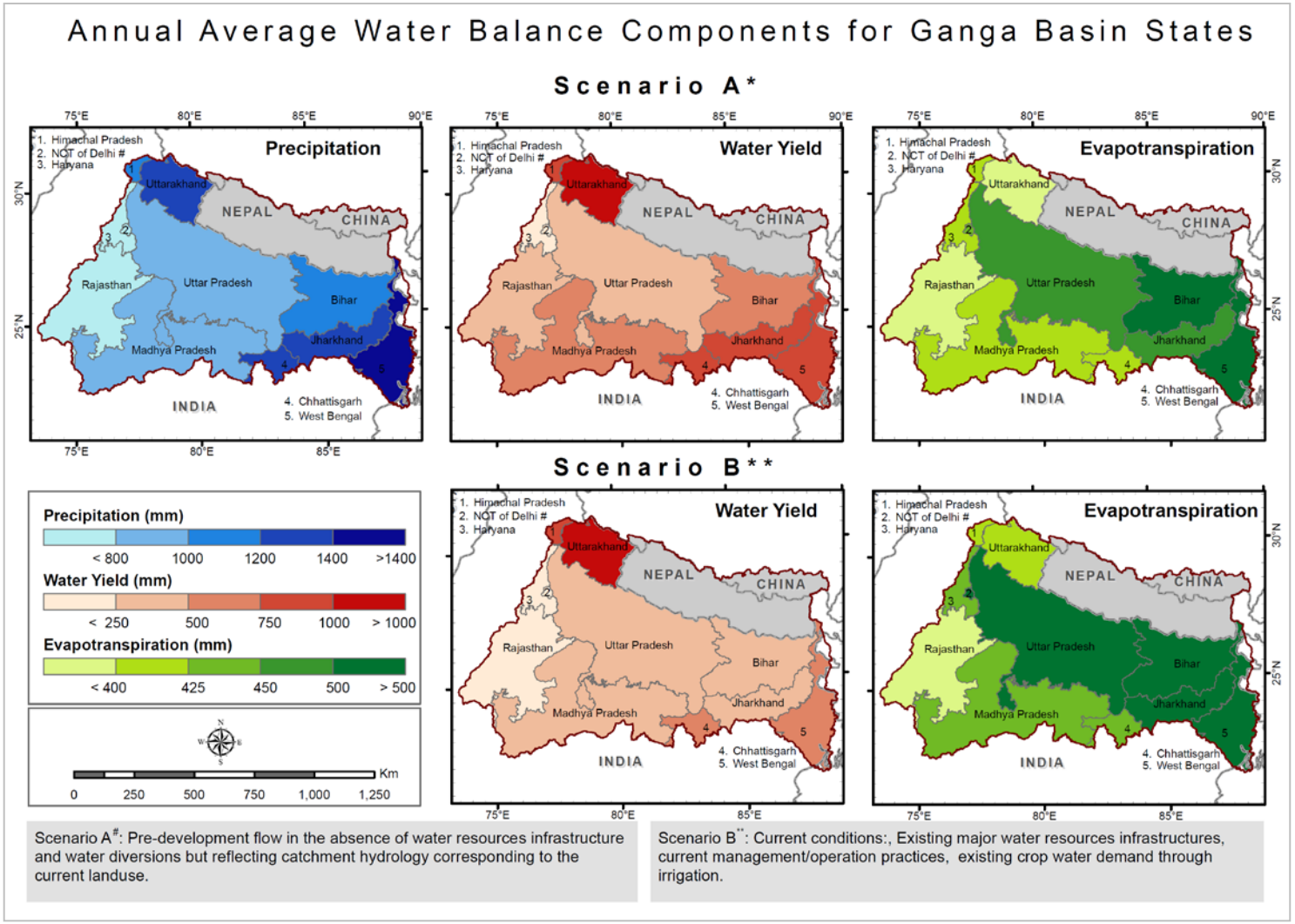


Figure 12: Spatial Depiction: Annual Water Balance Components (BCM/year) - State Level

Sediment Flow at State Level

Average annual sediment flow in million metric tons per year has been aggregated at state level for scenario A and scenario B.

Annual Sediment Flow in MT/year for Scenario A and Scenario B - State level

Table 4 shows the average annual sediment flow for each states of India in the Ganga basin.

Table 4: Stream Flow: Annual Sediment flow (Million metric tons (MT)/year) - State Level

Country	Abbrevi-ation	Scenario A+		Scenario B++	
		Sediment In	Sediment Out	Sediment In	Sediment Out
Average Annual Sediment Flow (MT/year)					
Himachal Pradesh	HP	0.0	11.2	0.0	6.3
Haryana	HAR	15.2	22.0	9.0	11.5
NCT of Delhi	DEL	20.0	20.2	11.0	11.0
Madhya Pradesh	MP	0.0	100.2	0.0	58.1
Rajasthan	RAJ	17.8	58.8	6.9	32.8
Uttarakhand	UK	0.0	139.9	0.0	117.7
Chhattisgarh	CHG	0.0	15.9	0.0	8.1
Uttar Pradesh	UP	428.2	451.8	304.7	171.3
Jharkhand	JHK	0.0	48.6	0.0	21.7
Bihar	BIH	676.8	603.7	638.4	387.1
West Bengal	WB	641.4	639.6	403.7	373.9

* India at Farakka

+ Scenario A: Pre-development flow in the absence of water resources infrastructure and water diversionsbut reflecting catchment hydrology corresponding to the current landuse
++ Scenario B: Current conditions: Existing major water resources infrastructures, current management/operation practices, existing crop water demand with irrigation wherever applicable.

Figure 13 and Figure 14 show the graphical representation of the values of sediment flow at state level for Scenario A and Scenario B respectively.

