

Assessment of Environmental Flows in Ghaghra River Systems

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Abstract— Stream- Aquifer water table equilibrium plays important role in continuous flows in tropical rivers particularly during lean season. Restricting groundwater extraction to maximally 90% ensures base flow contribution towards environmental flows in river. Analysing present and desired state of rivers- Sharda, Ghaghra and Rapti at critical locations, selected in homozonation zones based on (i) aquatic biodiversity habitats, (ii) cultural heritage sites, (iii) slopes, (iv) hydrology (GDSQ) and (v) geo-morphological information. The basic motivations of E-Flows include knowledge of hydrology and hydraulics; whereas thematic areas like-fluvial geomorphology, aquatic biodiversity and socio-cultural and livelihood aspects suggest the desired flows at various locations on a river.

The Environmental Flows recommendations at six sites – Paliya Kalan on Sharda, Elgin bridge, Ayodhya, Turtipar on Ghaghra, Balrampur and Birdghat on Rapti river, all originating from Nepal are tributaries of Ghaghra river that confluence into Ganga river in Bihar. E-Flow sites falling in Uttar Pradesh only have been discussed here.

It is concluded that lean season flows have been an issue in Ghaghra River Systems, wherein the present day flows are lower than the recommended E- Flows. The wet season E-Flows are nearly achieved by the present day observed wet season flows. Thus, implementing E-Flows is a matter of policy and practice of the state and support of its people who value the necessity of good health of a river.

Keywords: Environmental flows, sustainable development, livelihood, river integrity, river health.

I. INTRODUCTION

Implementing environmental flows have been narrated by many researchers for policy and practice [eds.Tickner et al 2020]. Embedding E-Flows implementation set out two pathways- the one emphasizes river basin planning [Gawane et al, 2020], and second asks for policy shift in operation of existing control structures [Opperman et al 2020]. Such adaptability is essential for changing climate. UN Sustainable Development Goals-SDG 6.4 stipulates sustainable water withdrawals, and SDG 6.6 aimed at halting the degradation of water related ecosystems. Dams built for hydropower and barrages constructed for diversion of river's water for agricultural and other uses can substantially impact hydrological regimes, and fragmenting aquatic habitats [Grill et al 2019].

E-Flows Assessment (EFA) and implementation is seen as a tool for integrated water resource planning and management towards sustainability of water resources. EFA is the science- based process of determining appropriate flow regimes in a river for desired health to achieve from the present status.

The WWF-India has entered into a partnership with UP WaMReC and UP SWaRA, c-Ganga IIT Kanpur, PSI Dehradun and IFRI along with independent partners (including the author) to initiate the environmental flow assessment for 8 major rivers in UP as shown in Figure 1.

Out of this, E-Flows assessment of three rivers of Ghaghra basin of Uttar Pradesh is reported here as below:

1. Sharda river at Paliya Kalan, Pilibhit ($80^{\circ}33'2.818''\text{E}$, $28^{\circ}22'56.352''\text{N}$),
2. Ghaghara river at Elgin bridge ($81^{\circ}28'49.712''\text{E}$, $27^{\circ}5'45.956''\text{N}$), Ayodhya ($82^{\circ}12'36.445''\text{E}$, $26^{\circ}16'39.095''\text{N}$) and Turtipar ($83^{\circ}52'45.183''\text{E}$, $26^{\circ}8'30.26''\text{N}$),
3. Rapti river at Balrampur ($82^{\circ}13'48.479''\text{E}$, $27^{\circ}26'11.214''\text{N}$) and Birdghat ($83^{\circ}20'27.873''\text{E}$, $26^{\circ}44'36.206''\text{N}$).

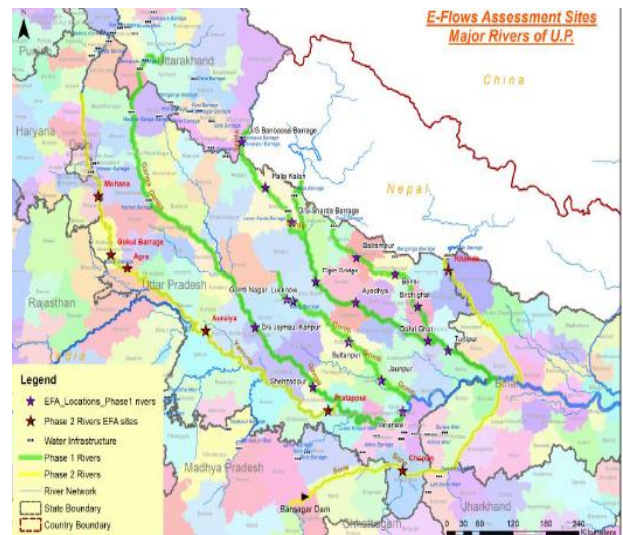


Figure 1 Major Rivers Draining Uttar Pradesh And The Selected Sites For E-Flow Assessment

(Credit: WWF-India UP Major Rivers EFA Report, 2021)

II. METHOD & METHODOLOGY

Dolphin is the flows motivating species in these locations. Certain varieties of Indian Major Carps (IMCs) are also found at these locations and their hydraulic habitat requirements would be met, if the Dolphin's hydraulic habitat requirements are maintained. Out of diversified approaches to assessment and implementation of E-Flows, one has to choose as to which method might best suit for their context including the policy dimension and existence of appropriate legislation and regulation. Many researchers put forward proposals for adapting objective-setting, planning and management of water resources to take account of climate uncertainties.

The knowledge of hydrology and hydraulics forms the backbone of any E-Flows assessment exercise; whereas the thematic areas like – fluvial geomorphology, aquatic biodiversity and socio-cultural & livelihood aspects motivate (suggest) the desired flows at various locations on a river. Fluvial geomorphology considers longitudinal, lateral and vertical connectivity along with planform dynamics and sediment movements as their critical parameters while motivating E-Flows; on the other hand, for the aquatic biodiversity, the flagship species, Vulnerable, Threatened, Near Threatened, native species, flows and water level sensitive species are prime motivations for E-Flows. The socio-cultural and livelihood thematic, while motivating E-Flows look at societal interactions with the river, in terms of cultural rituals (bathing, worshipping, and other auspicious activities). This thematic also considers aesthetic value of the river along with non-consumptive subsistence livelihood aspects as well.

