LUCKNOW DEVELOPMENT AUTHORITY, LUCKHNOW

HYDROLOGICAL STUDY FOR GOMTI RIVER FRONT DEVELOPMENT

DEPARTMENT OF CIVIL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

ROORKEE – 247 667

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Hydrological Study for Gomti River Front Development

Dept. of Civil Engineering
Indian Inst. of Tech. Roorkee
Roorkee-247 667, Uttarakhand, India
Tel.: 91-1332-285423
Fax: 91-1332-275568
email: zulfifce@iitr.ernet.in

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Client Lucknow Development Authority Vipin Khand, Gomti Nagar Lucknow, Uttar Pradesh	***Client representative*** O.P. Misra Executive Engineer
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Authors Z. Ahmad *Professor* Dept. of Civil Engineering Indian Institute of Technology Roorkee Roorkee-247 667.	***Date*** 25 May 2013
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EXECUTIVE SUMMARY

Lucknow -The City of Nawabs and the capital of Uttar Pradesh State is situated on the banks of river Gomti. It is a perennial alluvial river and characterized by sluggish flow throughout the year, except during the monsoon season, when heavy rainfall causes a manifold increase in the runoff.

Inspired by the river front development of Sabarmati rive in Ahmadabad city of Gujarat, the Lucknow Development Authority (LDA), Lucknow is planning to develop the river front of Gomti upstream of the barrage through utilisation of unused lands on both sides of the river for construction of public recreational facilities and beautification of the surroundings. The task of hydrological study of the proposed river front development has been assigned to Dept. of Civil Eng., IIT Roorkee with the following scopes:

a) To reproduce the existing conditions of flood flow in river Gomti through mathematical modelling by utilising the hydrological and geometrical data.
b) To quantify the effect of proposed river front development on river morphology and high flood levels at different locations.
c) To quantify the effect of proposed river front developmental on the existing major structures (bridge/barrage) built across the river.
d) To assess the impact of flood flow on capacity of existing drains to discharge into the river system.

For carrying out the above study, a mathematical model of Gomti river from Gomti barrage to 6800 m upstream has been developed using the Army Corps of Engineer's (USACE) Hydrologic Engineering Center's (HEC) River Analysis System program (HEC-RAS) Version 4.1.0. The values of Manning's roughness coefficient were assigned to each cross section based on the surface characteristics of the river. Each cross-section was divided into main channel and flood plain. Five bridges namely Harding, Railway, Daliganj, Hanuman, and Nishatganj are located across the Gomti river at the chainage 6400, 5600, 5400, 3600, and 1700 m, respectively. Data pertaining to these bridges in respect of elevation of lower and upper chord, width of bridge, distance from upstream cross-section to deck, piers details, bridge modelling equation were entered into the bridge editor of the HEC RAS. Energy and Yarnell equations are used for the computation of losses through the bridge. Yang's relationship for the sediment transport was adopted while sediment sorting was carried out using Exner's formulation. Ruby's relationship was adopted for the computation of sediment fall velocity.

The developed HEC RAS model was run for the following conditions:

a) Calibration of model with the use of recorded water level and corresponding discharge in the month of August 2008 at various locations of the Gomti river. The calibrated value of Manning's coefficient for main channel and flood plain comes out 0.019 and 0.03, respectively for the best matching of computed water surface with the observed water level in August 2008.
b) To study the flood embankments on HFL, the model was run with flood embankments and the simulated HFL was compared with the recorded HFL in

year 1960 at different sections. The model was run under mobile bed condition of the river to study the aggradation & degradation behaviour.

c) To study the effect of reclamation of land on the HFL of Gomti river, the model was run with reclaimed land. The simulated HFL, average velocity, bed shear stress, and bed level changes were studied with and without reclamation of land for river front development.

The return period for the flood in the Gomti river for the river front development has been taken 100 years as per guidelines of IS 12094:2000. The maximum recorded discharge in Gomti river passing through Lucknow in the period 1923 to 1959 was 75000 cusecs, while the ever maximum recorded discharge is 125890 cusecs in the year 1960. The design flood discharge in Gomti river at barrage has been estimated 3654.81 m^3/s, while for Kukrail nala, the peak discharge is taken 425 m^3/s. The HFL at Gomti barrage for discharge equal to 3654.81 m^3/s is 111.6 m.

The available particle size gradation of bed materials of Gomti river from 0.5 to 2.5 m depths and locations Nishatganj, Bhaisakund, Kudiaghat & Hanuman Setu have been analysed. The average size of bed material is equal to 0.32 mm, which gives unity silt factor.

With the consideration of Lacey's perimeter and existing section of the Gomti river in the study reach, it is proposed to keep minimum width of Gomti river at its HFL equal to 250 m, however, at some locations, it is kept slightly less than 250 m in view of historical Monuments in the flood plain of the river as given in Table 4.

The simulated water surface profile with flood embankments has been compared with recorded HFL in year 1960 and found that if peak flood of magnitude 3564.81 m^3/s will pass through the river, the HFL shall be 1.25 m higher than the recorded HFL in year 1960 at chainage 6800 m. Affluxes due to Railway and Harding bridges are 0.30 m and 0.20 m, respectively. Such high affluxes are due to inadequate length of these bridges. Over the year, silting has occurred over the bed of the river and the bed level has gone up by 1.5 m compared to the bed level of the river in year 1960.

To study the effect of reclaimed land for river front development of Gomti river keeping width of river 250 m, the model was run for peak flood equal 3564.81m^3/s from chainage 0 to 500 m; 3139.81 m^3/s from the chainage 500 m to 6800 m; and water level at Chainage 0 equal to 111.6 m. Values of the hydraulic parameters like water surface, velocity, bed shear stress, river bed level were obtained.

Comparison of water surface profiles in the river reach from Chainage 0 to 6800 m without and with river front development keeping width of channel 250 m reveals that with proposed land reclamation for RFD does not change the water surface noticeably. A negative afflux of the order of 4 cm has been noted from chainage 6500 m to 6800 due to acceleration of flow on account of contraction in flow. However, positive afflux of the order of 3 cm has been observed from Chainage 3600 m to 6400 m.

Simulated velocity with land reclamation for RFD is higher than the velocity without RFD, however, such differences is practically negligible in major length of the Gomti river. An increase in velocity by 20% with RFD from Chainage 6500 m to 6800 m is attributed to the acceleration of flow.

The bed shear stress shall increase by 30% (approx.) in the reach from Chainage 6500 m to 6800 m with proposed river front development. This is conformal to the lowering of water level and increase in velocity in this reach. In the other reach of the river also, an increase in bed shear stress with RFD has been noticed. There shall be negligible morphological changes in the Gomti river under the river front development.

No construction work shall be carried out that protrudes towards to the river in its proposed width. Such protrusion should not be from the bed of the river as well. However, 25 m wide pucca promenades at natural surface level of the river may be developed along both the banks within the proposed width of the river. A width of 200 m of the river shall be kept mobile for facilitation of bed aggradation & degradation.

The land that can be reclaimed is indicated in the attached drawing, while in reaches from chainage 3200-3460 m and Chainage 1180-1580 m, land should be made available to the river for facilitation of flood water without any obstruction.

The top levels of the flood embankments are not adequate as the available free board is less than the required 1.5 m free board. The extent of raising the left and right banks to accomplish 1.5 m free board under design flood & river front development above the existing banks level are given in Table 4.

There are six hydraulic structures across the Gomti river in the reach under consideration for the river front development. These six structures are Gomti barrage, Nishatganj bridge, Hanuman bridge, Daliganj bridge, Railway bridge and Harding bridge. In view of changes in the hydraulic parameters of the Gomti river on account of river front development, the adequacy of the structures under changed hydraulic conditions has been checked.

The length of barrage from abutment to abutment is 202.60 m, however, under the river front development a width of river 250 m has been proposed upstream of the barrage. Thus there would not be any increase in the unit discharge of the river at the Gomti barrage. Further, the flow in the river is subcritical flow which results in no changes in water level at barrage due to envisage changes upstream of it. Also, no morphological changes on the Gomti river have been found due to river front development. In view of above points, it is clear that the river front development will not cause any damage to the Gomti barrage.

Adequacy of the existing five bridges across Gomti river upstream of the Gomti barrage have been evaluated from the scour consideration as per IRC:5-1998 and IRC:78-2000. Nishatganj and Daliganj bridges were found safe as their existing foundation is lower than the required founding level. However, such computation could not be carried out for Hanuman Setu due to unavailability of its general arrangement drawing.

The undersized length of Railway & Harding bridges has resulted in high unit discharge and high scour depth. The existing founding levels of the Railway & Harding bridges are at higher level compared to the required level thereby these bridges are unsafe from the scour considerations. The following measures may be taken up to safeguard these bridges:

(a) The length of the Railway and Harding bridges shall be increased by a suitable distance.
(b) Retrofitting shall be provided to control the scour near the bridge pier and abutment in the form of riprap, collar etc.

A detail study along with soil investigation at these bridge sites is required for carrying out the above measures.

There are sixteen drains/nalas that outfall into Gomti river in a reach from Gomti barrage to 6.8 km upstream of it. The HFL of these nalas at their outfall into Gomti river is higher than the HFL of Gomti river during flood, therefore, pumping stations are provided to pump the water from the nalas to Gomti river.