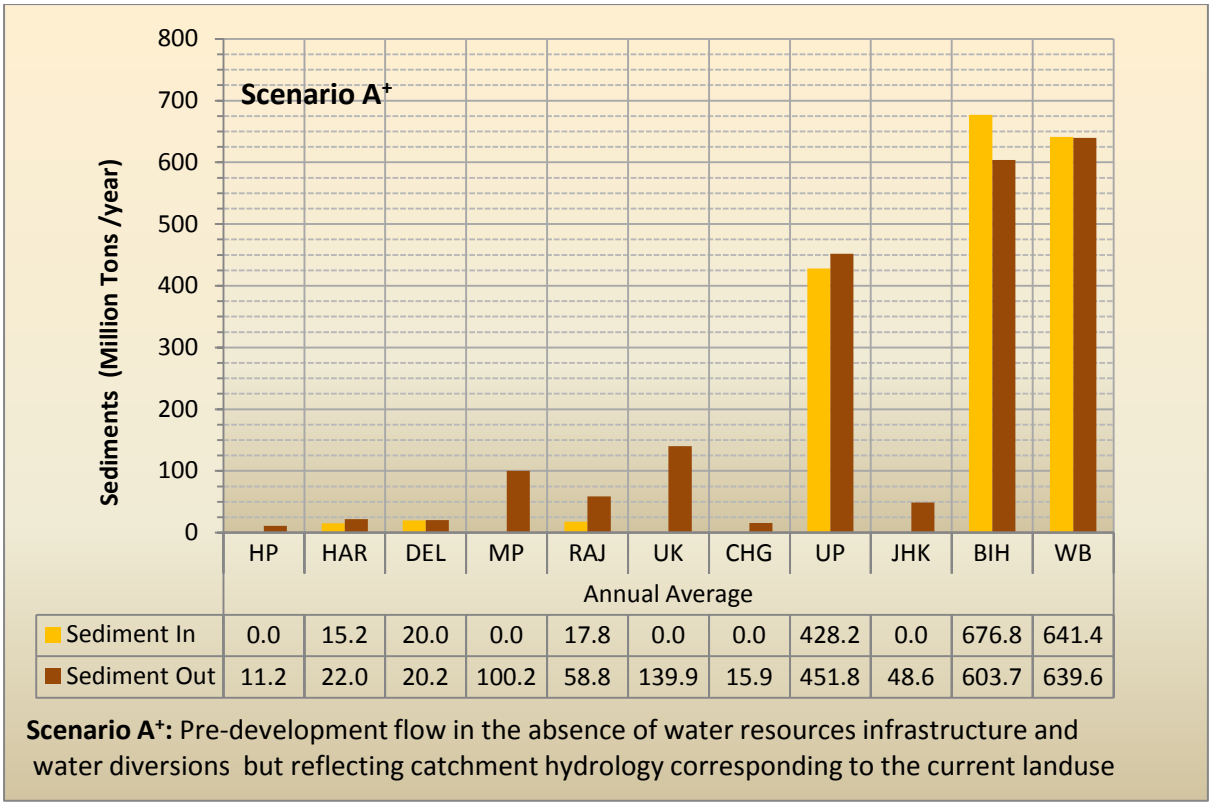


Figure 13: Graph : Annual Sediment flow (MT/year) - State Level - Scenario A

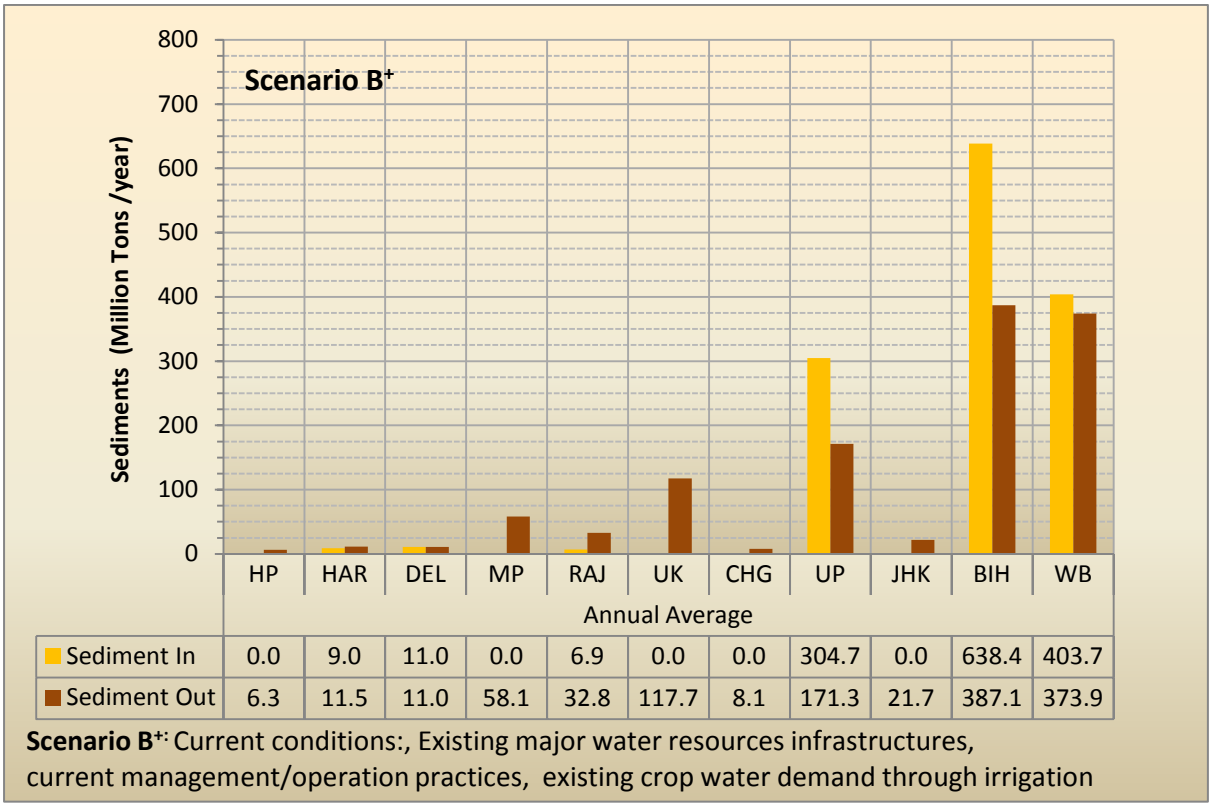


Figure 14: Graph : Annual Sediment flow (MT/year) - State Level - Scenario B

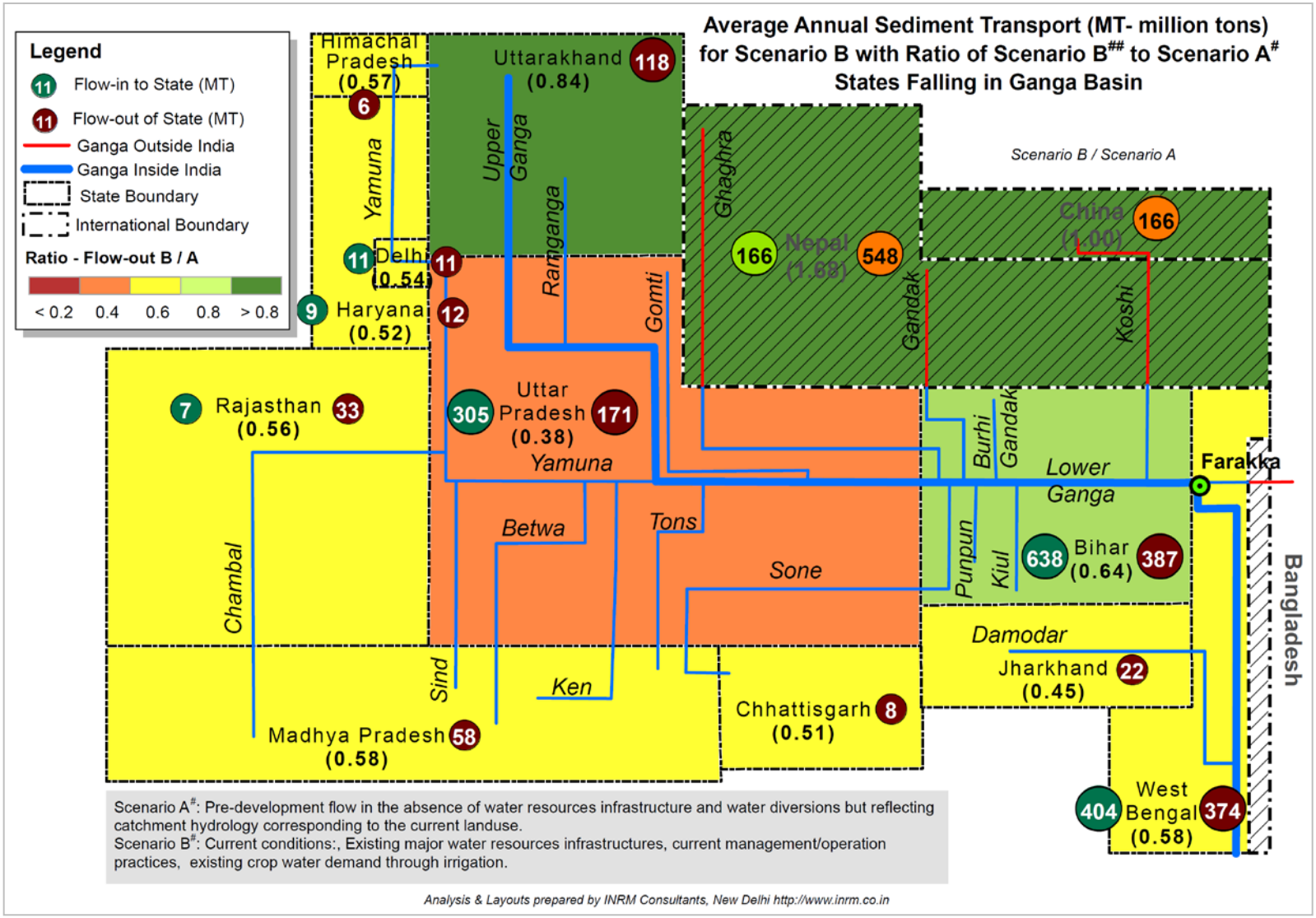


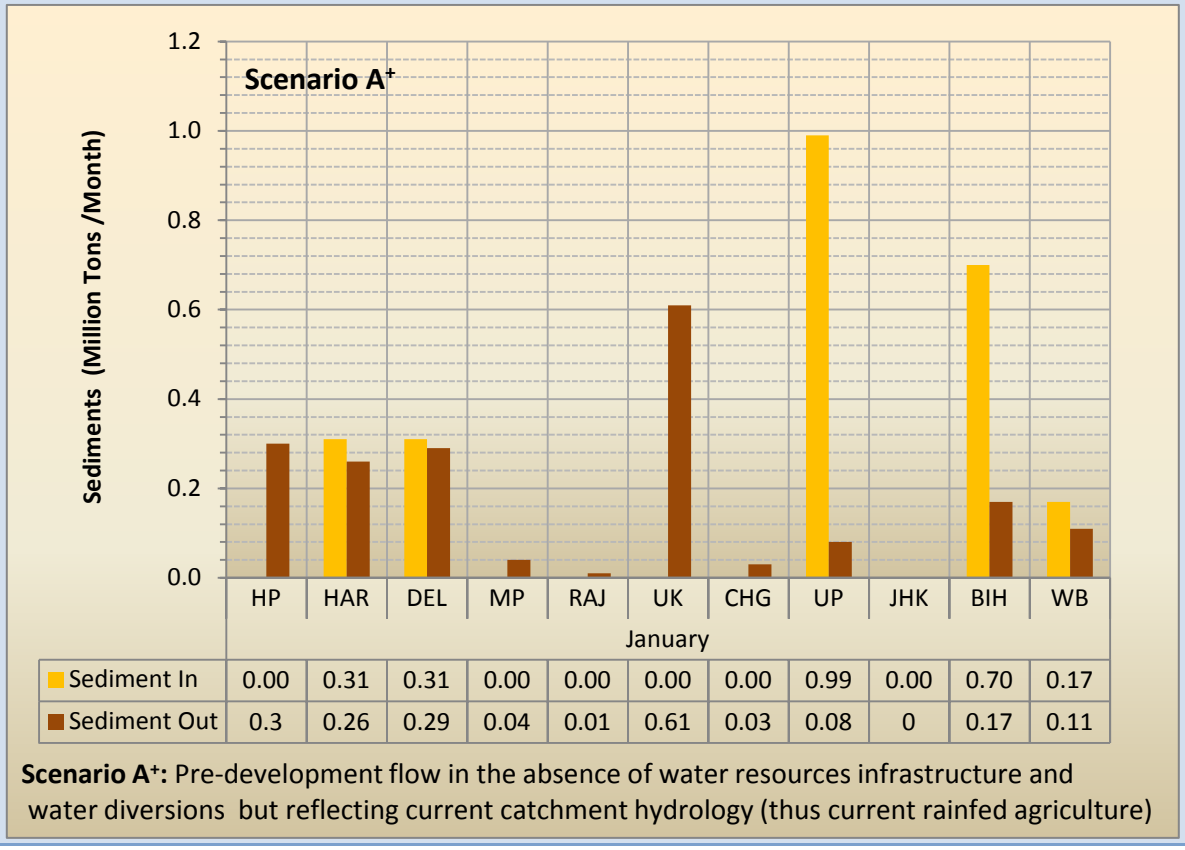
Figure 15: Spatial Depiction: Annual Sediment Flow (MT/year) - State Level

Monthly Sediment Flow in MT/month - Scenario A - State level

Average monthly sediment flow has been aggregated at state level for scenario A for long term average year.

Figure 16 shows graphical representation of the long term average monthly values of stream flow at state level for Scenario A.

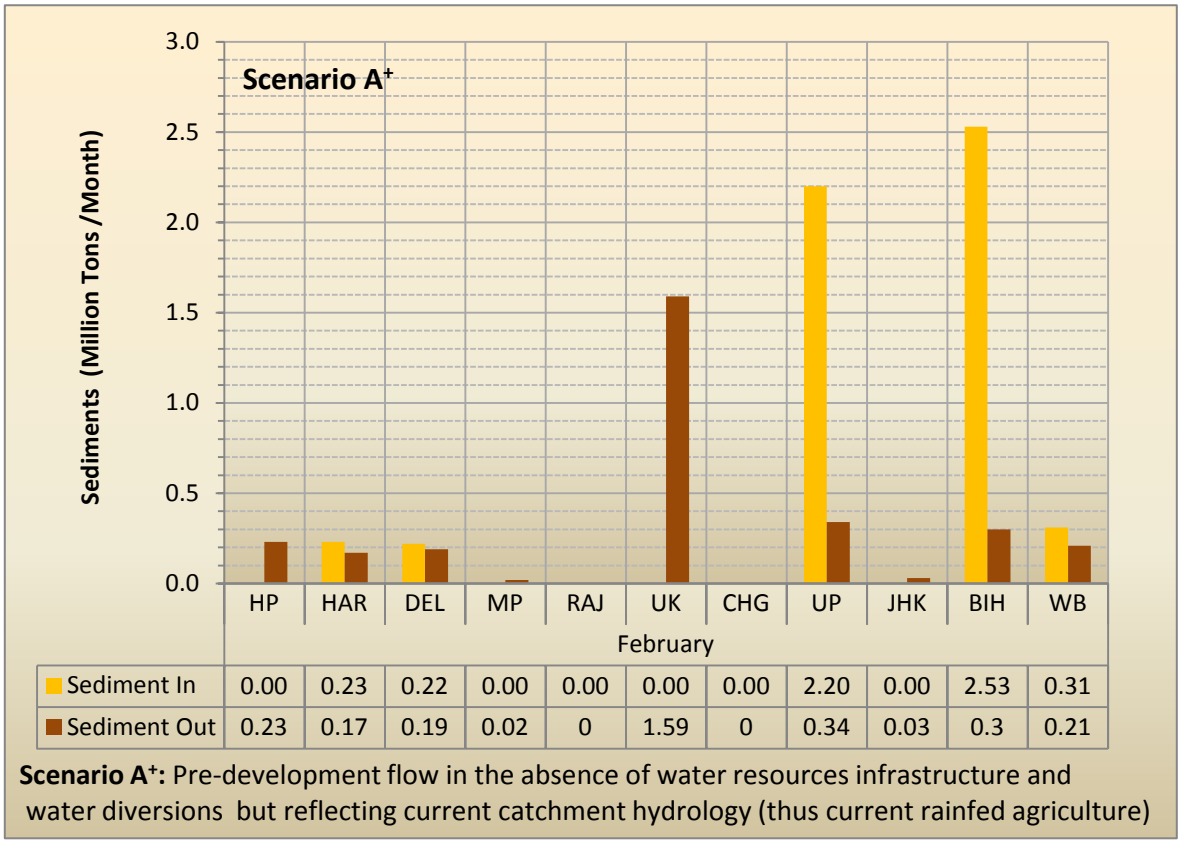
Figure 16: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.31	0.31	0.00	0.00	0.00	0.00	0.99	0.00	0.70	0.17
Sediment Out	0.3	0.26	0.29	0.04	0.01	0.61	0.03	0.08	0	0.17	0.11