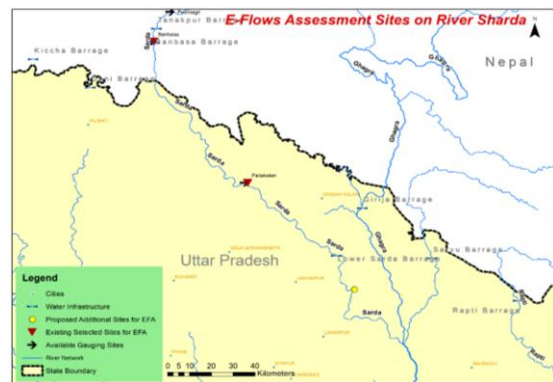
III. PRESENT AND DESIRED STATUS OF SHARDA, GHAGHRA AND RAPTI RIVERS

1. Sharda River

River Sharda originates at Kalapani (Uttarakhand state) in Himalayas at an EL 3600 m and flows along Nepal's western border with India and joins River Ghaghra in Sitapur district, Uttar Pradesh. Sharda basin area falling in Nepal is 35.4% and in India is 14871 km².

The total length of river within Uttar Pradesh state is about 257 km (basin area 3126.66 km²) as shown in Figure 2 A&B. Nepal's Shuklaphanta national park and Api-Nampa conservation park and India's Dudhawa Tiger Reserve biodiversity have been threatened by fragmentation of river due to existing barrages at Tanakpur and Banbasa both in Uttarakhand state within 18 km distance and most wanted Pancheshwar Multipurpose Project (proposed in future at 70 km u/s of Tanakpur, 300 m high dam, live storage capacity of 582 m³/s, installed capacity 6480 MW) that is said to provide lean season's releases for irrigation both in India and Nepal.

Average sediment load at Palia Kalan (2005-2015) CWC gauge site is 46869 tons per day (17.17 million tones /year) for catchment area 17676 km² i.e. 2.65 tons per day per km². This corresponds to a catchment denudation rate of 0.67 mm/year. In lean flow years the sediment is low while the high flow years have high sediment load. The sediment load is maximum in the month of August in correspondence to stream flow. The average annual discharge in Sharda river at Banbasa barrage is 658 m³/s whereas at Palia Kalan average monsoonal flow is 1126.12 m³/s and non monsoon is hardly 137.92 m³/s. The E-Flows site is about 6 km from Palia Kalan town. Selected location is near the Sharda river bridge (there is a road and a railway bridge as well, the site is in between both the bridges – towards road-bridge side).



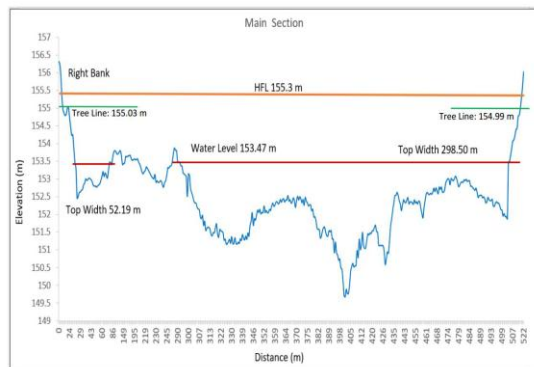


Figure-2 A, B, C, Palia Kalan E-Flow Location And Cross Section On The Sharda River

Fluvial geomorphology, aquatic biodiversity socio-cultural thematic groups survey is narrated below.

A. Fluvial Geomorphology

The dominant substrate particles observed is sand and silt. Fishing and agriculture are the main activities around this location. Sugarcane is the primary crop. This corresponds with several sugar production plants located in the area. Various geomorphic features around Palia Kalan are shown in Figure 3. While floodplain flows are usually aggradational, scour occurs around obstruction.

The sinuous pattern in the vicinity of the road and railway bridge is indicative of scouring leading to the removal of considerable volumes of soil and transmission downstream to drive accelerated sedimentation and formation of large lateral bars downstream. Capacity for channel migration is high in this reach in both the U/S and D/S region of the road bridge. In general, the longitudinal connectivity is good throughout and lateral connectivity is good mostly in the D/S side. Additionally, the floodplains are well inundated during monsoon.

B. Aquatic Biodiversity

A total of 10 species were recorded at this site, of which *Wallago attu* which is commonly called “Lanchi” or “Paran”, is found to be Vulnerable (VU) as per the IUCN Red List data, this fish species also has good commercial value. Some of the other fish species found at this location were – *Cirrhinus mrigala*, *Cirrhinus reba*, *Mystus cavasius*, *Channa punctata*. A few deep pools were observed in the river, where dolphins were spotted multiple times during the survey in monsoon season, at this location. Two adult individual were observed in the river. According to the fishermen and the farmers, they see Dolphins during both the seasons (summer and monsoon), however, the frequency is much more during the monsoon season, when the water level increases.

C. Socio-cultural

The respondents accessed the river for cutting and gathering wood. Other activities include – fishing, bathing livestock and for rituals. The *Chhat Puja* is celebrated extensively along Sharda Nagar. In the summer, the water level is low, this means water levels are inadequate for bathing or fishing and the river does not satisfy either that who depends on it for livelihoods or for social-cultural sustenance. In the winter, the flows marginally improve. In the monsoon, the flows are considered to be adequate for all the user groups. Floods too are welcomed into the fields for their fertile silt.