As such there is no significant difference in HFL of Gomti river in its reach under consideration due to river front development compared to the existing condition. Therefore, the impacts of river front development on the capacity of existing drains to discharge into the river system shall be negligible.

Date: 25 May 2013 **(Z. Ahmad)**
Place: Roorkee Professor of Civil Engineering

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1. BACKGROUND

Lucknow - The City of Nawabs and the capital of Uttar Pradesh State is situated on the banks of river Gomti that begins its journey from Fulhar Jheel in Madhotanda. After flowing through the districts of Shahjahanpur, Kheri, Lucknow, Barabanki, Sultanpur, Faizabad and Jaunpur, ultimately confluences with river Ganga near Varanasi. The cities, Lucknow, Sultanpur and Jaunpur are three major cities situated on its banks. The Gomti is a perennial alluvial river and characterized by sluggish flow throughout the year, except during the monsoon season, when heavy rainfall causes a manifold increase in the runoff. The average lean flow recorded in the month of April at Hanuman Setu is of the order 15 cumecs (Dutta et al. 2011). A barrage across the Gomti river was constructed near Gomti nagar for storage of water upstream of it.

Inspired by the river front development of Sabarmati rive in Ahmadabad city of Gujarat, the Lucknow Development Authority (LDA), Lucknow is planning to develop the river front of Gomti upstream of the barrage through utilisation of unused lands on both sides of the river for construction of public recreational facilities and beautification of the surroundings.

Vide letter No. 05/AA-PU3 dated 21.4.12, Er. S.N. Tripathi, Chief Engineer, LDA, Lucknow requested Prof. & Head, Department of Civil Engineering, IIT Roorkee for carrying out hydrological study of Gomti river in view of its river front development. Subsequently, the task of hydrological study was assigned to Prof. U. C. Kothyari, Dept. of Civil Eng., IIT Roorkee. Due to unfortunate demise of Prof. U.C. Kothyari in Dec. 2012, the task is now with Prof. Z. Ahmad of IIT Roorkee. A site visit was undertaken by Prof. Ahmad on January 16, 2013 to get apprised the ground reality.

This report provides the detailed hydrological study for the river front development of Gomti upstream of the barrage.

2. SCOPE OF WORK

The following scopes of work were mutually arrived at for carrying out the hydrological study of the Gomti river:

e) To reproduce the existing conditions of flood flow in river Gomti through mathematical modelling by utilising the hydrological and geometrical (cross-sections) and thus to calibrate the mathematical model for predicting the impact of bank developmental activities on river morphology.

f) To quantify the effect of proposed river front development measures on river high flood levels at different locations and thus determine the afflux caused due to these, if any.

g) To quantify the effect of proposed river front developmental measures on the existing major structures (bridge/barrage) in the river and thus to assess the adequacy of existing measures around the structures against river scour etc.

h) To assess the impact of flood flow on capacity of existing drains to discharge into the river system.

i) To quantify the effect of proposed river front development measures on the flood conditions impacting the other bank of the river (right bank).

The details of the study carried out are given in this report.

3. SITE VISIT

A visit to the Gomti river was made by the writer along with concerned officers from the LDA, Lucknow on January 19, 2013. The following points were noted during the site visit:

- The Gomti barrage is used only for ponding the water and not for diverting the flow into canal or drinking water. Drinking water to Lucknow is supplied through Sharda canal system.
- Consequent to the ever maximum flood in Gomti river in 1960, flood embankments were constructed along both the banks of the river up to 7 km

upstream of the barrage. The distance between these two embankments varies from 250 m to 450 m.

- The width of the Gomti river from Gomti barrage to 7 km upstream of it is varying. Gomti river has wide width between Kukrail nala to Nishat ganj bridge; Hanuman setu to Daligang bridge; and upstream of the Railway Bridge. In these reaches, land can be reclaimed for the commercial development. However for other reaches of river up to 7 km upstream of the barrage only promenades can be developed as a part of the river front development.
- The Gomti river has narrow cross-section downstream of the Hanuman setu particularly near the Mohit Mahal, where river has been encroached from its right bank.
- There are five bridges on Gomti river from Gomti barrage to 7 km upstream of it. These brides are Nishantganj bridge, Hanuman setu, Daligang bridge, Railway bridge, and Harding bridge. The length of Railway and Harding bridges from abutment to abutment is short compared to other bridges.
- Nalas that discharge into Gomti river upstream of the barrage are provided with the pumping station, which pump the storm water into Gomti river during the flood once the HFL of Gomti river is higher than the HFL of the nalas. However, such pumping is not required in non-monsoon period.
- Kukrail is the major nala that joins the Gomti river from its left bank at about 0.5 km upstream of the barrage. The maximum flood in the Kukrail is of the order of 425 m^3/s. Flow from Kukrail nala join Gomti river through gravity and not being pumped like other nallas. A STP plant is constructed on the right bank of the Kukrail nala for treatment of sewage.
- As such, there are no slum encroachments on its banks from the barrage to 7 km upstream; however, localized encroachment in form of pucca structure protruding in the deeper channel of the river was noticed at Saheed Smarak.

Photographs taken during the site visits are shown in Figs. 1a-e below:

Figure 1a Gomti barrage

Figure 1b Nishatganj Bridge on river Gomti

Figure 1c Shaheed Smarak

Figure 1d Left bank of Gomti river near Shaheed Smarak

Figure 1e Kukrail nala upstream of its confluence with Gomti river

4. AVAILABLE DATA

The following data were made available by the project authorities.

(a) Toposheet of the Gomti river from Kudiaghat to Gomti Barrage including bridges across the river and other structures in vicinity of the river.

(b) Cross-section of the Gomti river from Chainage 0 (Gomti barrage) to 68000 m upstream at interval of 200 m.

(c) L-section of Gomti river from Chainage 0 (Gomti barrage) to 6800 m.

(d) Name of bridges and their length from one abutment to other along with their location.

(e) GAD of the Nishatganj Bridge, Dalignj Bridge, Railway Bridge, and Harding Bridge.

(f) Details of Hanuman Bridge in terms of water way, lower and upper crown levels, shape and sizes of piers etc.

(g) Yearly peak discharge and corresponding HFL at Hanuman Bridge in period 1969-2010. Maximum recorded discharge in Gomti river in period 1923 to 1959 is 75000 cusecs. The ever maximum discharge equal to 125890 cusecs was recorded in year 1960.

(h) Recorded daily maximum water level at Nimsar, Bhatpurwa, Gaughat, Hanuman Setu, Gomti Barrage in the month of August of year 2008.

(i) Recorded HFL, river bed level, top levels of both the banks, and average width of river from Chainage 0 to Chainage 6370 m. The bed level of river as in year 1960.

(j) Details of drains joining the Gomti river at its different chainages.

(k) Particle size gradation of bed material of Gomti river from different depths & locations.

5. METHODOLOGY

For carrying out the hydrological study of river front development of Gomti, the following methodologies have been adopted:

1. The design peak discharge and HFL in the Gomti river shall be estimated from the available discharge and HFL data.
2. A mathematical model of Gomti river from Gomti barrage to 6.8 km upstream shall be developed with the use of geometrical data of the river and estimated peak discharge and corresponding HFL at Barrage using HEC River analysis system (RAS).
3. The developed HEC RAS model shall be run for the following conditions:

   (a) With the use of recorded water level and corresponding discharge in the month of August of year 2008 at various locations of the Gomti river, the developed model shall be calibrated. The water level at various locations shall be computed using the HEC RAS model for an assumed Manning's coefficient and the computed water surface shall be compared with the observed water level. Those Manning coefficients shall be considered for further analysis which produces water surface profile that matches well with the observed water level.

   (b) The model shall also be run for estimated design flood with existing sections of river, i.e., with both flood embankments and the water surface profile shall be compared with the recorded HFL in year 1960 at different sections. It is to be noted that the flood embankments were constructed after the flood of year 1960. This run will reveal the effect of flood embankments on HFL. The model shall be run under mobile bed condition of the river to study the aggradation & degradation behaviour.

(c) The model shall also be run for estimated design flood with reclaimed land and the water surface profile shall be compared with the simulated HFL for design discharge without reclaimed land to study the effect of reclamation of land on the HFL of Gomti river. In addition to HFL; average velocity, bed shear stress, and bed level changes shall also be studied with and without reclamation of land for river front development.

4. The safety of the existing bridges across Gomti river in the study reach shall be checked from the scour consideration as per relevant IRC codes.
5. Assessment of impact of river front development on discharging capacity of the existing drains out falling into Gomti river shall be carried out by knowing the HFL and peak discharges of these drains and simulated HFL in the Gomti river under river front development.
6. Inundation in upstream area of Gomti barrage due to generated afflux in Gomti river under river front development shall be studied.

6. ESTIMATION OF DESIGN FLOOD & HFL

For the design of flood protection embankments, the HFL is fixed on the basis of flood frequency analysis. As per IS 12094:2000, a flood of 25 years frequency in case of predominantly agricultural area is considered for the design of flood embankments, while 100 years flood is taken if the concerned embankments are to protect townships, industrial areas or other places of strategic and vital importance. Thus in the present case, the return period for the flood for the river banks development of Gomti river at Lucknow has to be taken 100 years in view of protection of Lucknow township.