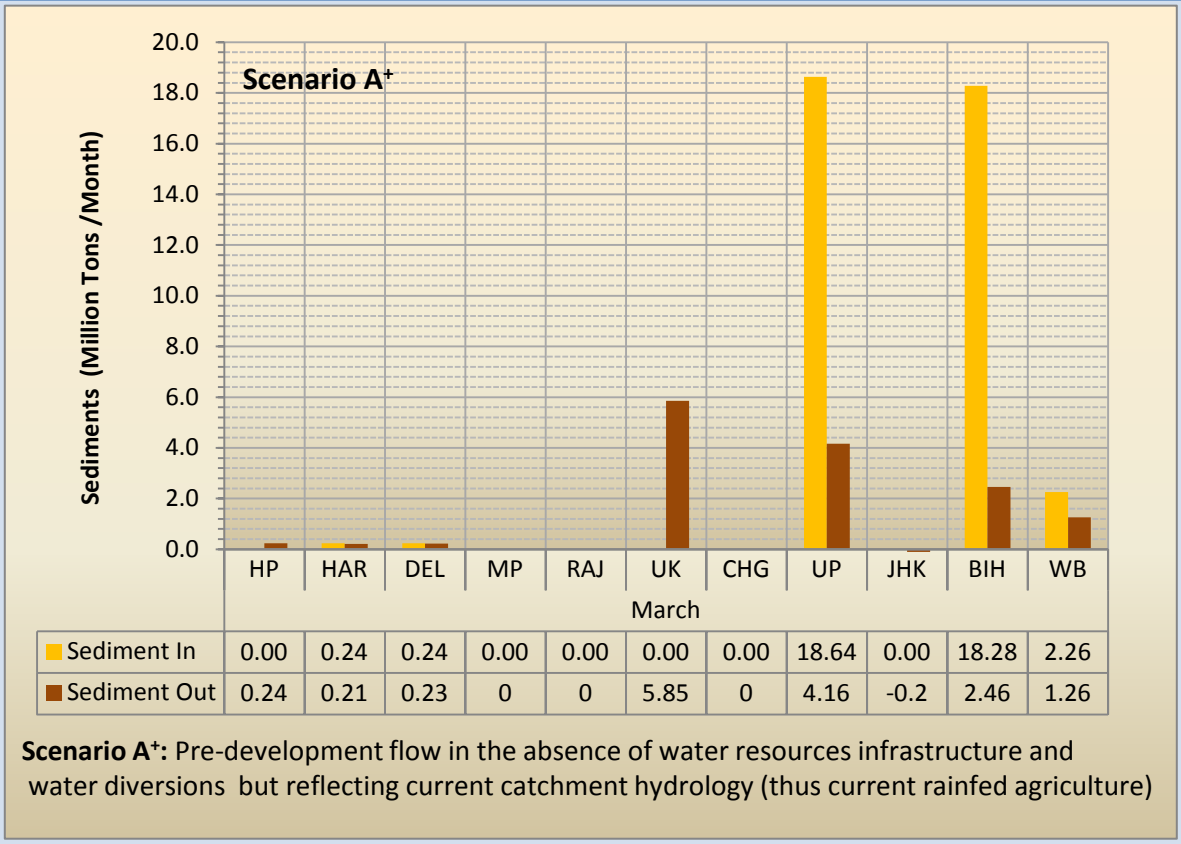
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 16: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.23	0.22	0.00	0.00	0.00	0.00	2.20	0.00	2.53	0.31
Sediment Out	0.23	0.17	0.19	0.02	0	1.59	0	0.34	0.03	0.3	0.21

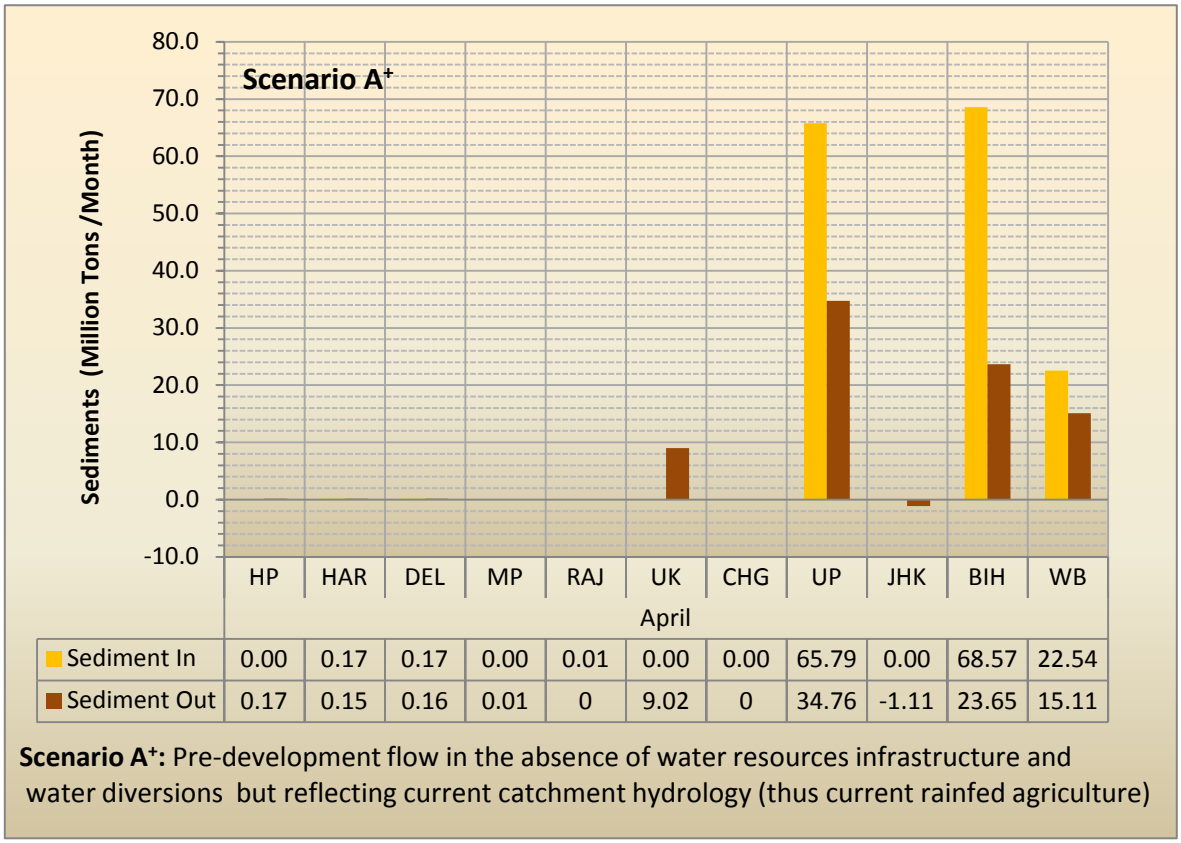
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.24	0.24	0.00	0.00	0.00	0.00	18.64	0.00	18.28	2.26
Sediment Out	0.24	0.21	0.23	0	0	5.85	0	4.16	-0.2	2.46	1.26

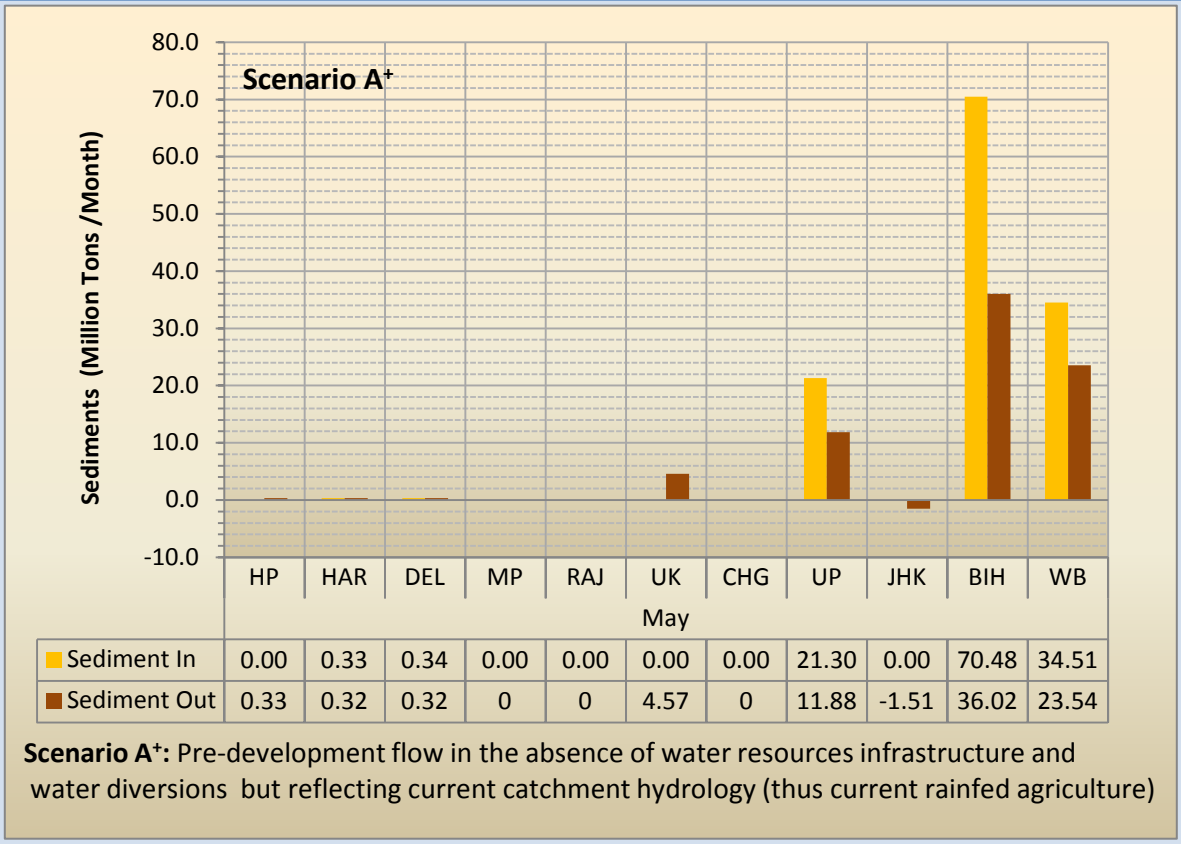
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 16: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.17	0.17	0.00	0.01	0.00	0.00	65.79	0.00	68.57	22.54
Sediment Out	0.17	0.15	0.16	0.01	0	9.02	0	34.76	-1.11	23.65	15.11

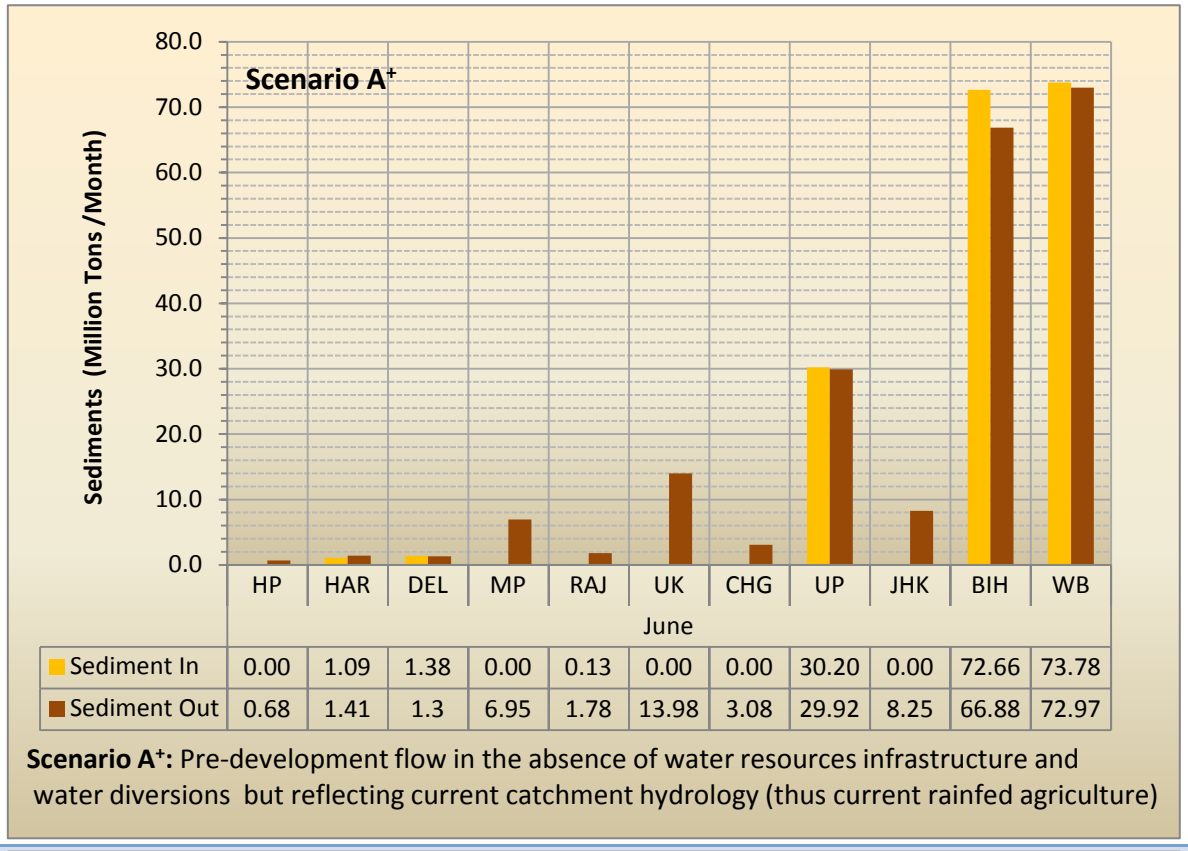
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.33	0.34	0.00	0.00	0.00	0.00	21.30	0.00	70.48	34.51
Sediment Out	0.33	0.32	0.32	0	0	4.57	0	11.88	-1.51	36.02	23.54