FIGURE 3 PICTURES EXHIBITING VARIOUS GEOMORPHIC FEATURES AROUND PALIA KALAN SITE ON SHARDA RIVER



TABLE 1: PRESENT AND DESIRED STATE OF SHARDA RIVER AT PALIA KALAN SITE

S. No.	Thematic area	Present State	Reasoning/ Remarks – Present state	Desired State
1	Fluvial Geomorphology	Slightly Modified	Good longitudinal and lateral connectivity, with well-inundated floodplains during monsoon	Near Pristine
2	Aquatic Biodiversity	Slightly Modified	Rich fish diversity, including native fish species, along with presence of Dolphins	Near Pristine
3	Socio-cultural	Moderately Modified	Shallower river stream, reduced water levels lead to difficulty in carrying out rituals during summer season, plus declining fish catch is another reason	Slightly Modified

2. Ghaghara river

The river rises in Tibet, flows through Nepal and, crosses the Himalayas at Chisha Pani before finally confluence with the Ganga. Along its entire length, the Ghaghara bears several names including Karnali, Ghaghara and Saryu. In January 2020, the Government of Uttar Pradesh had decided to change the name of Ghaghara (between the river stretches from Gonda in UP to Rewalgañj in Bihar) to Saryu. The total length of the Ghaghara river is about 1080 km, out of which 604 km falls in Uttar Pradesh.

There are 3 E-Flows sites selected on Ghaghara river, Elgin bridge, Ayodhya and Turtipar (see Figure 1). Ayodhya is the most important socio-cultural site. Therefore, this location bears special significance, not only for this study but, for the government as well due to Ram Mandir Janm Asthan.

2.1 Elgin Bridge

The Elgin Bridge site (near Barabanki) is located between a railway and road bridge. The railway bridge is 3,695 feet long.

Due to the variability of the Ghaghara's course, Elgin Bridge was built on dry land, and the river was diverted under it. Thus, the selected river stretch around the E-Flows location only came into existence at the time of the construction of the railway bridge in the early nineteenth century. The flood discharge at this section is 8,77,000 cubic feet per second. The substrate is largely composed of sand and silt. Riverbanks are largely sandy and both the banks were exposed. Main habitat types include deep pools and run in the river. The cross section and geomorphic features of this location is given in Figure-4.



Elevation Profile from DGPS: CS 04 (Main Section)

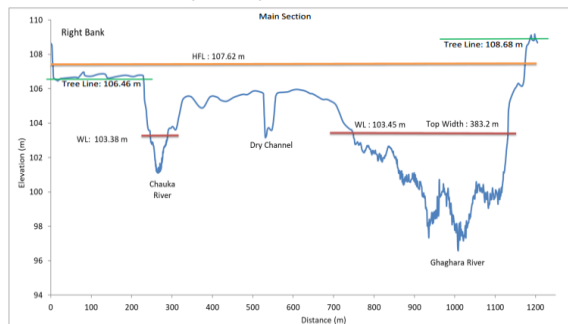


Figure 4 A, B, C: Elgin Bridge E-Flows Site Cross Section & Geomorphic Features On Ghaghara River

A. Fluvial Geomorphology

A number of alluvial islands, compound vegetated mid channel bars, are mapped and these are emergent even at 'bank full' stage, both at U/S and D/S of the Elgin Bridge site. The islands are commonly elongated in form, aligned with the direction of the flow. These are relatively stable features and they act as secondary storage of in-stream sediments

In summary, the Ghaghara river at this site is characterized by a braided morphology and is anabranching with large alluvial islands, small mid channel bars and lateral bars. The channel is mostly asymmetric with a wide main channel (avg. 300 m in low flow condition) and is susceptible to floods along the right bank of the channel belt. A sandy channel substrate and banks are noted. Many reaches upstream as well as downstream are identified as highly aggrading.

B. Aquatic Biodiversity

A total of 4 species were recorded from this site during summer and monsoon season, through field surveys and among these none were found to be in the IUCN Red List. Some of the authors, have reported, near this location: 4 species which are Near Threatened (NT) i.e. *Chitala chitala*, *Ompok bimaculatus*, *Ompok pabda* and *Ompok pabo*. *Chitala chitala* is a commercially important fish species and commonly known as "Chital".

The team spotted dolphin at the time of the survey in monsoon season but, the presence of dolphin at this location was reported round the year by the fishermen. Calves and adults dolphin are spotted occasionally.

C. Socio-cultural

People see the river as a changeable, unpredictable being. The survey team had the privilege of interviewing one of the last steamboat operators. He spoke of running the ferry across the Ghaghara when it was much wider than it is today. Apparently, the ferry could carry two trucks at one time. The depth of water was enough to accommodate these huge boats. The Ghaghara is worshipped as a divine river, its Himalayan origins adding to its sanctity. Several scores of people come to the ghat here to bathe during festival days. According to local people, the river is clean and has a relatively good biodiversity, with dolphins seen every day. The flows at present are though considered low, with the river having shrunk to less than half its original width.

At the same time, the floods are seen as being extremely destructive. The water level as it was at present (during the time of the survey) is considered barely adequate.

The river is considered to be clean, as people continue to use its water for cooking on various occasions.

TABLE 2: PRESENT AND DESIRED STATE OF GHAGHRA RIVER AT ELGIN BRIDGE E-FLOWS SITE				
S. No.	Thematic area	Present State	Reasoning/ Remarks – Present state	Desired State
1	Fluvial Geomorphology	Moderately Modified	Longitudinal and lateral connectivity is good. Floodplain is well inundated during the monsoon. Planform dynamics indicate that the river is highly migratory in this reach. Several reaches are prone to bank erosion as is also evidenced by bank protection measures in this stretch	Slightly Modified
2	Aquatic Biodiversity	Slightly Modified	Good connectivity and reasonable intact section, from the human interferences (except some fishing)	Near Pristine
3	Socio-cultural	Moderately Modified	The summer flows are perceived to be low from what is desired – the people's aspiration of a roaring river is not met	Slightly Modified

2.2 Ayodhya

The E-flows site has been selected between the two road bridges; the old bridge was constructed in 1966 and the new bridge came up as a part of the National Highway project. This site is characterised by a partly confined floodplain, with a valley margin close to the right bank adjacent to the Old Saryu Road Bridge. The E-Flows location is at Naya Ghat and the Cross Section is given as Figure 5.