The maximum recorded discharge in Gomti river passing through Lucknow in the period 1923 to 1959 is 75000 cusecs, while the ever maximum recorded discharge is 125890 cusecs in the year 1960. This discharge had created a lot of problems for the

Lucknow city. Subsequently, flood protection works in form of embankments were constructed along both the banks of river upstream of the Gomti barrage.

The annual maximum flood, recorded at Hanuman Setu gauge site by Central Flood Forecasting Unit of C.W.C, are available from 1969 to 2011 and given in Table 1. During the period 1969 to 2011, the maximum annual flood = 3085 m^3/s was recorded on 11.09.1971 (Fig. 2).

Table 1 Annual maximum recorded flood at Hanuman Setu

Year	Maximum gauge at Gaughat (m)	Date of maximum discharge	Gauge at D/S of Hanuman Setu (m)	Discharge (cumecs)	Discharge (cusecs)
1969		03.10.69	106.575	568.190	19865
1970		01.09.70	107.585	583.480	20581
1971	112.49	11.09.71	110.850	3085.000	107053
1972		16.09.72	106.496	433.760	16710
1973		11.10.73	107.072	648.840	22880
1974		12.08.74	106.405	436.490	15396
1975		10.08.75	107.018	613.000	21622
1976		26.08.76	107.315	712.290	25124
1977		27.08.77	106.603	479.950	16929
1978		14.09.78	106.845	646.640	19281
1979		25.07.79	105.730	129.060	4584
1980	110.61	26.07.80	109.305	1816.790	64880
1981	108.00	03.10.81	107.745	595.330	21015
1982	109.92	07.09.82	108.640	1311.610	48771
1983	108.54	29.09.83	107.330	988.830	34920.2
1984	106.08	04.09.84	105.380	229.960	8117
1985	110.88	20.09.85	109.780	2106.540	74361
1986	106.10	25.08.86	105.500	249.240	8807
1987	106.80	04.09.87	105.640	265.000	9364
1988	107.69	31.08.88	106.390	415.000	14664
1989	106.88	22.08.89	105.610	262.000	9258
1990	107.35	22.08.90	106.060	506.460	17896
1991	107.14	12.09.91	105.880	406.640	14369
1992	105.44	16.09.92	105.460	290.060	10249
1993	105.67	28.09.93	105.285	83.720	2958
1994	106.80	01.09.94	104.490	201.090	7106
1995	106.65	15.09.95	105.135	364.170	12868
1996	106.30	04.09.96	106.040	262.100	9252
1997	107.59	19.09.97	105.210	382.430	13500
1998	108.17	10.09.98	107.020	612.000	21600
1999	106.04	05.09.99	105.480	246.740	8710
2000	106.76	13.09.00	105.490	248.030	8758
2001	106.22	19.08.01	105.810	247.010	8722

2002	106.38	18.09.02	105.040	305.560	10786
2003	108.23	29.09.03	107.430	752.000	26560
2004	108.14	30.09.04	106.900	649.200	22917
2005	105.95	22.09.05	105.680	267.100	9429
2006	109.50	19.06.06	106.290	434.300	15331
2007	109.16	05.09.07	105.640	265.000	9355
2008	110.00	29.08.08	109.010	986.000	34805.80
2009	108.05	17.10.09	106.700	585.520	20668.85
2010	107.65	28.09.10	106.310	416.000	14684.80
2011	107.5	28.09.11	106.100	510.450	18018.80

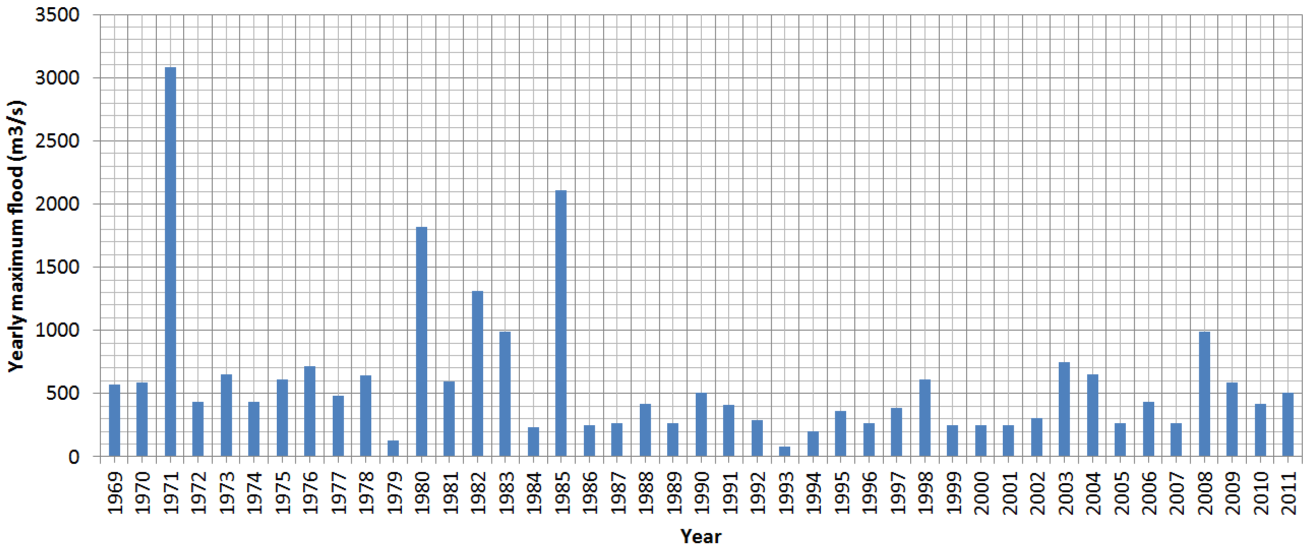

Figure 2 Annual maximum recorded flood at Hanuman setu in period 1969 to 2011

The Gomti barrage was designed for flood discharge of 4252 m^3/s. Other salient points of Gomti Barrage are

Catchment area	= 8725 km^2 (3408 Sq Mile)
Design discharge	= 4252 m^3/s (150000 cusecs)
High flood level	= 111.60 m (in 1960)
Pond level	= 105.50 m
Top of abutment	= 114.40 m
Sill level	= 100.80 m
Number of span	= 10 Nos.
Width of each span	= 18.00 m
Size of gate	= 18.00 × 4.95 m
Abutment to abutment width	= 202.50 m
Silt factor	= 1

During the period 1923 to 2012, the ever maximum recorded flood was 3564.81 m^3/s (125890 cusecs) in year 1960 and corresponding HFL at Gomti Barrage was 111.6 m.

Thus flood in Gomti river equal to 3564.81 m^3/s has return period more than 90 years, which is comparable to 100 years requirement of the IS code for the flood embankment works. Therefore, the flood = 3564.81 m^3/s is considered as design discharge for the river front development. The HFL at Gomti barrage corresponding to design discharge 3564.81 m^3/s is taken 111.6 m.

7. ESTIMATION OF SILT FACTOR

Particle size gradation of bed materials of Gomti river from 0.5 to 2.5 m depths and locations Nishatganj, Bhaisakund, Kudiaghat & Hanuman Setu are given Table 2. The average size distribution of river bed material up to a depth of 2.5 m below the bed is shown in Fig. 3. Silty-clayey soil is available on the surface of river bed, however, at depth more than one meter the soil is sandy soil. Table 2 reveals that the particle size varies from 0.075 mm to 0.425 mm. However, it likely that particle size shall be more at higher depths. Therefore, the depth averaged size of the river bed material may be taken equal to 0.32 mm.

Silt factor = $1.76\sqrt{d}$ for bed material size d =0.32 mm

f =1.0

Thus, a silt factor equal to unity shall be used to check the adequacy of foundation level of the existing bridges on Gomti river from scour consideration. It is to be noted that the Gomti barrage is also designed for unity silt factor.

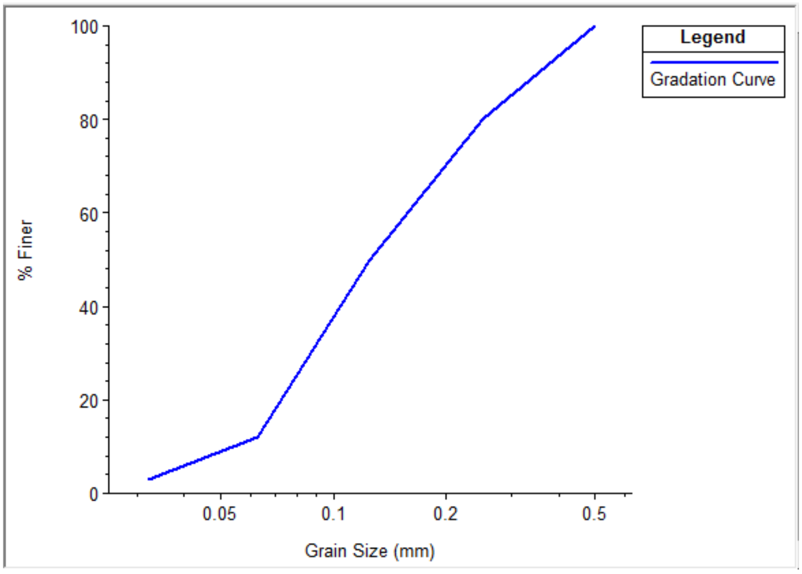

Figure 3 Particle size distribution of river bed material

Table 2 Sub soil data of Gomti river at Lucknow

(a) SITE: Sub Soil Investigation at Nishant Ganj, Gomti River Lucknow.