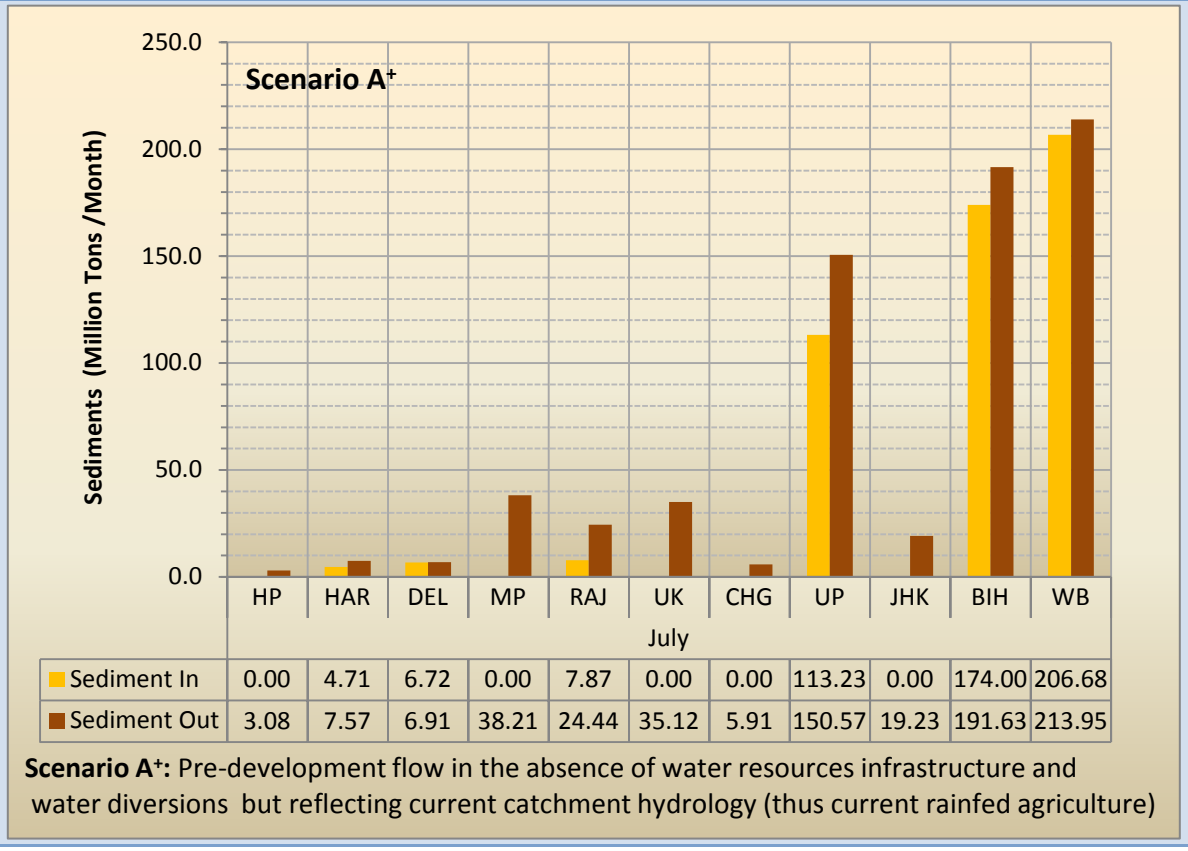
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 16: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	1.09	1.38	0.00	0.13	0.00	0.00	30.20	0.00	72.66	73.78
Sediment Out	0.68	1.41	1.3	6.95	1.78	13.98	3.08	29.92	8.25	66.88	72.97

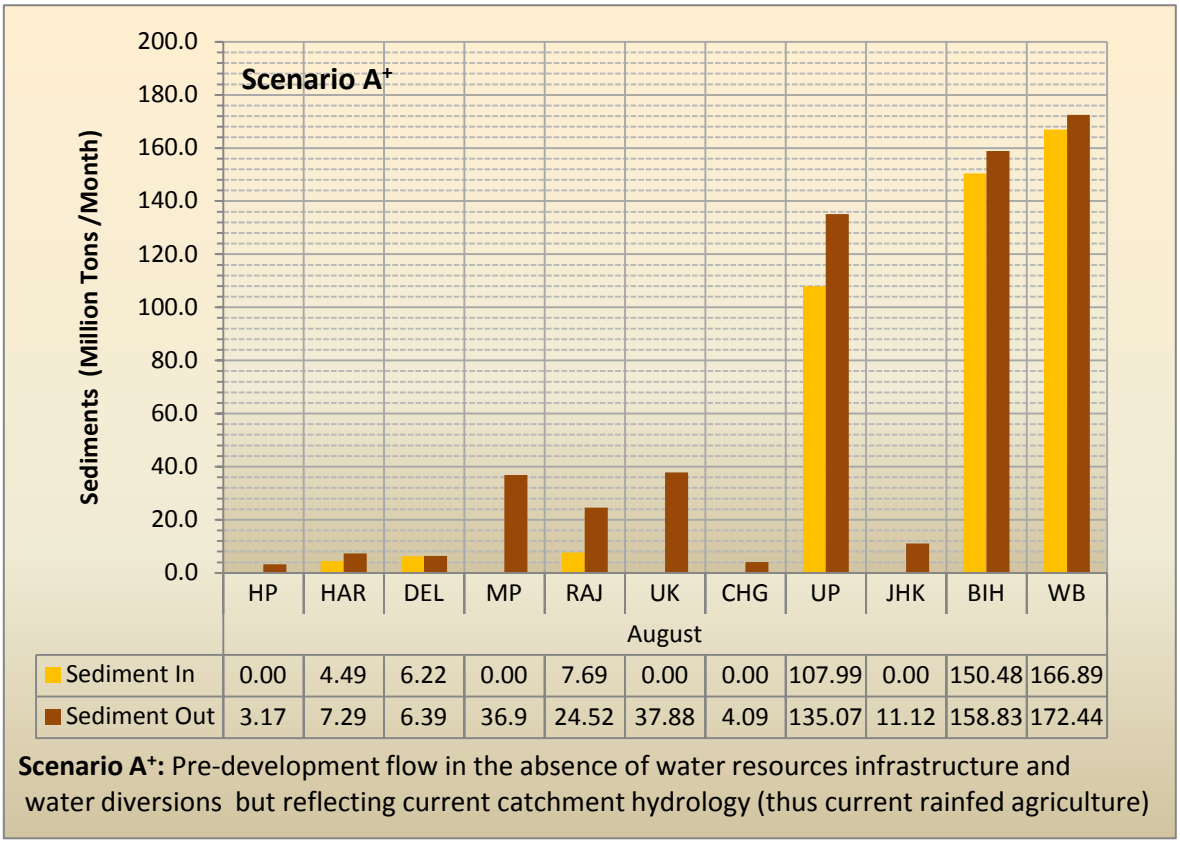
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	4.71	6.72	0.00	7.87	0.00	0.00	113.23	0.00	174.00	206.68
Sediment Out	3.08	7.57	6.91	38.21	24.44	35.12	5.91	150.57	19.23	191.63	213.95

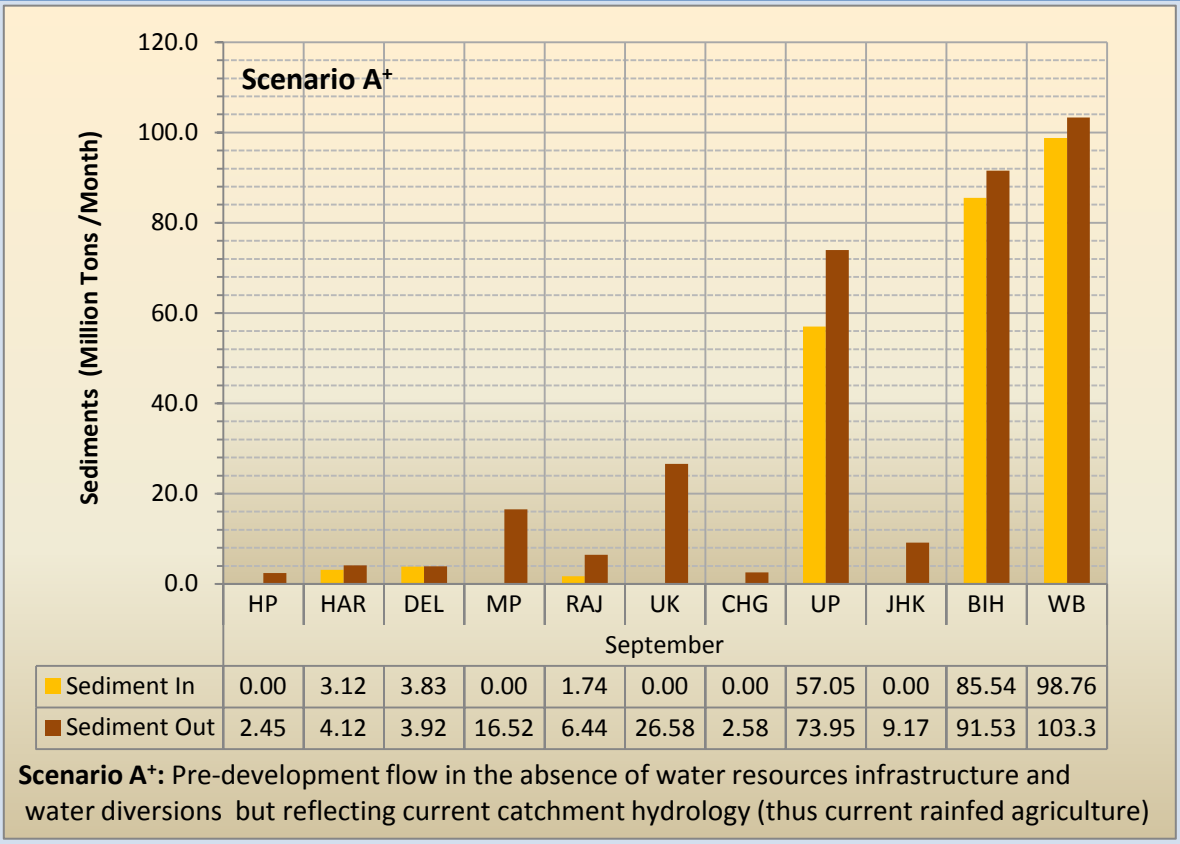
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 16: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	4.49	6.22	0.00	7.69	0.00	0.00	107.99	0.00	150.48	166.89
Sediment Out	3.17	7.29	6.39	36.9	24.52	37.88	4.09	135.07	11.12	158.83	172.44

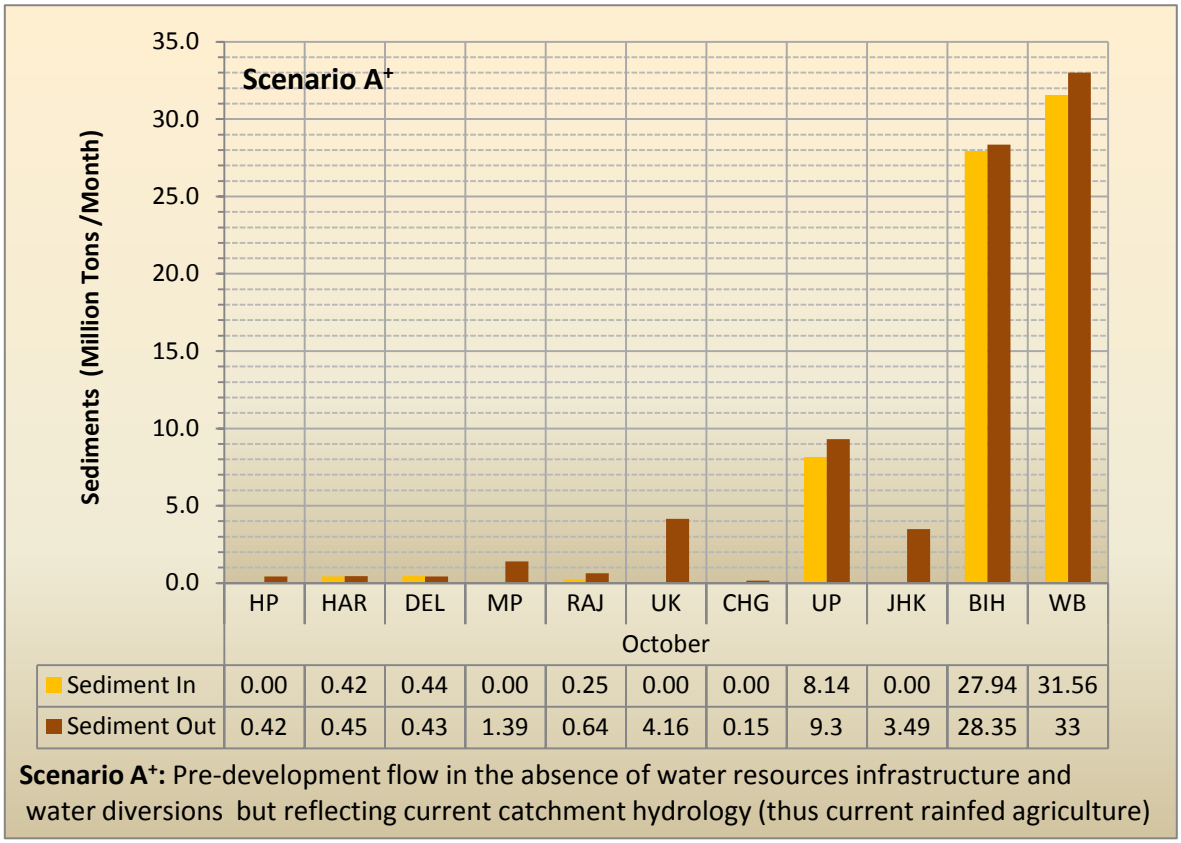
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	3.12	3.83	0.00	1.74	0.00	0.00	57.05	0.00	85.54	98.76
Sediment Out	2.45	4.12	3.92	16.52	6.44	26.58	2.58	73.95	9.17	91.53	103.3