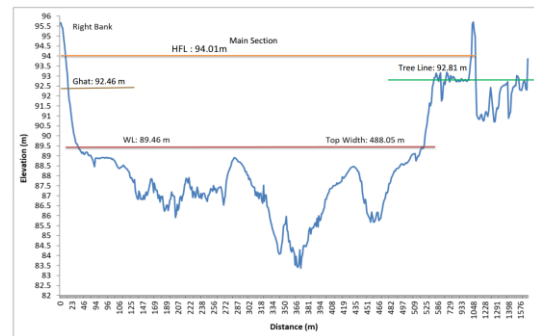


Figure 5 A, B, C : Location, Cross Section & Geomorphic Features Of Ghaghra (Saryu) River At Naya Ghat In Ayodhya

A. Geomorphology

The Ghaghara river at Ayodhya is characterised by a braided morphology and is anabranching with large alluvial islands both U/S and D/S and large mid channel bars and lateral bars. The channel is mostly asymmetric with a wide main channel (avg. 600m in low flow condition) and is susceptible to floods along the left bank of the channel belt near the cross-section sites. Both sandy channel bed material and banks are noted. Several reaches of the river in this stretch are identified as hotspots of aggradation.

Considering the last 30 years' data, the sediment load at Ayodhya site is 398217 tonnes per day (145.45million tonnes/year) for 80,889 km² i.e. 4.92 tonnes per day per km². This corresponds to a catchment denudation rate of 1.29 mm/year. In low flow years the sediment load is low while the high flow years have high sediment load. The sediment load is maximum in the month of August in correspondence to stream flow

B. Aquatic Biodiversity

At Ayodhya, a total of 7 fish species were recorded, but none of them are reported under IUCN Red List data. However, 3 species recorded in the secondary literature have been reported from Faizabad which is close to Ayodhya, and these species are under Near Threatened (NT) category i.e. *Chitala chitala*, *Ompok bimaculatus* and *Ompok pabda*. *Chitala chitala* is commonly called "Chital" and is economically important species. At this location, dolphin was spotted during survey and its occurrence was reported by the fishermen as well. During fishing, they had observed dolphin many times in slightly upstream of this site in the river.

C. Socio-cultural

The river here is intricately connected with stories from the Ramayan, including Rama's birth and life. One of the respondents also said that this river originates from Vishnu's eye from his seat in Mansarovar. Hindu devotees also come here for a ceremonial dip after bathing in the Ganga. According to several respondents, when one takes a dip at Prayag in Allahabad, one's sins are removed only to cloak the body; the sins continue to cling to the pilgrim. However, when one bathes here after bathing in the Ganga, the sins are washed away. This location is one of the key socio-cultural destinations for scores of people, because of mythological association of the river with Ayodhya city.

Various socio-cultural activities, including – ritual bathing, *aachman*, daily *aarti* etc. are common activities around this location (see Figure 6).



Figure 6 A & B: Cwc Gauge At Ayodhya Site And Activities At Ghats On Ghaghara River

2.3 Turtipar

The Turtipar site on the Ghaghara river is located in Ballia district and this is the most downstream site on the Ghaghara before it outfalls into the Ganga, ~105 km downstream. The Ghaghara river flows in NW-SE direction in this stretch and except for a state highway and a railway bridge, more than 100 years old, across the river, there is no major intervention around this site. The site is in a rural setup. Deep pools and run were found in the river, which makes for good habitat for the dolphin. The substrate type was mainly composed of sand and clay. Fishing is the only activity observed at this site. The Cross Section of Turtipar site and geomorphic setting is given in Figure 7.

TABLE 3: PRESENT AND DESIRED STATE OF GHAGHRA RIVER AT NAYA GHAT, AYODHTA E-FLOWS SITE

S. No.	Thematic area	Present State	Reasoning/ Remarks – Present state	Desired State
1	Fluvial Geomorphology	Moderately Modified	Longitudinal connectivity is good, and the lateral connectivity is fair. The valley setting has a partly confined floodplain and the active flood plain is well inundated during monsoon. Planform dynamics indicate that the river is susceptible to in-channel migration	Slightly Modified
2	Aquatic Biodiversity	Moderately Modified	From the species perspective, there are human disturbances around the site, although local priests do not permit fishing. The boats have long rotors, which should be prohibited – therefore battery operated boats should be permitted	Slightly Modified
3	Socio-cultural	Degraded	The group aspires to achieve a class above the next river health class – mainly to ensure a healthy river full of life and support for its people or socio-cultural visitors who come from far flung places to perform cultural rituals on the banks of the river in this auspicious town	Slightly Modified

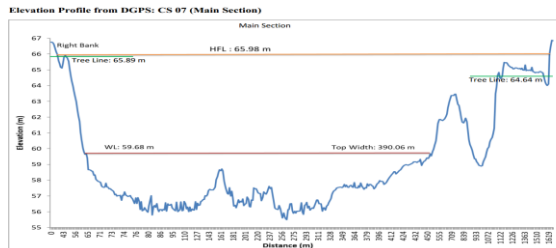


Figure 7 A&B: Cross Section And Geomorphic Settings Of Ghaghra River Around Turtipar E-Flows Site

A Fluvial Geomorphology

This site is characterized by a channel belt mostly confined by the valley margin for almost ~6 km, and a portion of partly confined floodplains in the U/S and D/S areas. Therefore, there is very little development of any active floodplain adjacent to the road and railway bridge. The main channel around the road bridge is characterized by an asymmetric form, low sinuosity and very low multiplicity. For most parts, the primary channel is flowing along the right bank.

The Ghaghara river at this site is characterized by a sinuous pattern and hosts large lateral bars, mid channel bars and few alluvial islands. The channel is mostly asymmetric with a wide main channel (avg. 450 in low flow condition) and is susceptible to floods along the right bank of the channel belt. A sandy channel substrate and banks are noted, with calcareous bed material exposed in some areas in low flow condition and portions of pedogenic calcareous bank material.

While considering the last 10 years' data (2005-15), the sediment load in Ghaghara river at Turtipar site is 410557 tonnes per day (149.96 million tonnes/year) for 113088 km² i.e. 3.63 tonnes per day per km².