Bore Hole No: 1

SI. No		Depth (m)	% Material passing on I.S Sieves				Atterberg's Limit		
		below	4.75	2.00	0.425	0.075	L.L	P.L	P.I
		G.L.	mm	mm	mm	mm	%	%	
1		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		0.50	100	100	98	22	Non - Plastic		
2		1.00	100	100	99	15	Non - Plastic		
3		1.50	100	100	99	11	Non - Plastic		
4		2.00	100	100	99	10	Non - Plastic		
5		2.50	100	100	99	9	Non - Plastic		

(b) SITE: Sub Soil Investigation at Bhaisa Kund, Gomti River Lucknow

Bore Hole No: 2

SI. No		Depth (m)	% Material passing on I.S Sieves				Atterberg's Limit		
		below	4.75	2.00	0.425	0.075	L.L	P.L	P.I
		G.L.	mm	mm	mm	mm	%	%	
1		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		0.50	100	100	99	61	28	22	6
2		1.00	100	100	99	55	27	22	5
3		1.50	100	100	99	8	Non - Plastic		
4		2.00	100	100	99	7	Non - Plastic		
5		2.50	100	100	99	6	Non - Plastic		

(c) SITE: Sub Soil Investigation at Kudia Ghat, Gomti River Lucknow

Bore Hole No: 3

SI. No		Depth (m)	% Material passing on I.S Sieves				Atterberg's Limit		
		below	4.75	2.00	0.425	0.075	L.L	P.L	P.I
		G.L.	mm	mm	mm	mm	%	%	
1		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		0.50	100	99	98	69	26	21	5
2		1.00	100	100	99	45	Non - Plastic		
3		1.50	100	100	99	21	Non - Plastic		
4		2.00	100	100	99	12	Non - Plastic		
5		2.50	100	100	99	11	Non - Plastic		

(d) SITE: Sub Soil Investigation at Hanuman Setu, Gomti River Lucknow

Bore Hole No: 4

SI. No		Depth (m)	% Material passing on I.S Sieves				Atterberg's Limit		
		below	4.75	2.00	0.425	0.075	L.L	P.L	P.I
		G.L.	mm	mm	mm	mm	%	%	
1		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		0.50	100	100	98	15	Non - Plastic		
2		1.00	100	100	99	14	Non - Plastic		
3		1.50	100	100	98	12	Non - Plastic		
4		2.00	100	100	99	10	Non - Plastic		
5		2.50	100	100	99	9	Non - Plastic		

8. OVERVIEW OF HEC RAS

The HEC-RAS software was developed at the Hydrologic Engineering Center (HEC), which is a division of the Institute for Water Resources (IWR), U.S. Army Corps of Engineers. The HEC RAS is widely used worldwide to perform one-dimensional steady and unsteady flow river hydraulics calculations. The HEC-RAS system contains four one-dimensional river analysis components i.e., (a) steady flow water surface profile computations; (b) unsteady flow simulation; (c) movable boundary sediment transport computations; (d) water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

The version 4.1.0 of HEC-RAS updated in January 2010 is being used for modeling in the present study as it supports steady, quasi-unsteady and unsteady flow water surface profile calculations and sediment transport/ mobile bed computations simultaneously.

The steady flow water surface profiles component of the modelling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a single river each, a dendritic system, or a full network channels. The steady flow components are capable of modelling subcritical, supercritical, and mixed flow regime water surface profiles. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied like in bridges.

Water surafec profiles are computed from one cross section to the next by solving the energy equation with an interative procedure called the standard step method. The energy eqaution is written as follows for flow from cross-section 2 to 1:

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \tag{1}$$

Where Z_1, Z_2 = elevation of inverts of the main channel at sections 1 & 2, respectively

Y_1, Y_2 = Depth of flow at sections 1 & 2, respectively

V_1, V_2 = Average velocities at at sections 1 & 2, respectively

α_1, α_2 = Energy correction factors at sections 1 & 2, respectively

g = gravitational acceleration

h_e = energy head loss

The energy head loss (h_e) between two cross sections is comprised of friction losses and contraction or expansion losses. The equation for the energy head loss is as follows:

$$h_e = L\bar{S}_f + C\left|\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g}\right| \quad (2)$$

Where L = Reach length

$\bar{S}_f$ = representative friction slope between two sections

C = expansion or contraction loss coefficient

The data needed to perform steady flow analysis can be separated into geometric data and steady flow data (boundary conditions). The basic geometric data consists of establishing how the various river reaches are connected; cross section data; reach lengths; energy loss coefficients (friction losses, contraction and expansion losses); and stream junction information.

Data pertaining to bridges, culverts, etc. are also required to model such type of structures. The river system schematic is developed by drawing and connecting the various reaches of the system within the geometric data editor. Cross sections should be perpendicular to the anticipated flow lines and extend across the entire flood plain. Cross sections are requires at locations where changes occur in discharge, slope, shape or roughness; at locations where levees begin or end and at bridges or control structures such as weirs. The cross section is described by entering the station and elevations from left to right, with respect to looking downstream direction.

The value of Manning's roughness coefficient *n* depends on several factors like surface roughness; vegetation; channel irregularities; channel alignment etc. Three values of *n* can be assigned to each cross-section in HEC RAS. Contraction or expansion of flow due to changes in the cross section is a cause of energy loss between cross sections. The loss is computed from the contraction and expansion coefficients specified on the cross section data editor. Boundary conditions are necessary to establish the starting water surface elevations (WS) at the ends of the river system. The WS is only necessary at the downstream end for subcritical regime, while it is necessary at the upstream end for the supercritical regime, and the WS is necessary for both downstream and upstream for the mixed flow regime. Discharge information is required at each cross section starting from upstream to downstream for each reach. The discharge can be changed at any cross section within a reach.

The sediment transport component of the modeling system is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from bed aggradation and degradation over moderate time periods; typically days, months or years. Applications to single flood events are also possible.

The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring, if the case be.

The model is designed to simulate long-term trends of aggradation and degradation in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. The sediment module works with quasi-unsteady flow. The quasi-unsteady flow assumption approximates a continuous hydrograph with series of discrete steady flow profiles. For each record in the flow series, flow remains constant over a specified time window for sediment transport computations.

9. MODEL DEVELOPMENT

This section provides a description of the development of a hydraulic mathematical model for the Gomti river from Gomti barrage to 6.8 km upstream. The hydraulic modeling was performed using the Army Corps of Engineer's (USACE) Hydrologic Engineering Center's (HEC) River Analysis System program (HEC-RAS) Version 4.1.0. The first step in developing the HEC-RAS model was to create a HEC-RAS geometry file containing the stream network, cross sections and channel and overbank downstream reach lengths.

(a) Stream network

Lucknow Development Authority, Lucknow has proposed to develop the river front of Gomti river from Gomti barrage to upstream of Harding (Pucca) bridge in form of landscapes, park, ghats, commercial development, promenades etc. Therefore, 6800 m long reach of Gomti river from Gomti barrage to upstream of the Harding bridge has been modelled in HEC RAS as shown in Fig. 4.

The available cross-sections of the Gomti river at its different changes are shown in the Figs. 5 (a-e). These cross-sections from chainage 0 to 6800 m are modelled in this study. The reach lengths are provided in the cross-section editor file of HEC RAS. The main channel and flood plain is separated by markers as can be seen in Fig. 6.

The values of Manning's roughness coefficient n were assigned to each cross section based on the surface characteristics of the river. Each cross-section was divided into main channel and flood plain. Initially, based on the surface characteristics the main channel was assigned a Manning's coefficient 0.025 and flood plain 0.03 (Chow 1959). However, these Manning's coefficients were moderated for best matching of simulated and observed water surface profile.

The expansion and contraction coefficients were estimated based on the ratio of expansion and contraction of the flow area in the floodplain occurring at cross sections and at roadway crossings. Considering the gradual expansion and contraction, the expansion and contraction coefficients adopted at each cross-section were 0.3 and 0.1, respectively.

(b) Bridges Modelling

HEC-RAS requires four cross sections to be entered to model a bridge. The four cross sections include a downstream cross section where flow is fully expanded, a cross section at the downstream face of the structure, a cross section at the upstream face of the structure, and an upstream cross section prior to flow contraction. Five bridges built across Gomti river from Gomti barrage to 6.8 km upstream of it were modelled in this study. These bridges are Harding, Railway, Daliganj, Hanuman, and Nishatganj and located at chainages 6400, 5600, 5400, 3600, and 1700 m, respectively. Data pertaining to the above mentioned bridges in respect of elevation of lower and upper chord, width of bridge, distance from upstream cross-section to deck, piers details, bridge modelling equation were entered into the bridge editor of the HEC RAS. Figs. 7a-e shows modelled Harding, Railway, Daliganj, Hanuman, and Nishatganj bridges. Energy and Yarnell equations are used for the computation of losses through the bridge.