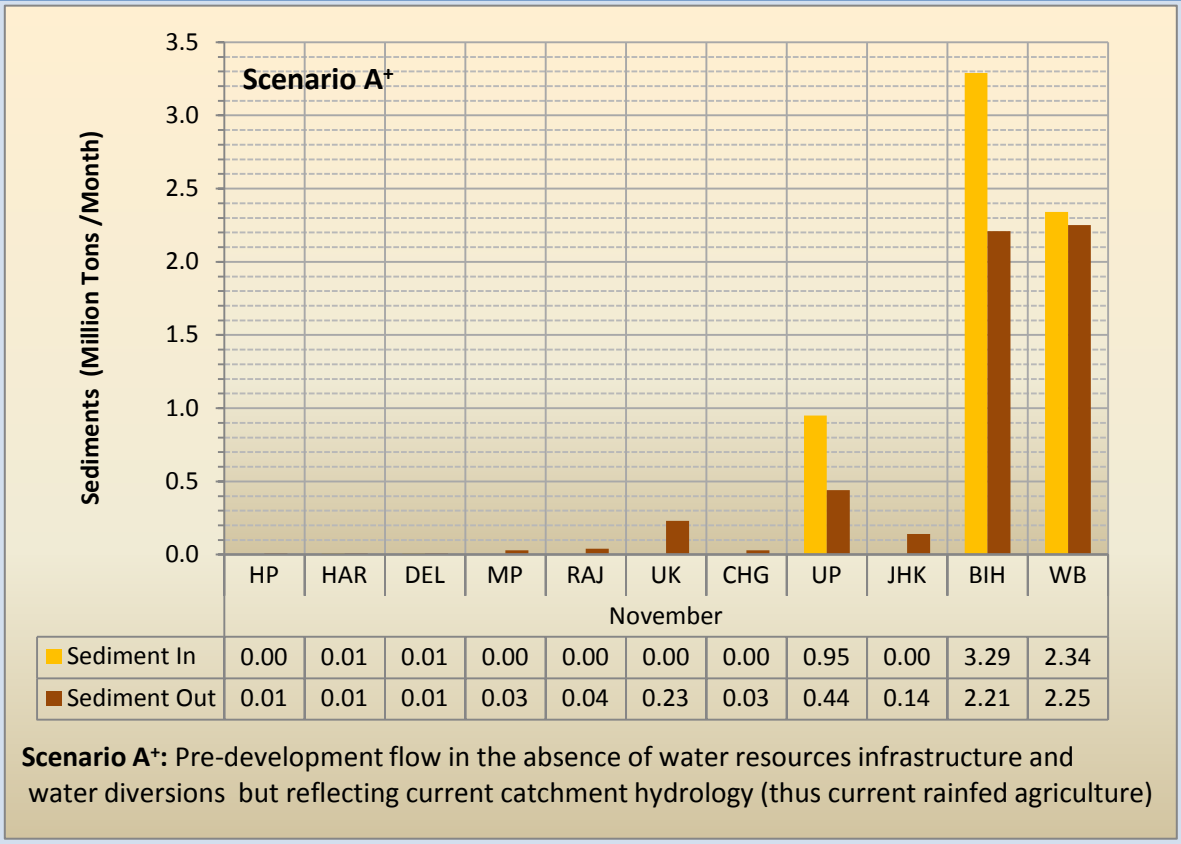
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 16: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.42	0.44	0.00	0.25	0.00	0.00	8.14	0.00	27.94	31.56
Sediment Out	0.42	0.45	0.43	1.39	0.64	4.16	0.15	9.3	3.49	28.35	33

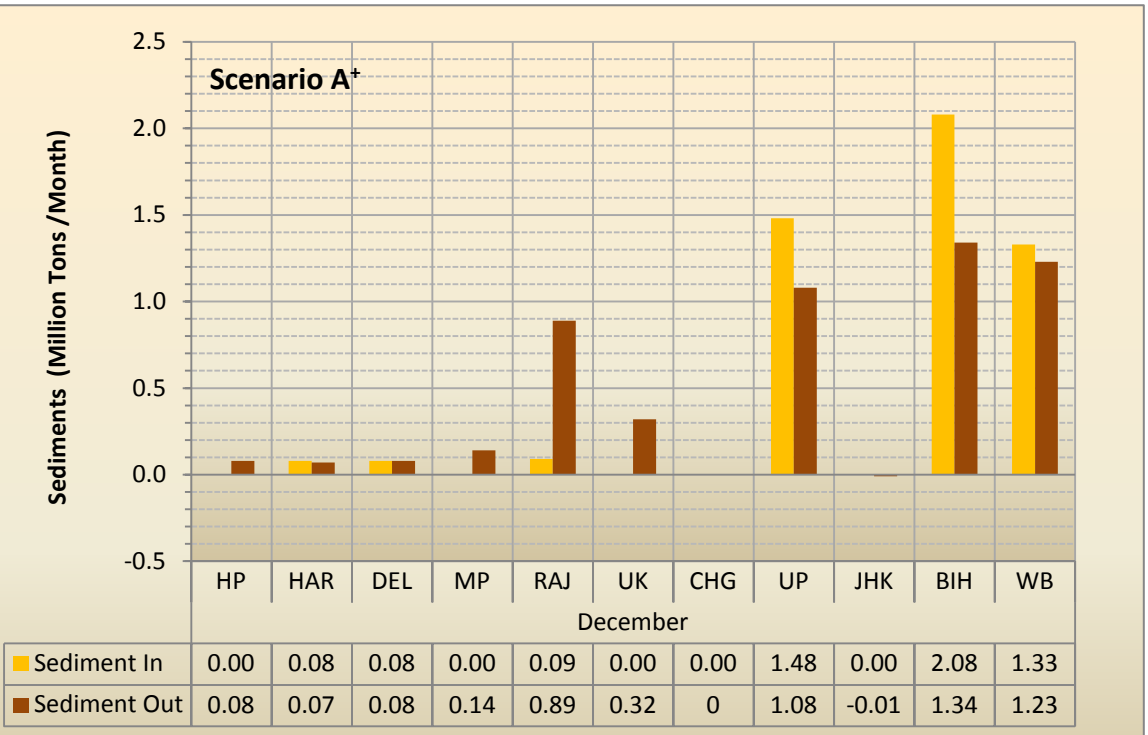
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.95	0.00	3.29	2.34
Sediment Out	0.01	0.01	0.01	0.03	0.04	0.23	0.03	0.44	0.14	2.21	2.25

Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Figure 16: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario A



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.08	0.08	0.00	0.09	0.00	0.00	1.48	0.00	2.08	1.33
Sediment Out	0.08	0.07	0.08	0.14	0.89	0.32	0	1.08	-0.01	1.34	1.23

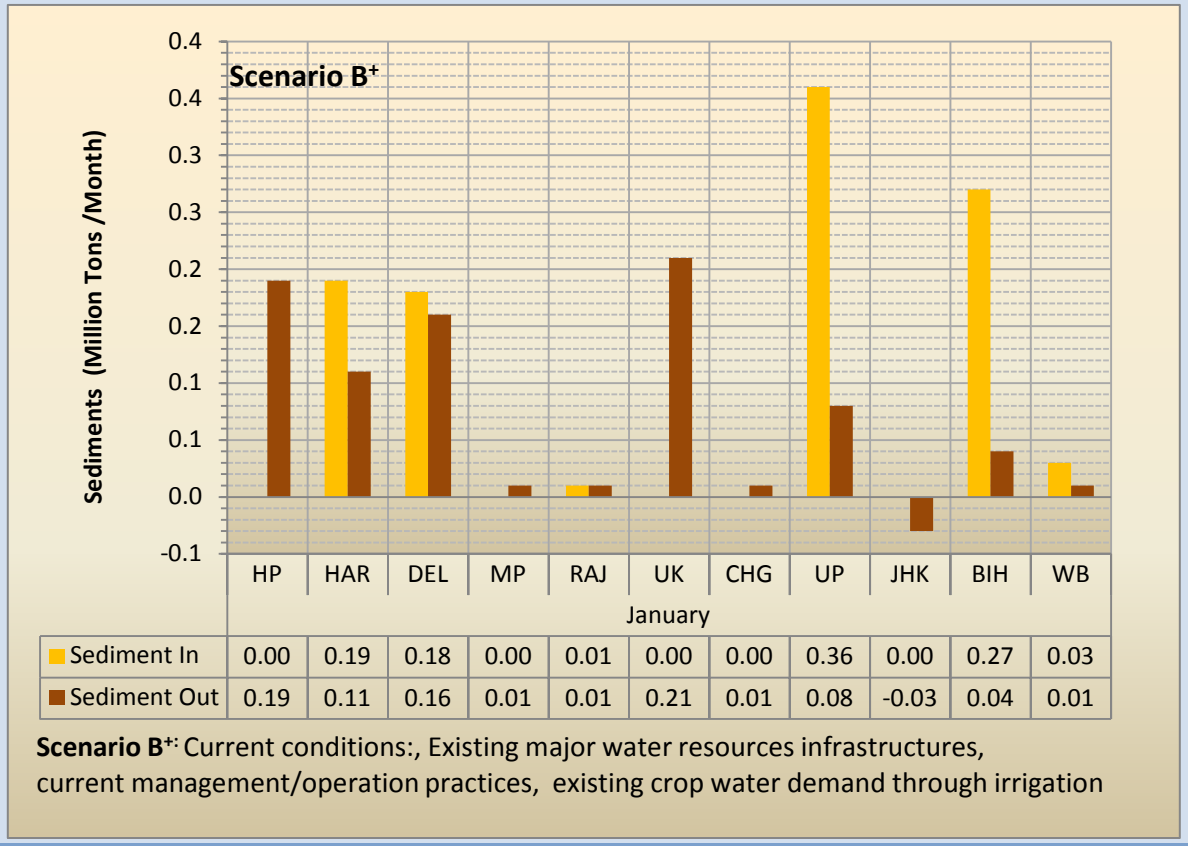
Scenario A+: Pre-development flow in the absence of water resources infrastructure and water diversions but reflecting current catchment hydrology (thus current rainfed agriculture)

Monthly Sediment Flow in MT/month- Scenario B - State level

Average monthly sediment flow has been aggregated at state level for scenario B for long term average year.

Figure 17 shows graphical representation of the long term average monthly values of stream flow at state level for Scenario B.