TABLE 4: PRESENT AND DESIRED STATE OF GHAGHRA RIVER AT TURTIPAR E-FLOWS SITE

S. No.	Thematic area	Present State	Reasoning/ Remarks – Present state	Desired State
1	Fluvial Geomorphology	Moderately Modified	The longitudinal connectivity is good. In-channel sedimentation is noted in downstream reaches & dredgers are used to remove excess sediments	Slightly Modified
2	Aquatic Biodiversity	Slightly Modified	Rich fish species diversity, with active Dolphins presence and relatively negligible human interferences	Near Pristine

This corresponds to a catchment denudation rate of 0.95 mm/year. In lean flow years the sediment load is low while the high flow years have high sediment load. The sediment load is maximum in the month of August in correspondence to stream flow (Table-4). Sediment load has increased during the last 10 year, as compared to last 30 years average.

B. Aquatic Biodiversity

The maximum number (25) of unique fish species in Ghaghara river were observed from Turtipar E-Flows location. Out of these, one is Vulnerable (VU) *Wallago attu* and the other one is under Near Threatened (NT) category, i.e. *Bagarius bagarius* under IUCN Red List data. Both the species are economically important as well. Dolphins were spotted many a times during the survey at this site. Adults and calves – both were spotted. As per the fishermen, dolphins are seen round the year at this location but, the frequency of observation increases during monsoon.

C Socio-Cultural

Turtipar has been established since ancient times as evidenced by Khaira Dih, the residence of Jamadagni Rishi and the birth place of his son Parashuram. Turtipar rail bridge 3912 feet long was built in 1903 which indicates the width of the river bed. This site experienced great disturbance during the great earthquake of 1934.

3 Rapti river

The Rapti River originates from midway between the western Dhaulagiri Himalaya and the Mahabharat Range (1000–3000 m) at an elevation 3200 meters in Nepal, enters in the territory of India in the district of Bahraich and traverses to join river Ghaghara at Kaparwar ghat, Barhaj in District Deoria.

The most prominent features of the meandering lower Rapti floodplain are ox-bow lakes, alternative channel bars, flood chutes, point bars, swirl pit, swamps or marshes, natural levee, dry channel and branching streams. Based on Homogenous Zonation, the river is divided into three distinct homogenous zones, i.e. having elevation range of 42 - 100 meter, 100 - 150 meter and 150 - 421 meter as shown in Figure 8.

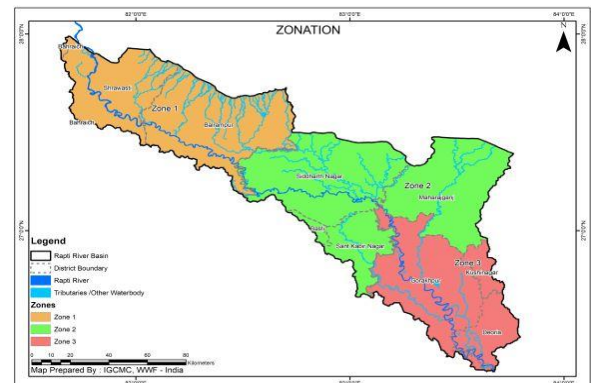


FIGURE 8A & B ELEVATION MAP AND E-F SITE LOCATION ON RIVER RAPTI

As per the IUCN Red Data List – 2020-1, 42 species are listed as Least Concern (LC) in Rapti River, 4 species are Near Threatened (NT); and 1 vulnerable (VU). 2 species are under Not Evaluated (NE) category. Two EF sites one each in Zone 1 and Zone-3 are selected.

3.1 Balrampur

Balrampur is located on the right bank of Rapti river. In the dry season, the river flows remain minimal in the river and the river becomes a narrow channel. The E-Flows locations is around 6 km away from the main city and the banks were free from encroachment. The location and its Cross Section of E-Flows are given in Figure 12.

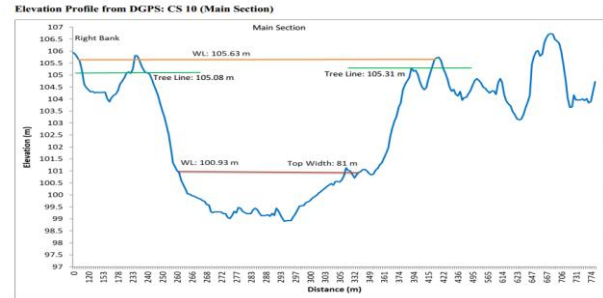


FIGURE 12 A & B E-F SITE LOCATION AND CROSS SECTION OF RIVER AT BALRAMPUR

The river in this stretch was once the cradle of Buddhist civilization. Today, the ruins of Sahet Mahet have been identified as Sravasti and this has led to a surge in the religious importance of the area. Magh mela, Navratri and Chhat puja are practiced extensively in this stretch.

TABLE 5: PRESENT AND DESIRED STATE OF RAPTI RIVER AT BALRAMPUR E-FLOWS SITE

	Thematic area	Present State	Reasoning/ Remarks – Present state	Desired state
1	Fluvial Geomorphology	Slightly Modified	The river around this location is fairly stable with a sinuous morphology and asymmetric channel form. The planform morphology does not show any appreciable dynamics	Near Pristine
2	Aquatic Biodiversity	Slightly Modified	The river is reasonably satisfactory state, with no major disturbances from the aquatic biodiversity perspective	Near Pristine
3	Socio-cultural	Moderately modified	Present day summer flows are extremely low, with the river shrinking to a stream in the centre. There are a very few pools where the water remains waist deep, but most of the stream is such that one can easily walk across.	Socio-cultural

3.2 Birdghat – Gorakhpur

Birdghat – Gorakhpur E-Flows site is at left bank of Rapti under a bridge at Gorakhpur-Lucknow highway. The data over the past 100 years show a considerable increase in the intensity and frequency of floods, with extreme events occurring every three to four years. Roughly, 20% of the population is affected by floods, which are an annual occurrence in some areas, causing huge loss of life, health and livelihoods for the poor inhabitants, as well as damage to public and private property. A small fisherman colony is located on the right bank of Rapti river at Birdghat Gorakhpur and a temple is also located under the bridge.