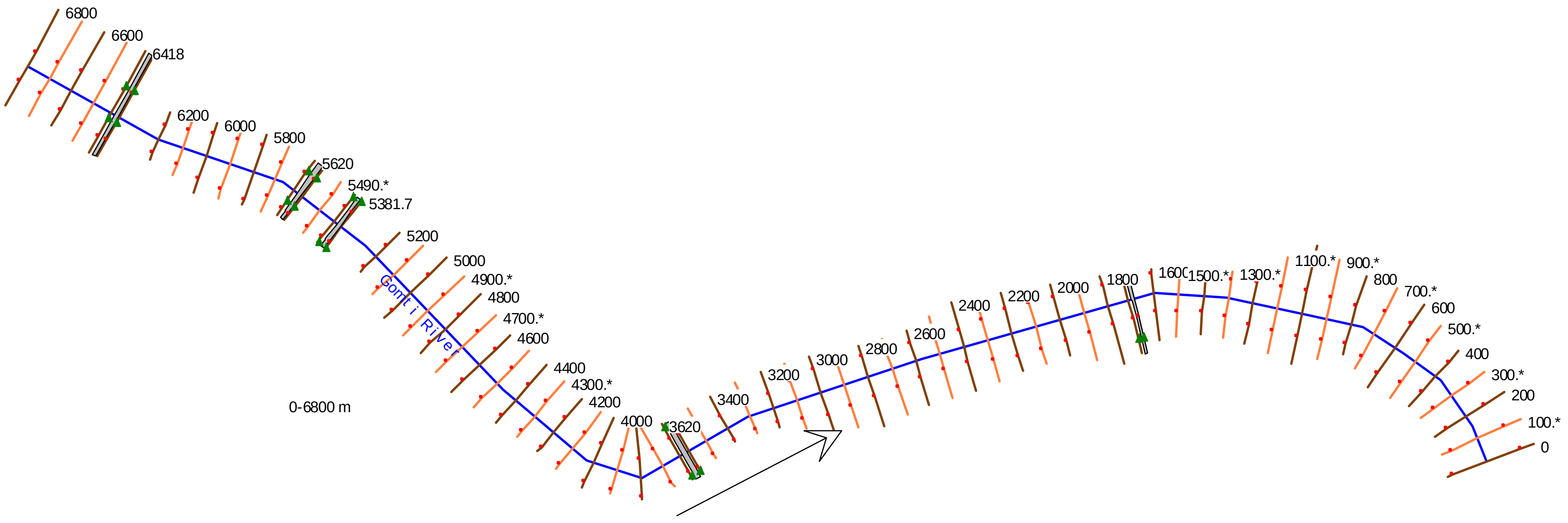

Figure 4 Simulated reach of Gomti river from chainage 0 (Gomti barrage) to 6800 m upstream