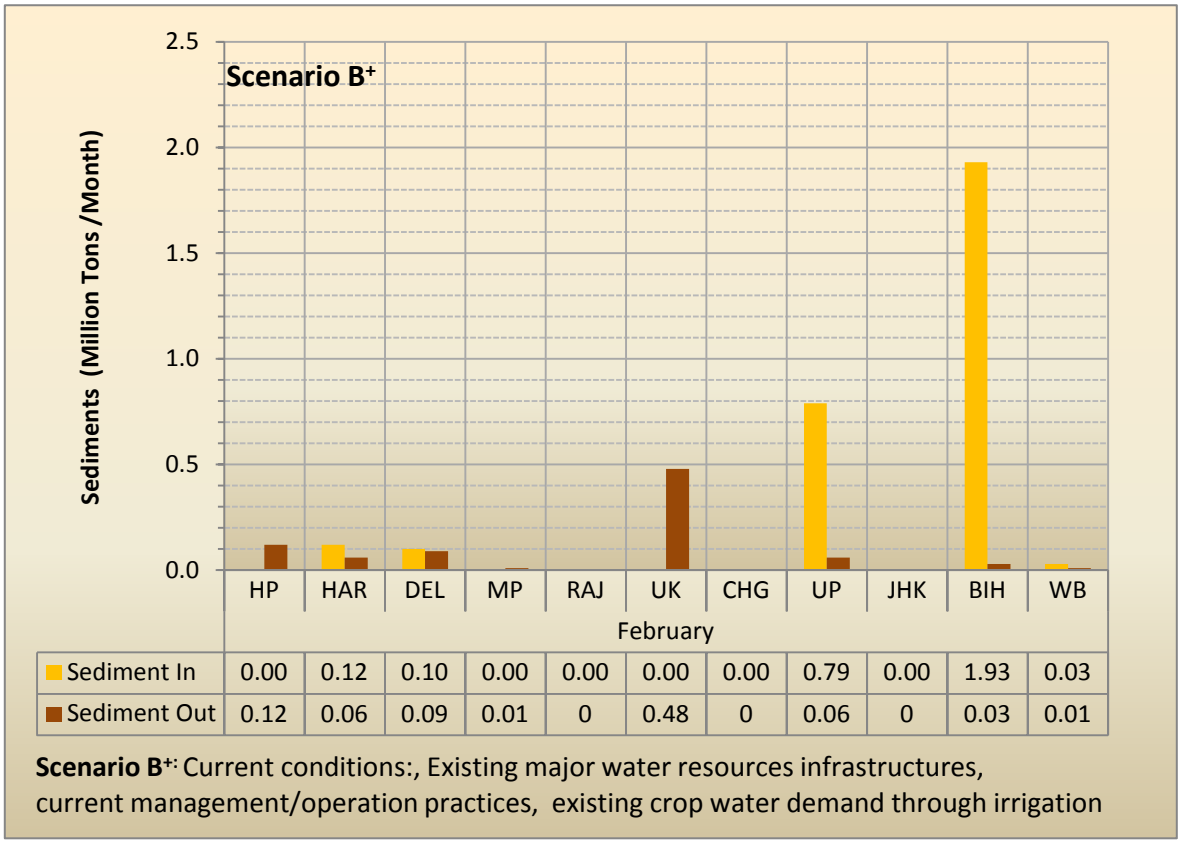
Figure 17: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.19	0.18	0.00	0.01	0.00	0.00	0.36	0.00	0.27	0.03
Sediment Out	0.19	0.11	0.16	0.01	0.01	0.21	0.01	0.08	-0.03	0.04	0.01

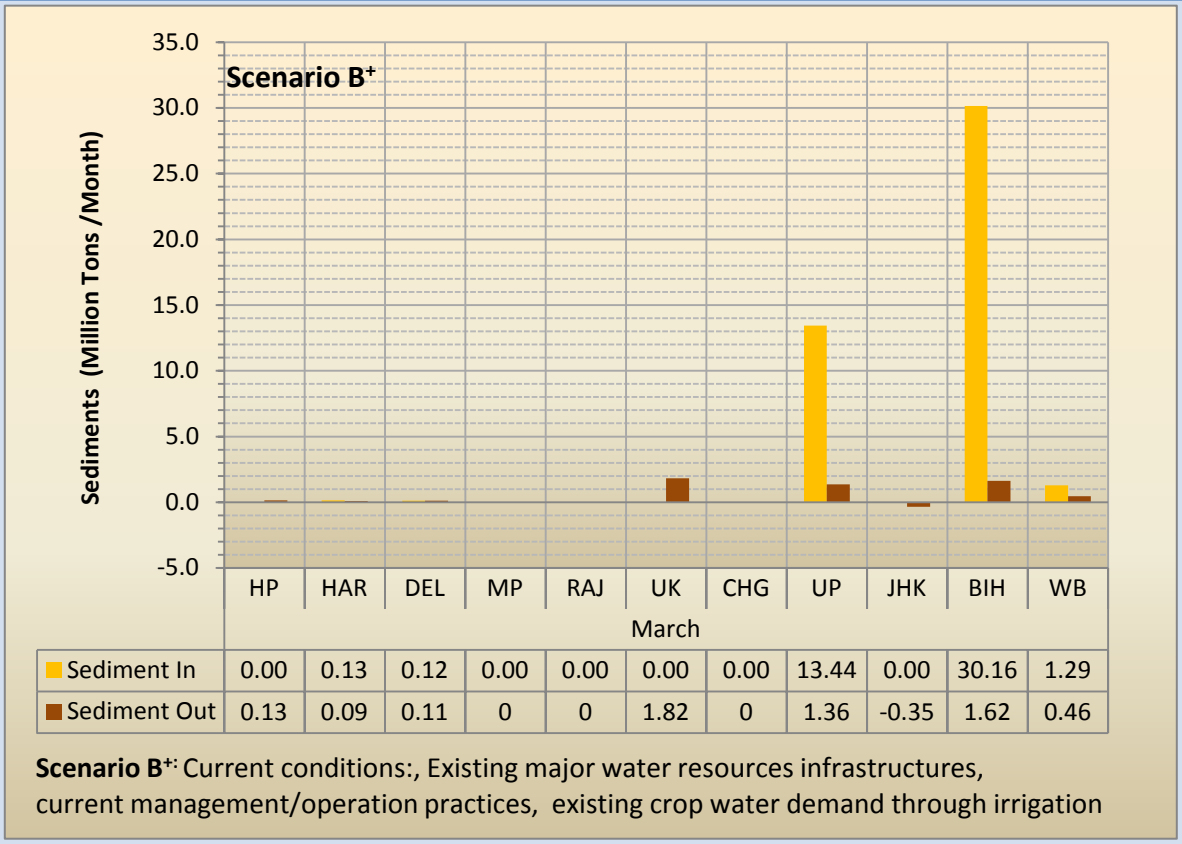
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 17: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.12	0.10	0.00	0.00	0.00	0.00	0.79	0.00	1.93	0.03
Sediment Out	0.12	0.06	0.09	0.01	0	0.48	0	0.06	0	0.03	0.01

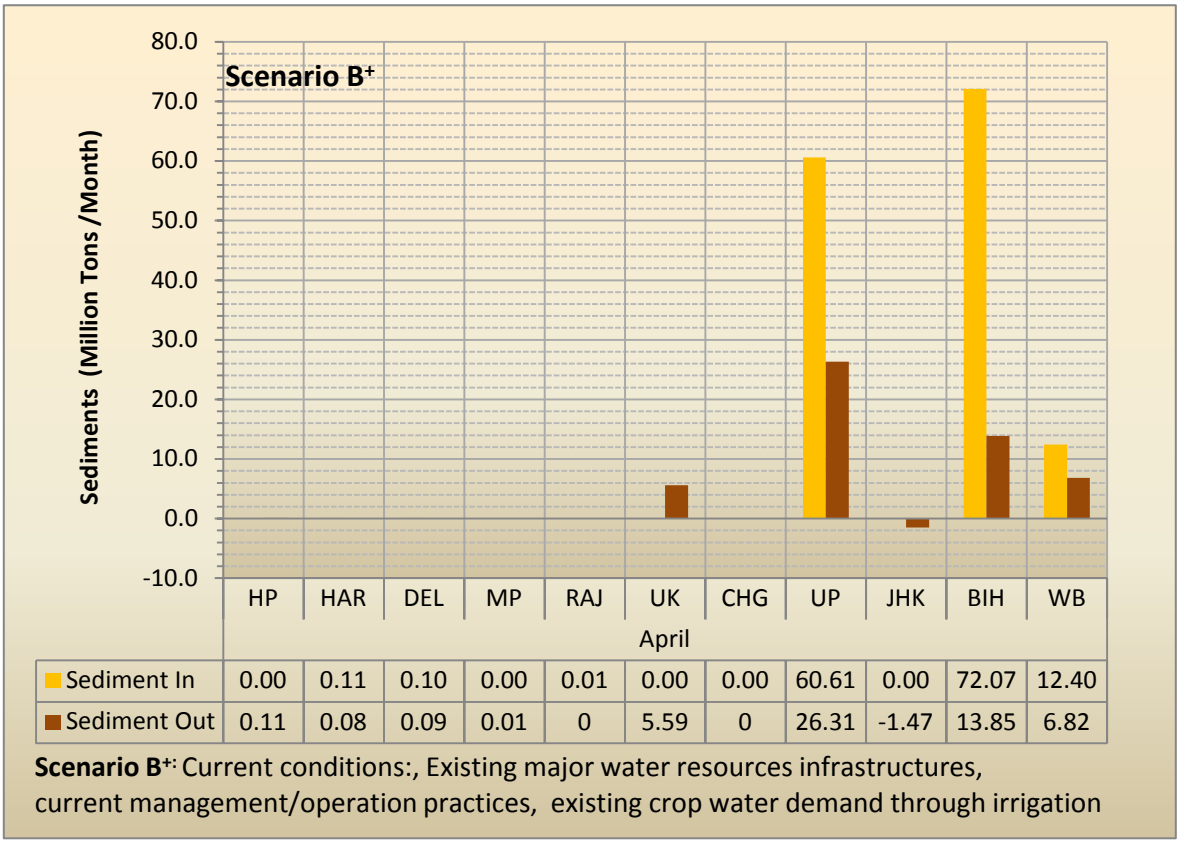
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.13	0.12	0.00	0.00	0.00	0.00	13.44	0.00	30.16	1.29
Sediment Out	0.13	0.09	0.11	0	0	1.82	0	1.36	-0.35	1.62	0.46

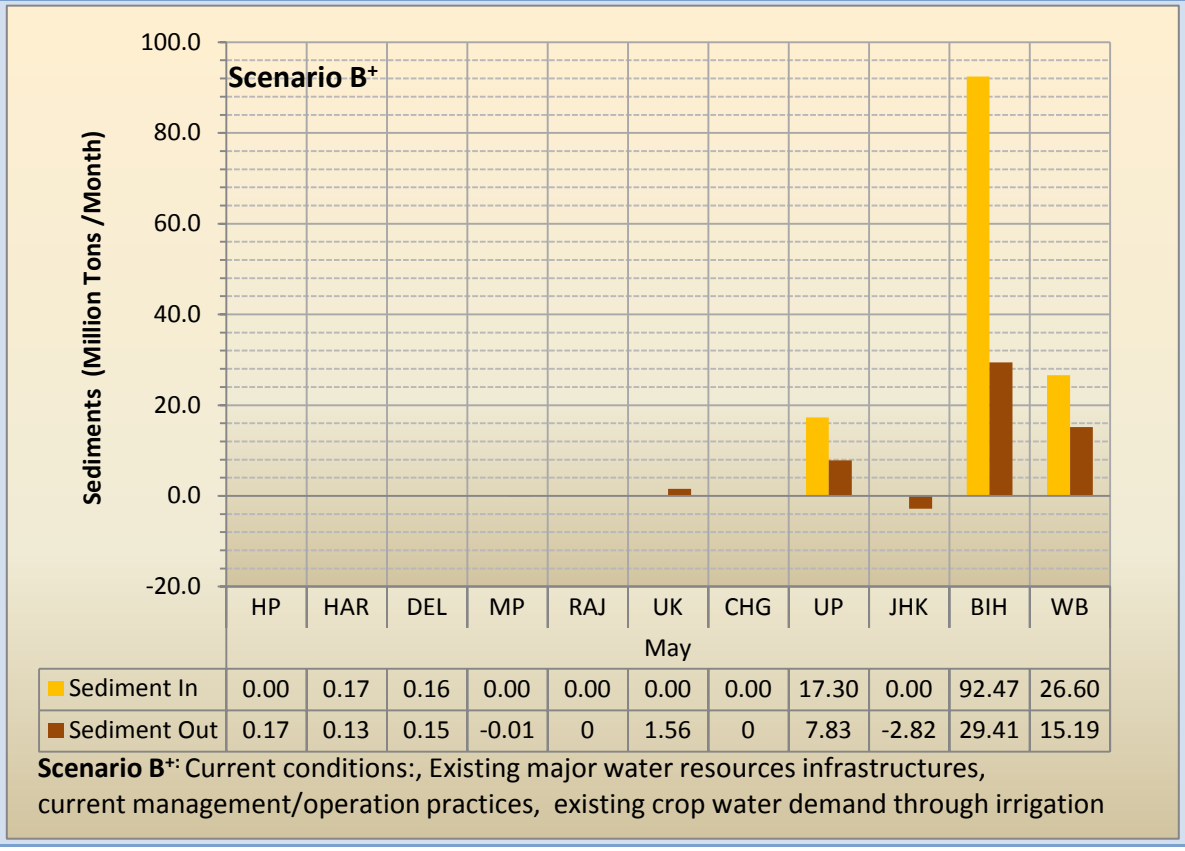
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 17: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.11	0.10	0.00	0.01	0.00	0.00	60.61	0.00	72.07	12.40
Sediment Out	0.11	0.08	0.09	0.01	0	5.59	0	26.31	-1.47	13.85	6.82