The substratum was mainly composed of sand and silt particles. Deep pools during monsoon, were found in upstream of the river, making good habitat for dolphin. Human interferences were evident, in terms of cremation, fishing, bathing and washing of cloths.

Considering the last 30 years' data, the sediment load in Rapti river at Birdghat site is 70811 tonnes per day (25.86 million tonnes/year) for 20,093 km² i.e. 3.52 tonnes per day per km². This corresponds to a catchment denudation rate of 0.93 mm/year. While considering the last 10 years' data, the sediment load at Birdghat site is 34048 tonnes per day (12.44 million tonnes/year) for 20093 km² i.e. 1.68 tonnes per day per km². This corresponds to a catchment denudation rate of 0.44 mm/year. Sediment load of Rapti has decreased during the last 10 year, as compared to last 30 years average. It has decreased from 3.52 tonnes per day per km² to 1.68 tonnes per day per km².

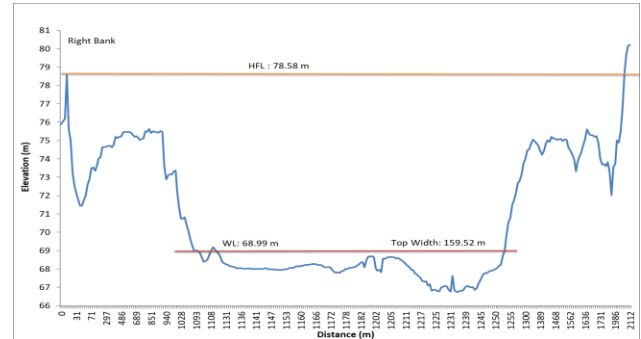


FIGURE 13 EF LOCATION AND CROSS SECTION OF RAPTI RIVER AT BIRDGHAT, GORAKHPUR

A Fluvial Geomorphology

The planform morphology of the Rapti river at Birdghat shows some dynamics related to movement of meanders and abandonment of meander bends over the last 3 decades. A major change is noted in terms of the extent for active floodplain, which has been increasing steadily since 1990. The channel width of the Rapti river does not show much change over the entire stretch of the river at Birdghat. The thalweg line between the years is also consistent over the years.

B. Aquatic Biodiversity

A total of 20 fish species were recorded from this location of a Rapti river. As per the IUCN red data list, only one species that is Wallago attu was found here, which fails under Vulnerable category. This is also a commercially important fish species and commonly called "Lanchi". Dolphins are seen during the monsoon season.

TABLE 6: PRESENT AND DESIRED STATE OF RAPTI RIVER AT BIRGDHAT, GORAKHPUR

S. No.	Thematic area	Present State	Reasoning/ Remarks – Present state	Desired state
1	Fluvial Geomorphology	Moderately Modified	Fairly stable site in terms of channel morphology, but shows some dynamics in terms of floodplain extent lately and it might suggest recent vulnerability of the site to floods	Slightly Modified
2	Aquatic Biodiversity	Moderately Modified	The river is reasonably satisfactory state, with evident longitudinal connectivity. Some human disturbances observed from aquatic biodiversity perspective	Slightly Modified
3	Socio-cultural	Moderately Modified	The present flows for lean season recedes till it is a small stream in the centre. Then water is up to knees or less till Holi	Slightly Modified

C. Socio-cultural aspects

City was founded in 15th century taking name from a shrine of Gorakhnath. The last flood in Gorakhpur was in 2000.

IV. MOTIVATION FOR E-FLOWS SETTING

Aquatic requirement for Dolphin or IMC have been considered. Flushing requirement is limited to 10-15 days only to submerge vegetation. The river water depth at various E-Flows sites is tabulated in Table 7 for maintenance year and drought year. The motivation for E-Flows setting is narrated below the Table 7.

**TABLE 7
DESIRED RIVER WATER LEVEL IN M FOR NORMAL AND DROUGHT YEAR FOR WET AND DRY SEASON AND FLUSHING REQUIREMENT**

Desired river water level in m	Normal Year Maintenance			Drought Year	
	Wet Season	Dry Season	Flushing	Wet Season	Dry Season
EF site					
1.0 Sharda-Palia Kalan	4.8	3.4	5.4(1000 m3/s)	3.8	3
2.1 Ghaghra-Elgin bridge	8.6	5	9.6 (>1500 m3/s)	6.2	3.5
2.2 Ghaghra-Ayodhya	8.6	5	9.5 (>5000 m3/s)	7	3
2.3. Ghaghra-Turtipar	7.95	4	9.25 (>6950 m3/s)	3	2
3.1 Rapti-Balrampur	4.9	2.25	7 (> 1300 m3/s)	4.9	2.25
3.2 Rapti-Birdghat	6.4	2	8.9	3	1.5

For maintenance Year

a. Aquatic Biodiversity: during the dry season, the recommended depth is essential for providing space for Dolphin's normal body movement and the food. Feeding ground increase with increasing depth. River dolphins tend to spend the majority of their time in areas where they have access to an abundant food supply.

During the wet season, the recommended water levels would aid formation of side pools/wetlands formed would also help and support the flourishing communities of small sized fishes and minnows that are found in this site, which shall be helpful since they are considered as important natural food for dolphins. The recommended depth would support complete inundation of side channels during wet season.

- b. **Fluvial Geomorphology:** The dry season recommendations will partially inundate the bars and maintain the longitudinal connectivity of the channel. The wet season recommendations will maintain lateral connectivity of the river at this site and keep the bar forms submerged
- c. **Socio-cultural Aspects:** convenient ritual bathing is critical from this perspective and the recommended depth would ensure the same.