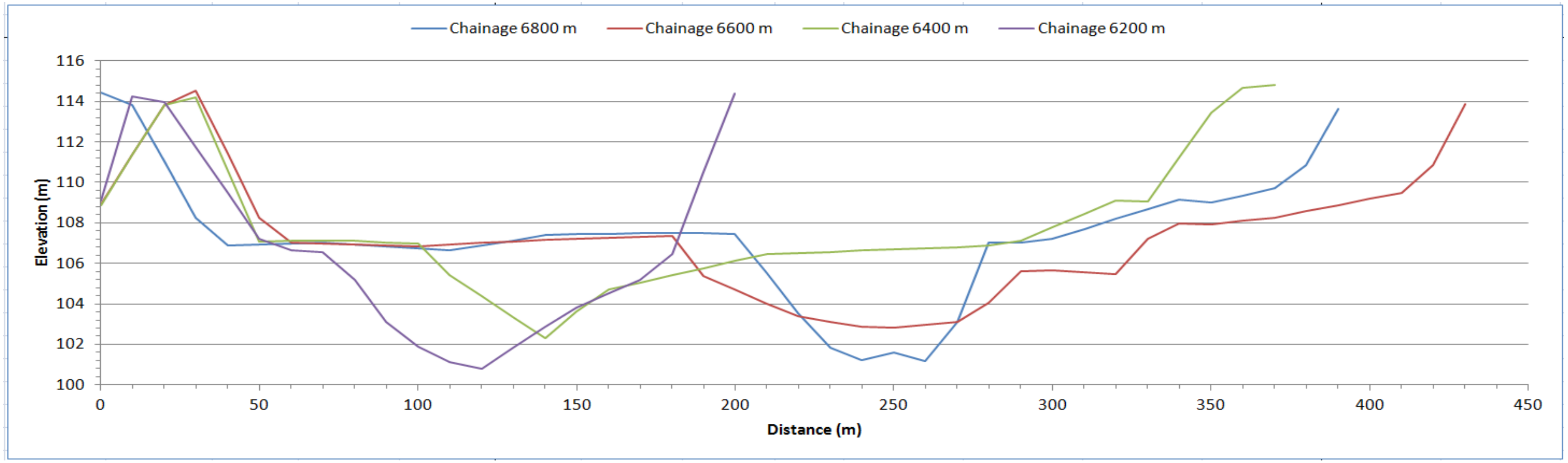

Figure 5a Cross-sections of Gomti river from chainage 6200 to 6800 m

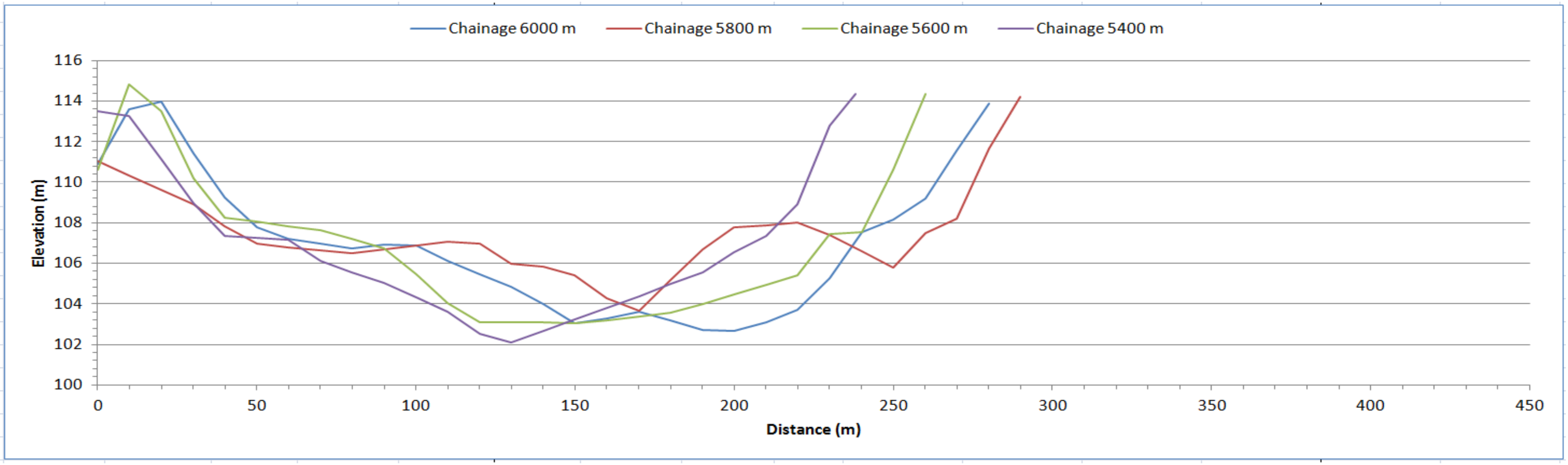

Figure 5b Cross-sections of Gomti river from chainage 5400 to 6000 m

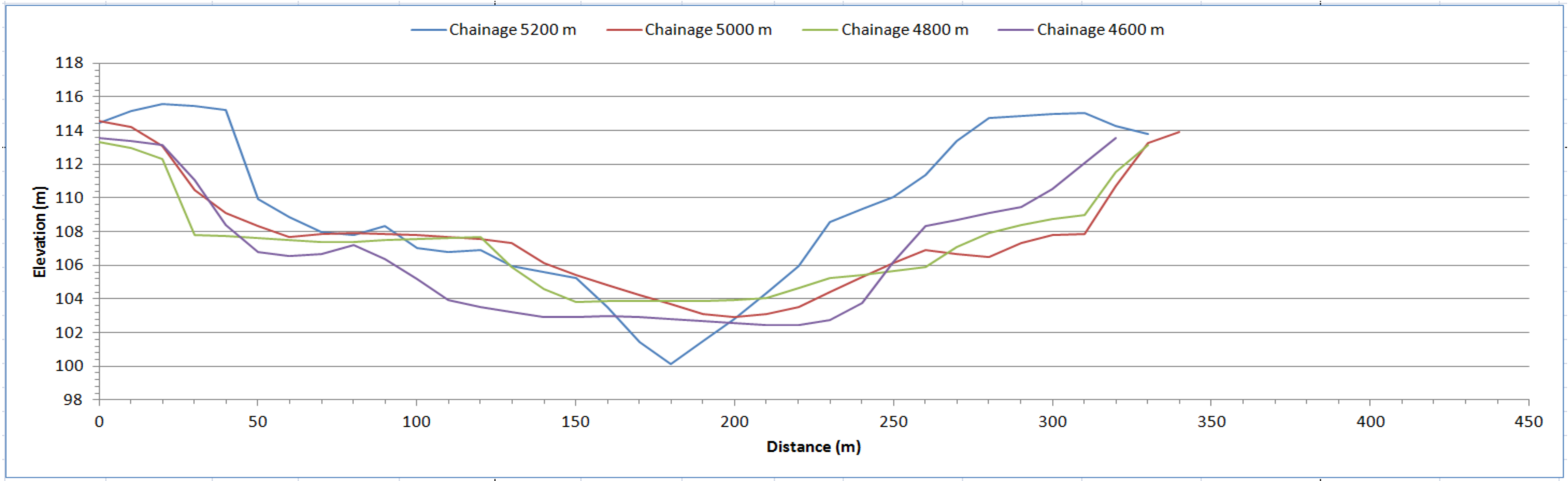

Figure 5c Cross-sections of Gomti river from chainage 4600 to 5200 m

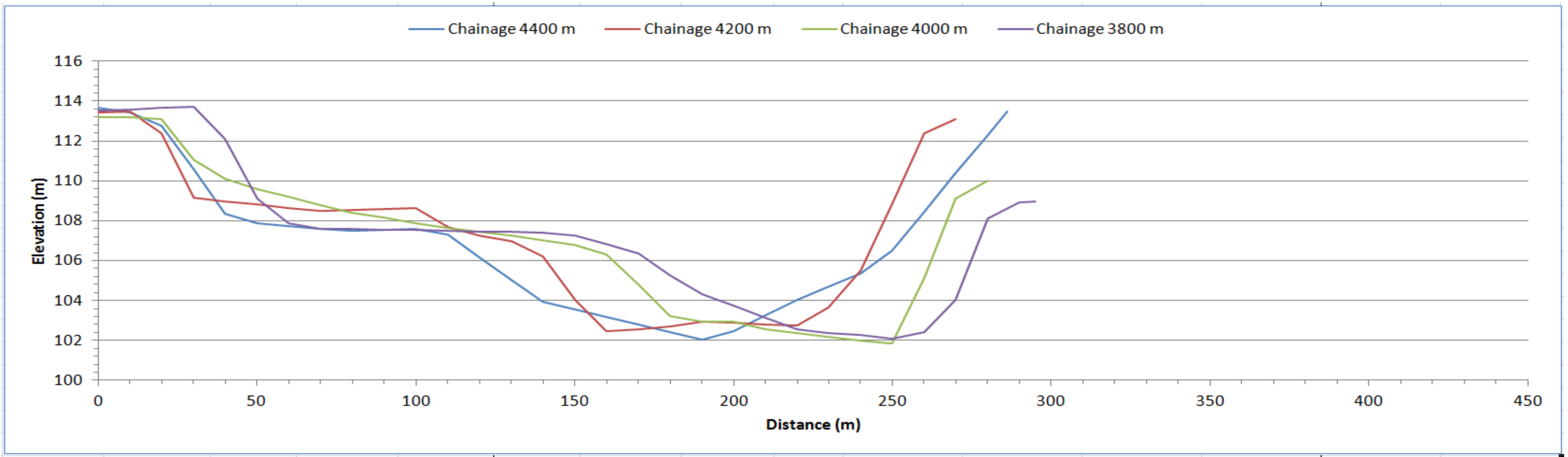

Figure 5d Cross-sections of Gomti river from chainage 3800 to 4400 m

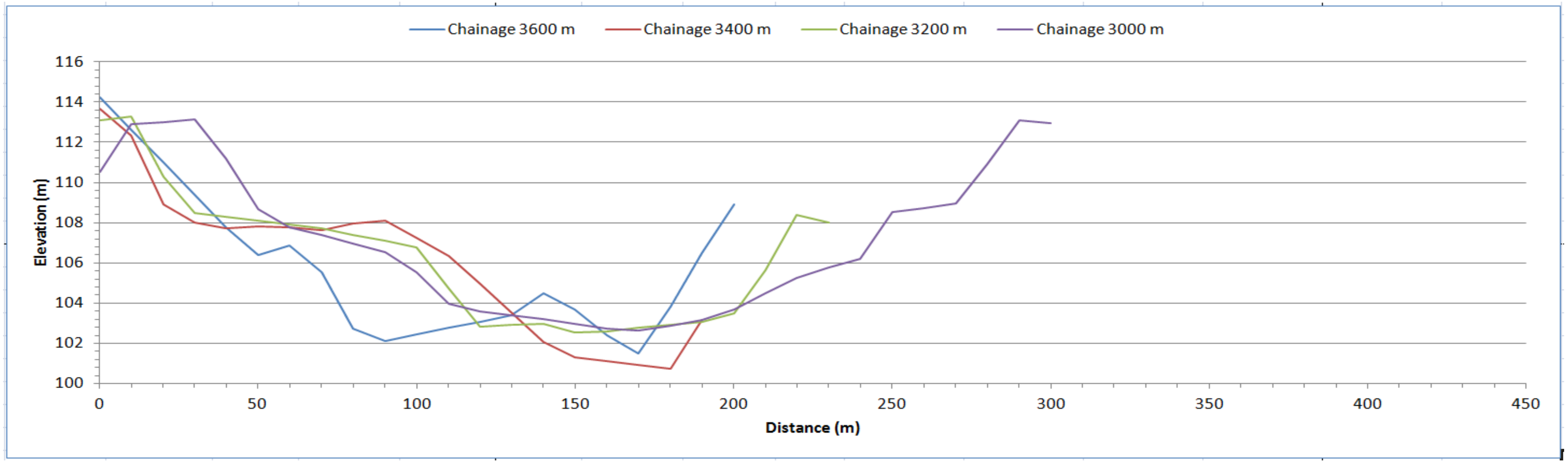