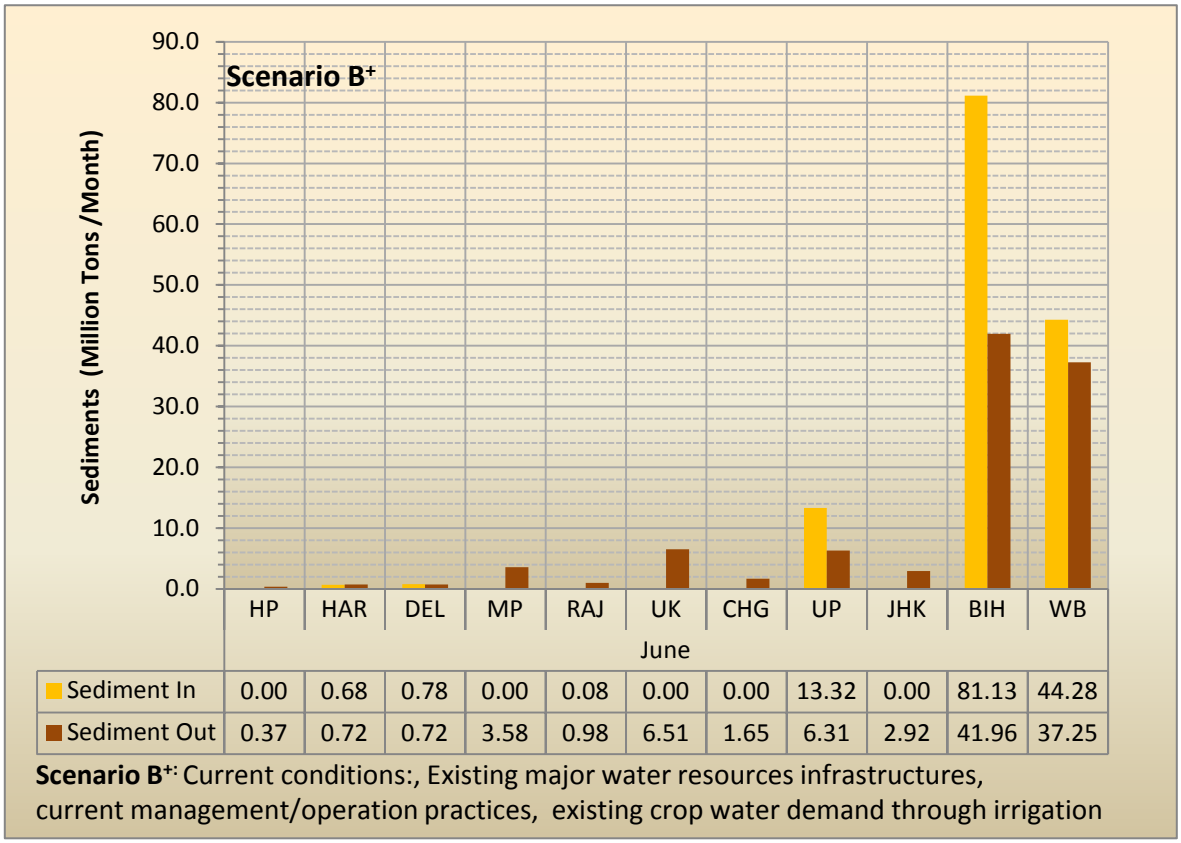
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.17	0.16	0.00	0.00	0.00	0.00	17.30	0.00	92.47	26.60
Sediment Out	0.17	0.13	0.15	-0.01	0	1.56	0	7.83	-2.82	29.41	15.19

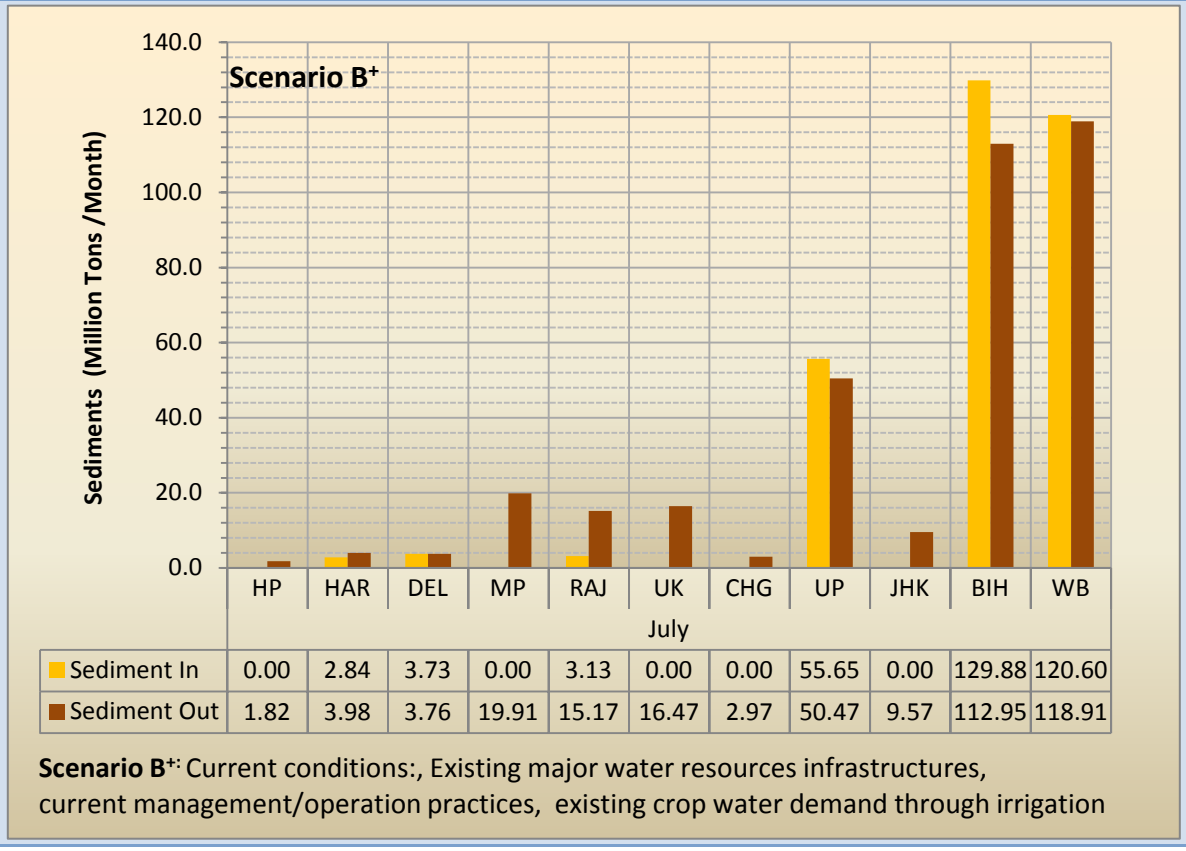
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 17: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.68	0.78	0.00	0.08	0.00	0.00	13.32	0.00	81.13	44.28
Sediment Out	0.37	0.72	0.72	3.58	0.98	6.51	1.65	6.31	2.92	41.96	37.25

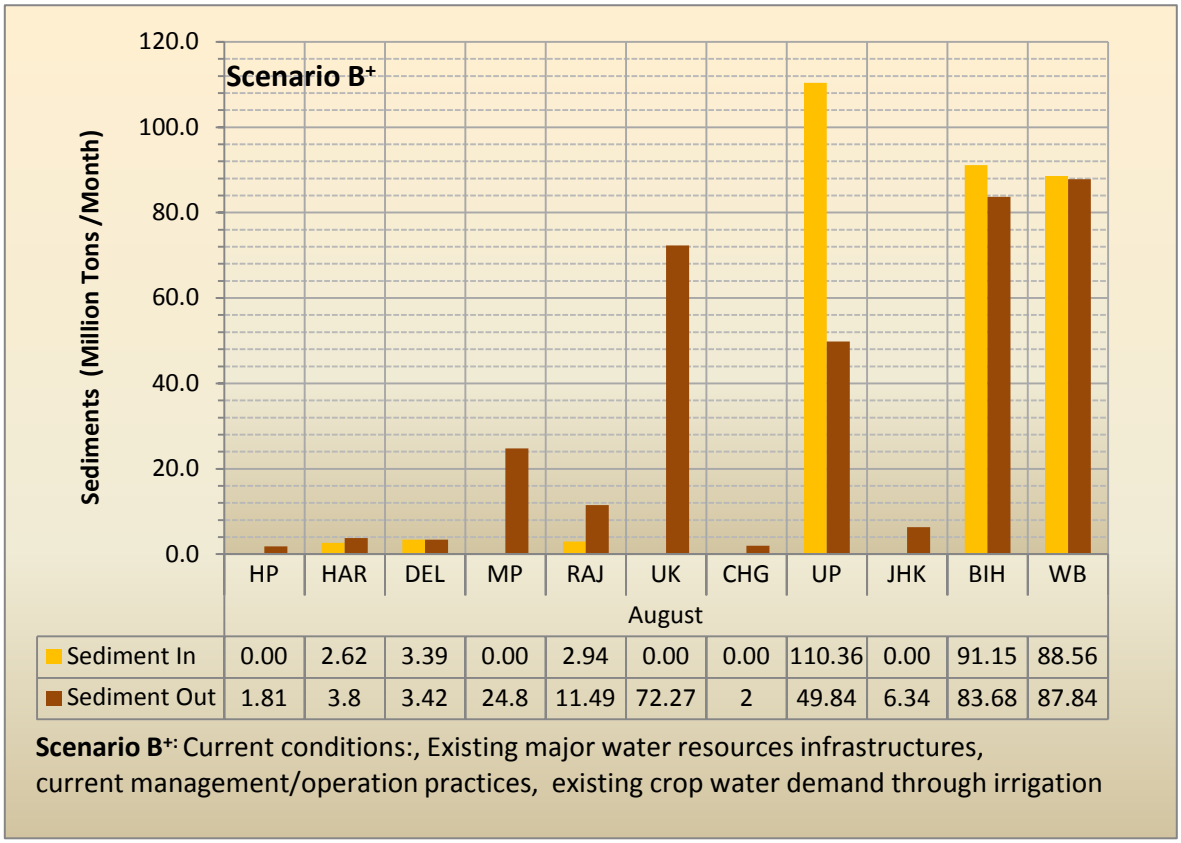
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	2.84	3.73	0.00	3.13	0.00	0.00	55.65	0.00	129.88	120.60
Sediment Out	1.82	3.98	3.76	19.91	15.17	16.47	2.97	50.47	9.57	112.95	118.91