For drought year

- **Aquatic Biodiversity:** for survival of dolphin population during stress conditions, the recommended depth is essential; this will also provide required width of the river bed, which is also necessary as per substratum condition at the site
- **Fluvial Geomorphology:** the recommended water levels are the least that are required for ensuring longitudinal connectivity during dry season and some level of lateral connectivity is the prime motivation for drought year
- **Socio-cultural Aspects:** the group concluded that, waist deep water is the minimum for convenient bathing. In a drought year, they are willing to wade further from the banks for a ritual dip

V. RECOMMENDED ENVIRONMENTAL FLOWS IN GHAGHRA RIVER BASIN

Informed hydrology for these sites is available. CWC stream flow data (1985-2015) max, min and average is used to compare recommended E-flows hydrographs as shown in Figure 14 A & B to Figure 19 A & B.

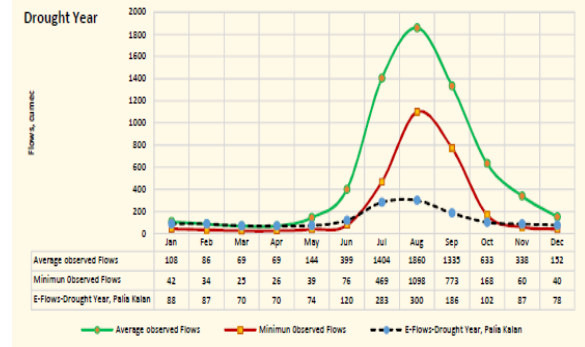
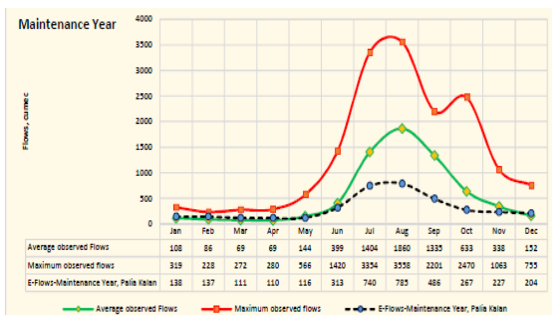


FIGURE 14A&B RECOMMENDED E-FLOWS MAINTENANCE AND DROUGHT YEAR IN SHARDA RIVER AT PALIA KALAN

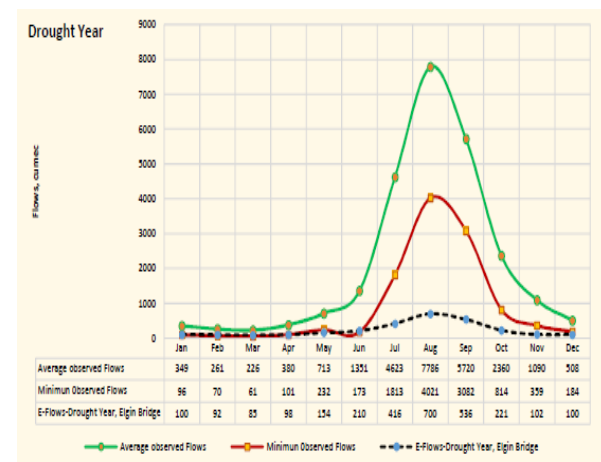
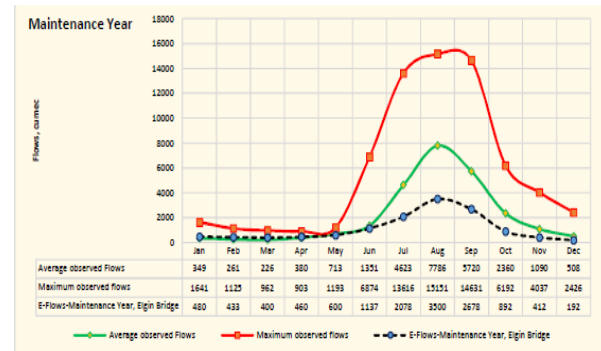