Figure 5e Cross-sections of Gomti river from chainage 3000 to 3600 m

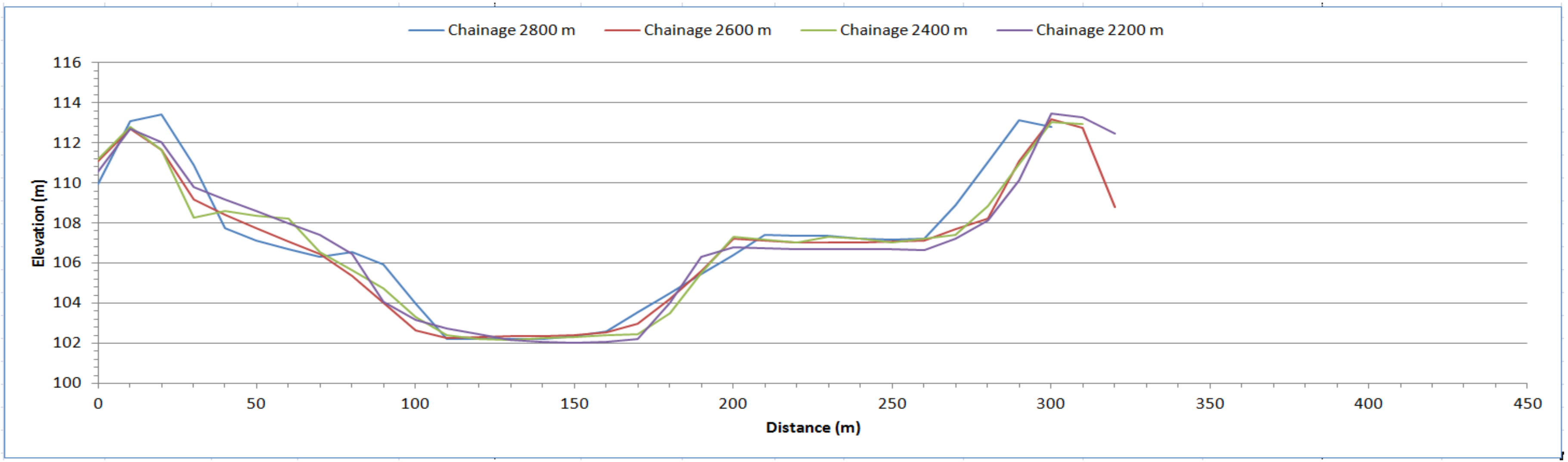

Figure 5f Cross-sections of Gomti river from chainage 2200 to 2800 m

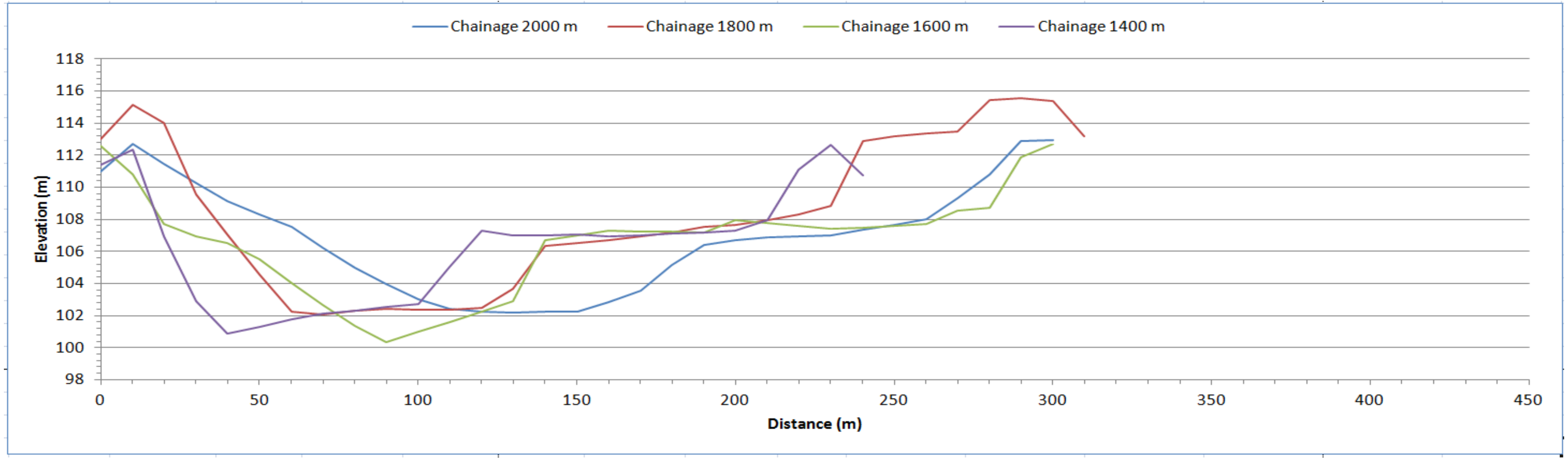

Figure 5g Cross-sections of Gomti river from chainage 1400 to 2000 m

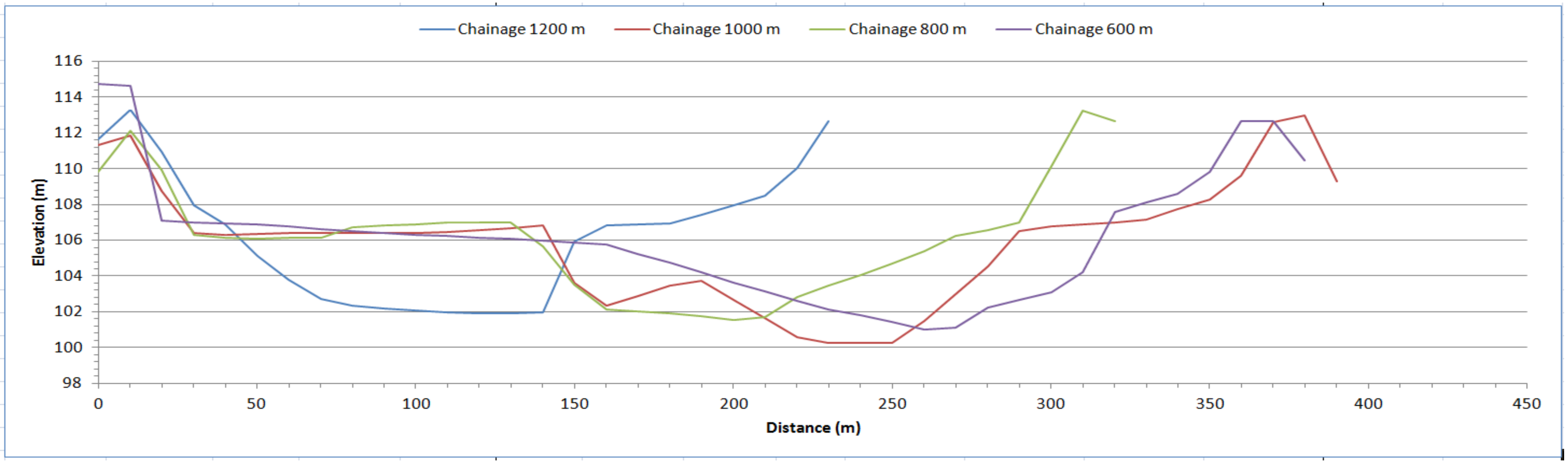

Figure 5h Cross-sections of Gomti river from chainage 600 to 1200 m

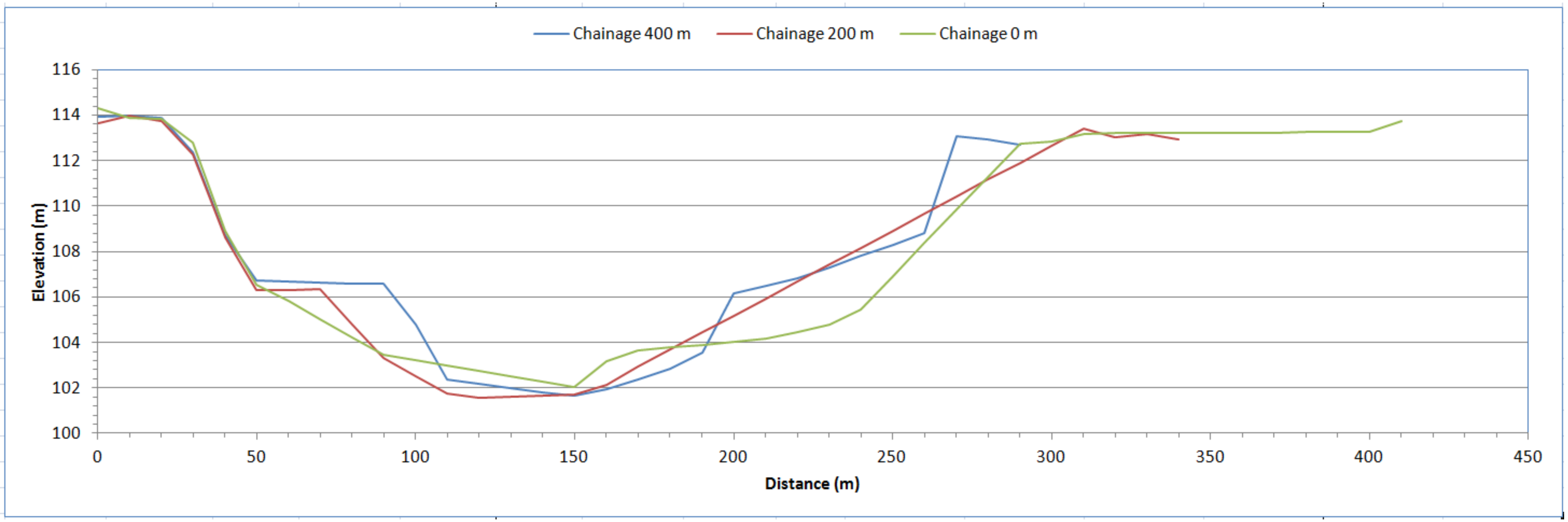