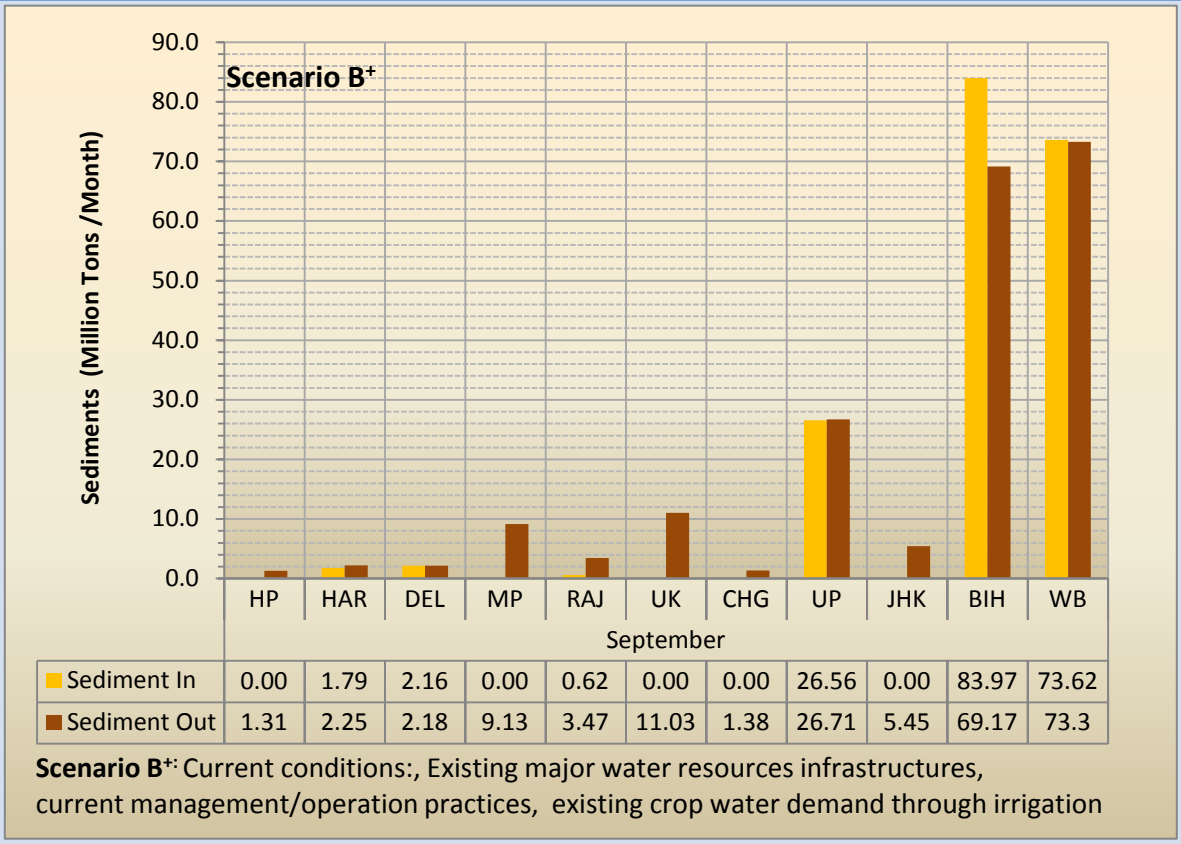
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 17: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	2.62	3.39	0.00	2.94	0.00	0.00	110.36	0.00	91.15	88.56
Sediment Out	1.81	3.8	3.42	24.8	11.49	72.27	2	49.84	6.34	83.68	87.84

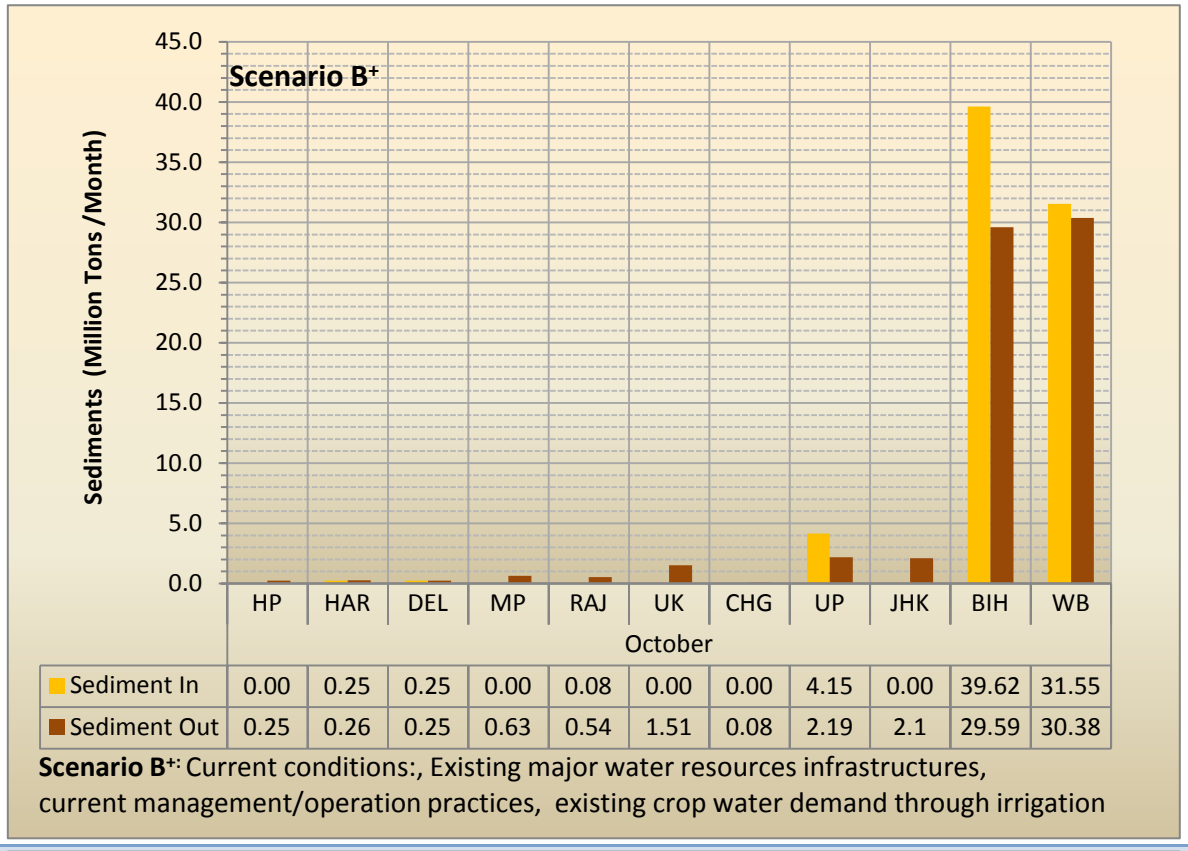
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	1.79	2.16	0.00	0.62	0.00	0.00	26.56	0.00	83.97	73.62
Sediment Out	1.31	2.25	2.18	9.13	3.47	11.03	1.38	26.71	5.45	69.17	73.3

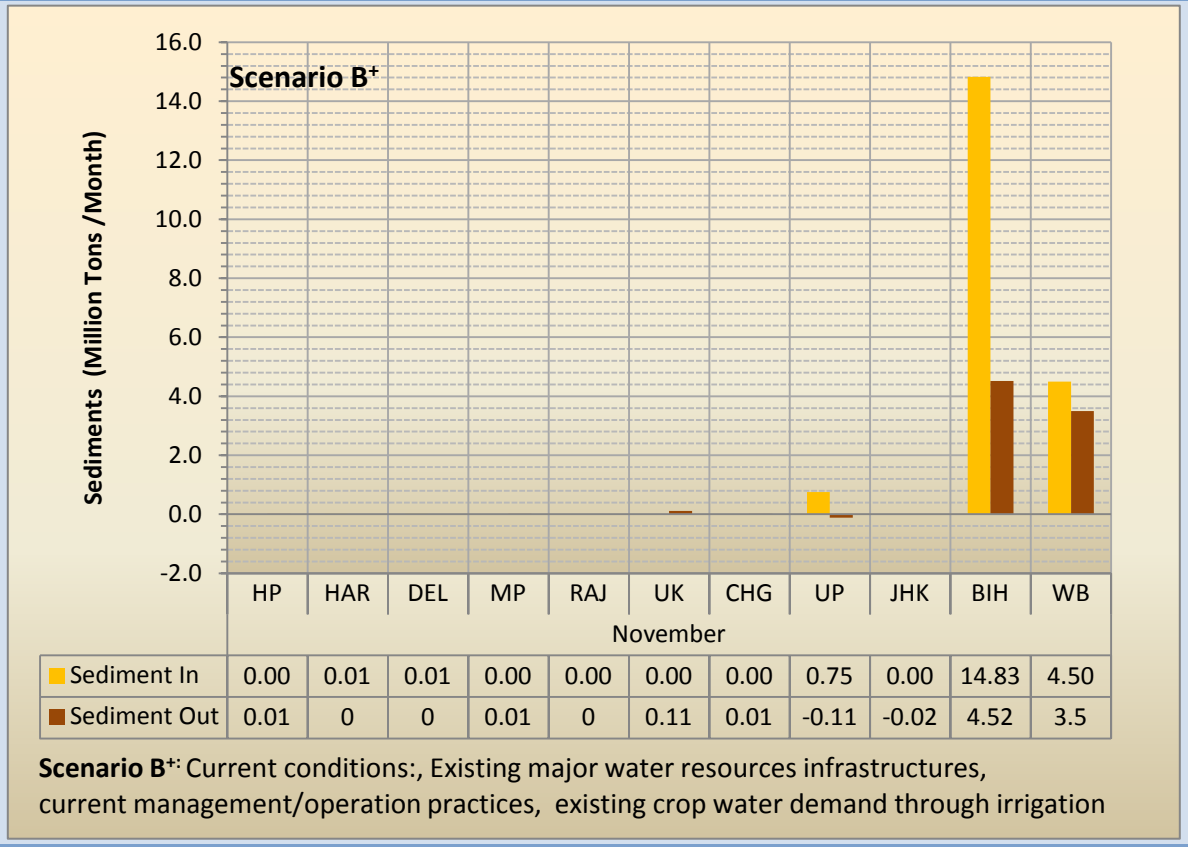
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 17: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.25	0.25	0.00	0.08	0.00	0.00	4.15	0.00	39.62	31.55
Sediment Out	0.25	0.26	0.25	0.63	0.54	1.51	0.08	2.19	2.1	29.59	30.38

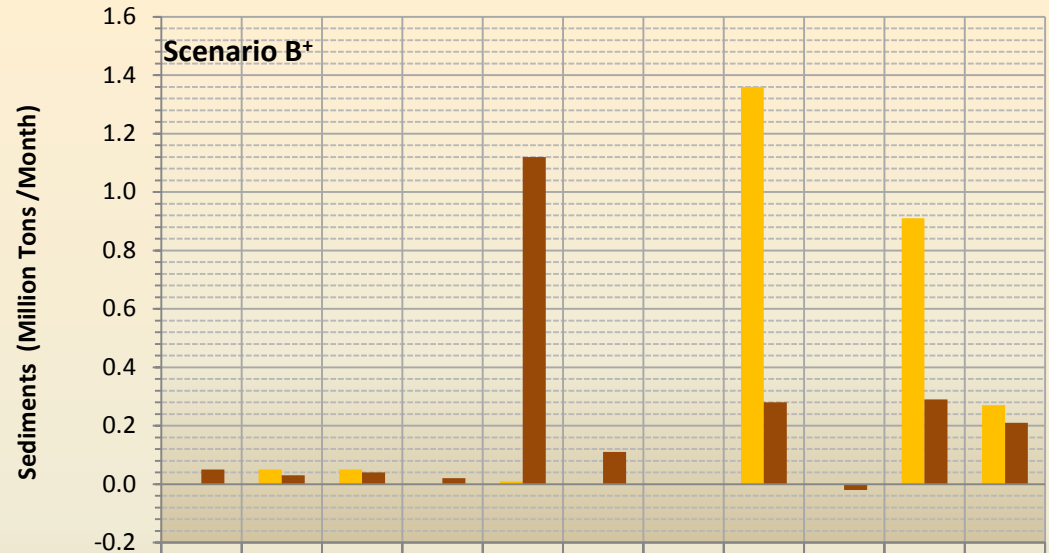
Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.75	0.00	14.83	4.50
Sediment Out	0.01	0	0	0.01	0	0.11	0.01	-0.11	-0.02	4.52	3.5

Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation

Figure 17: Graph: Average Monthly Sediment flow (MT/month) - State Level - Scenario B



	HP	HAR	DEL	MP	RAJ	UK	CHG	UP	JHK	BIH	WB
Sediment In	0.00	0.05	0.05	0.00	0.01	0.00	0.00	1.36	0.00	0.91	0.27
Sediment Out	0.05	0.03	0.04	0.02	1.12	0.11	0	0.28	-0.02	0.29	0.21

Scenario B+: Current conditions:, Existing major water resources infrastructures, current management/operation practices, existing crop water demand through irrigation