FIGURE 15A&B RECOMMENDED E-FLOWS MAINTENANCE AND DROUGHT YEAR IN GHAGHRA RIVER AT ELGIN BRIDGE

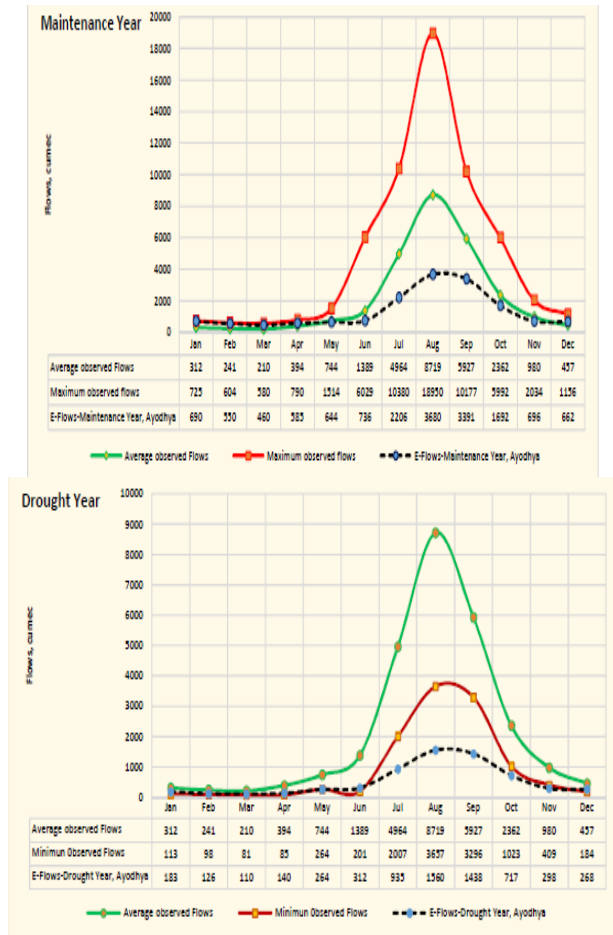


FIGURE 16A&B RECOMMENDED E-FLOWS MAINTENANCE AND DROUGHT YEAR IN GHAGHRA RIVER AT AYODHYA

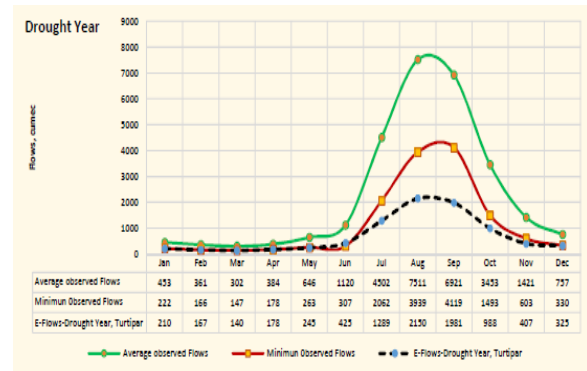
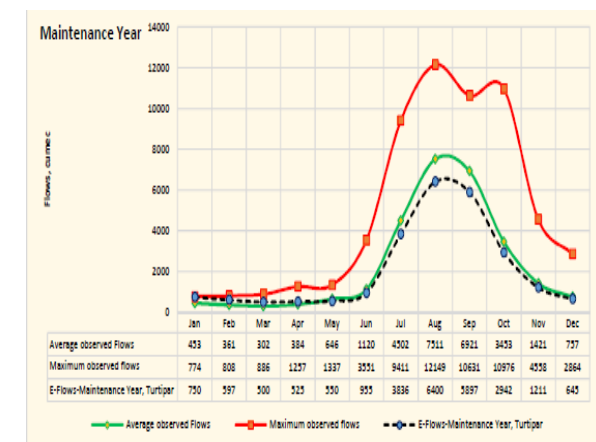


FIGURE 17A&B RECOMMENDED E-FLOWS MAINTENANCE AND DROUGHT YEAR IN GHAGHRA RIVER AT TURTIPTAR

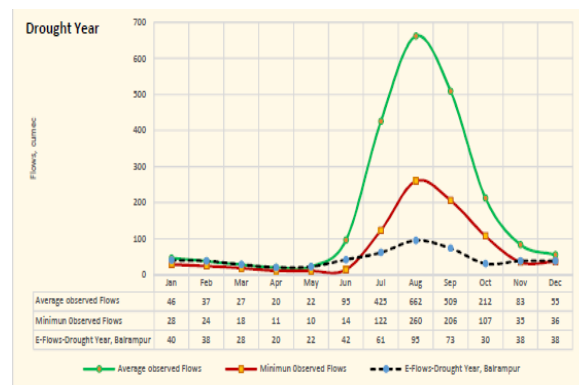
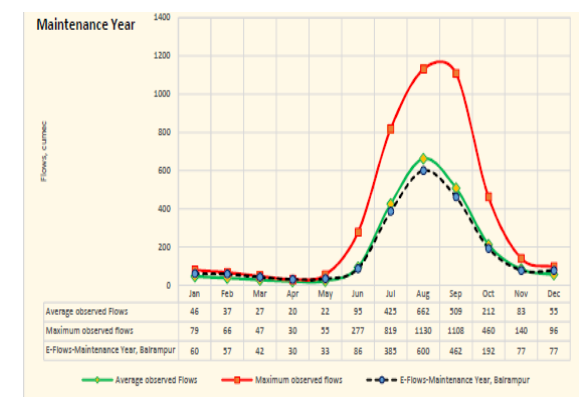


FIGURE 18 A&B RECOMMENDED E-FLOWS MAINTENANCE AND DROUGHT YEAR IN RAPTI RIVER AT BALRAMPUR

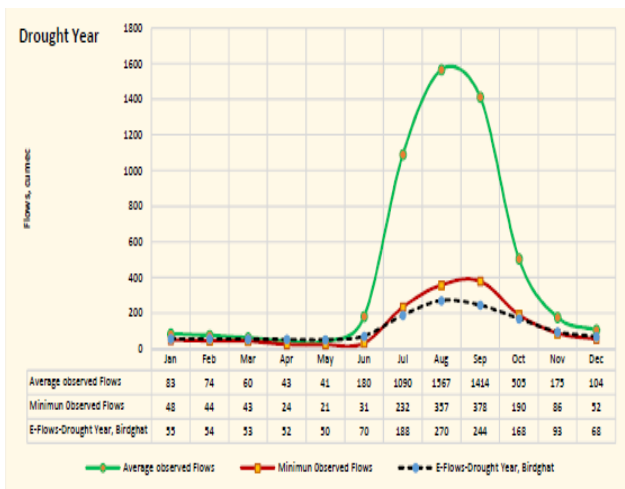
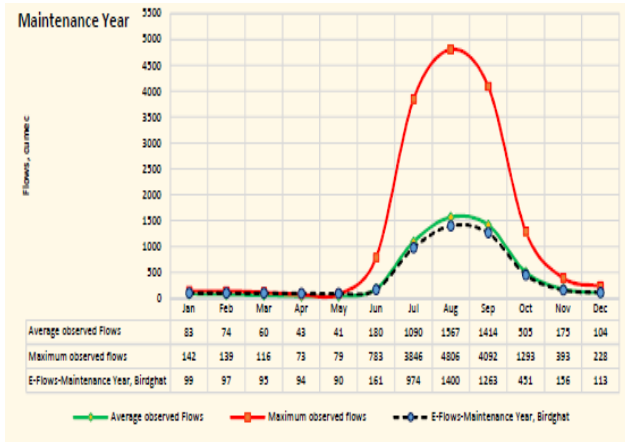


FIGURE 19A&B RECOMMENDED E-FLOWS MAINTENANCE AND DROUGHT YEAR IN RAPTI RIVER AT BIRDGHAT, GORAKHPUR

VI. CONCLUSION

It is concluded that lean season flows have been an issue in Ghaghra River Systems, wherein the present day flows are lower than the recommended E- Flows.

The wet season E-Flows are nearly achieved by the present day observed wet season flows. Stream- Aquifer water table equilibrium plays important role in continuous flows in tropical rivers particularly during lean season flows. Restricting groundwater extraction to maximally 90% ensures base flow contribution towards environmental flows in river. Thus, implementing E-Flows is a matter of policy and practice of the state and support of its people who value the necessity of good health of a river.

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