Figure 5i Cross-sections of Gomti river from chainage 0 to 400 m

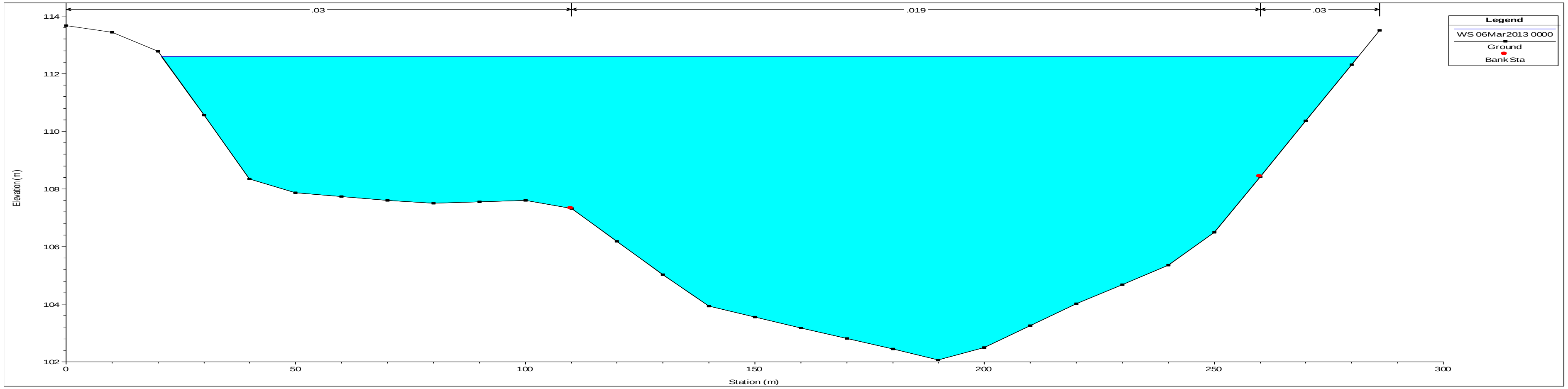

Figure 6 Modelled cross-section of Gomti river at chainage 4400 m in HEC RAS

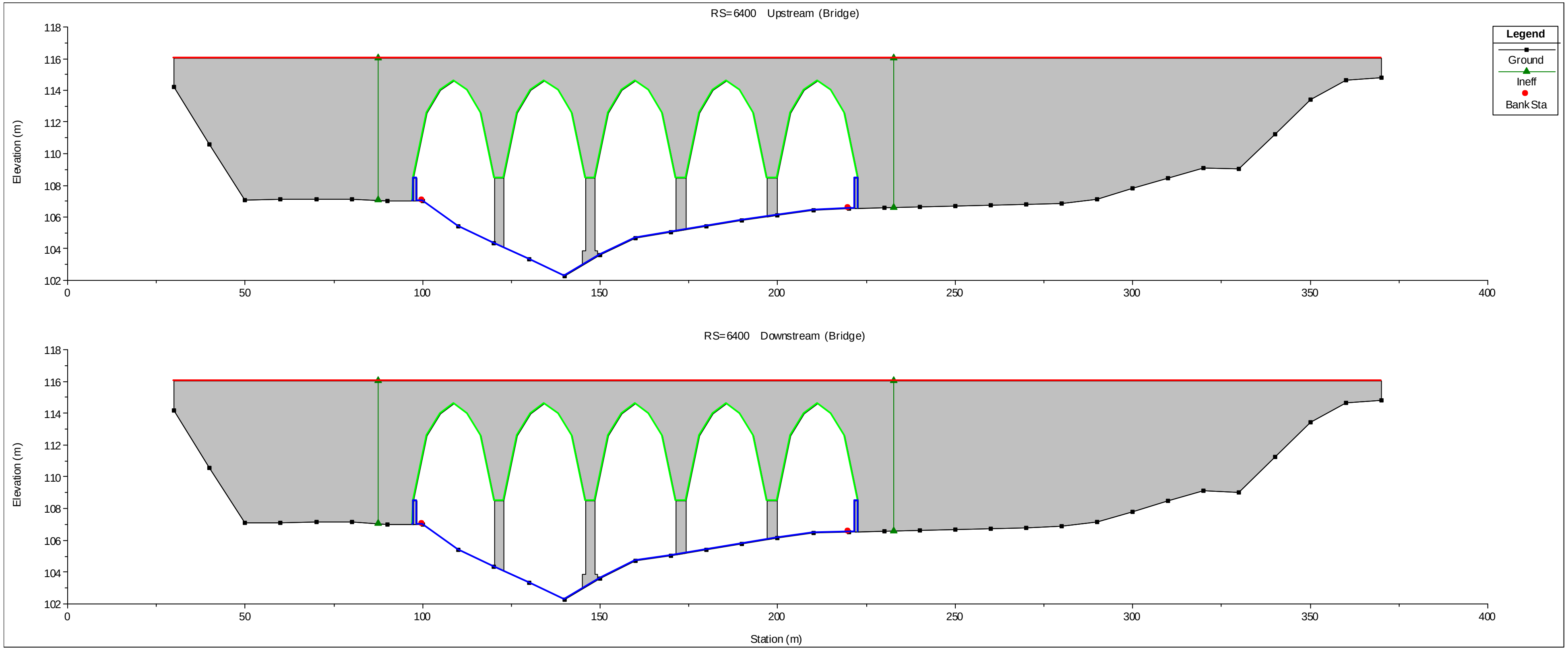

Figure 7a Modelled Harding bridge at Chainage 6400 m

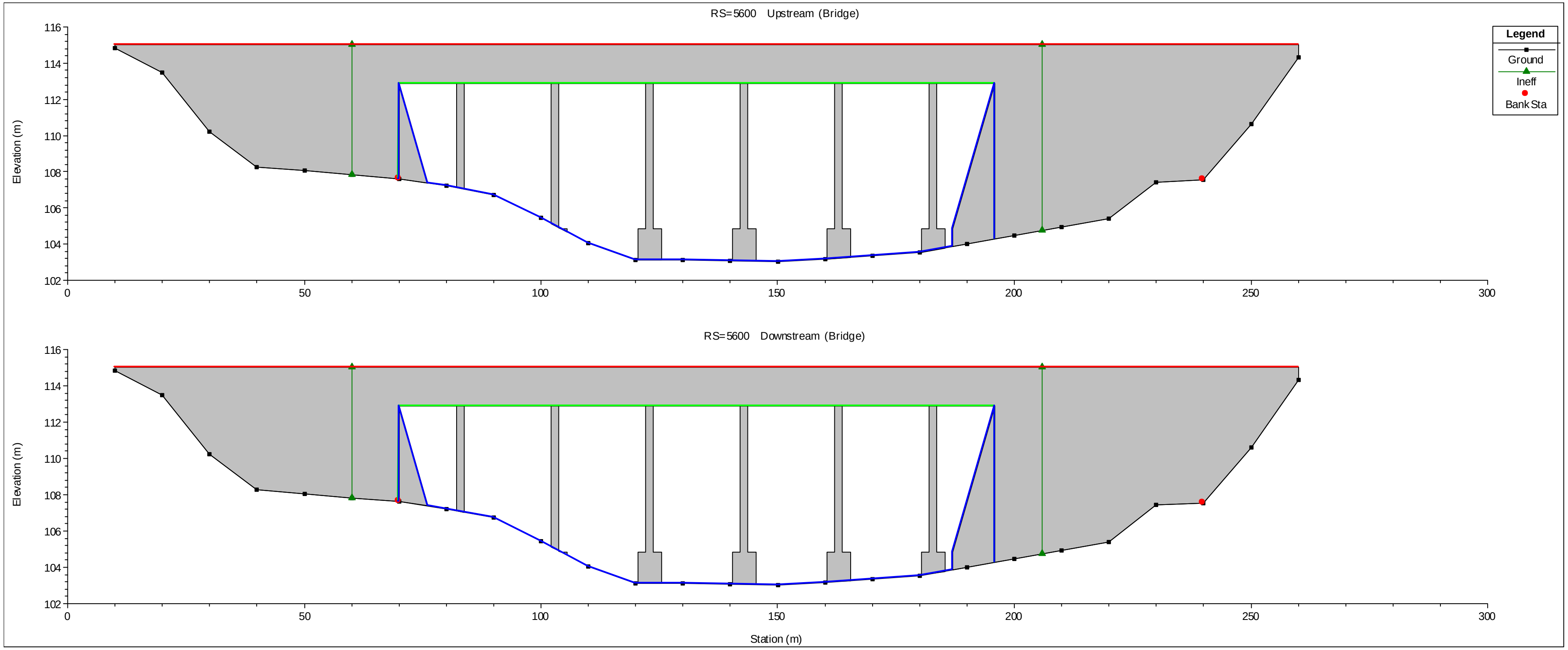

Figure 7b Modelled Railway bridge at Chainage 5600 m

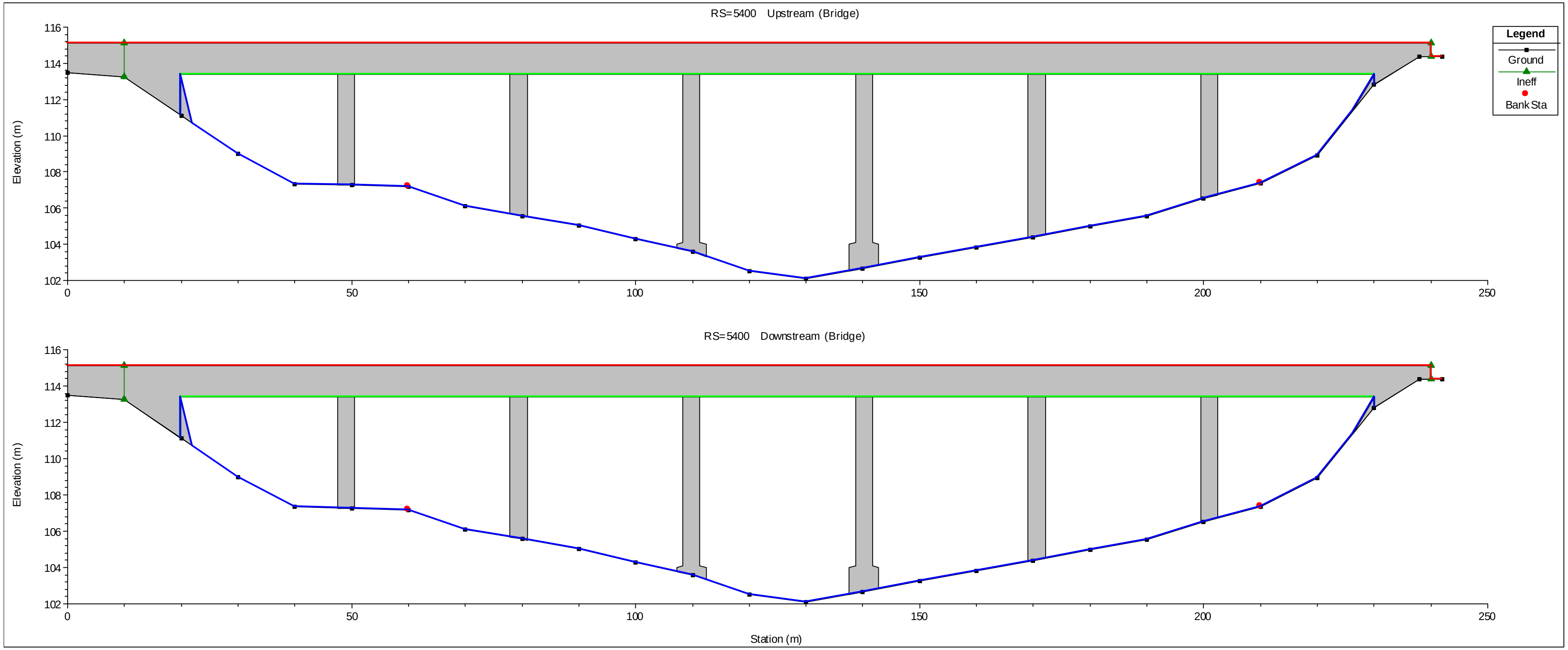

Figure 7c Modelled Daliganj Bridge at chainage 5400 m

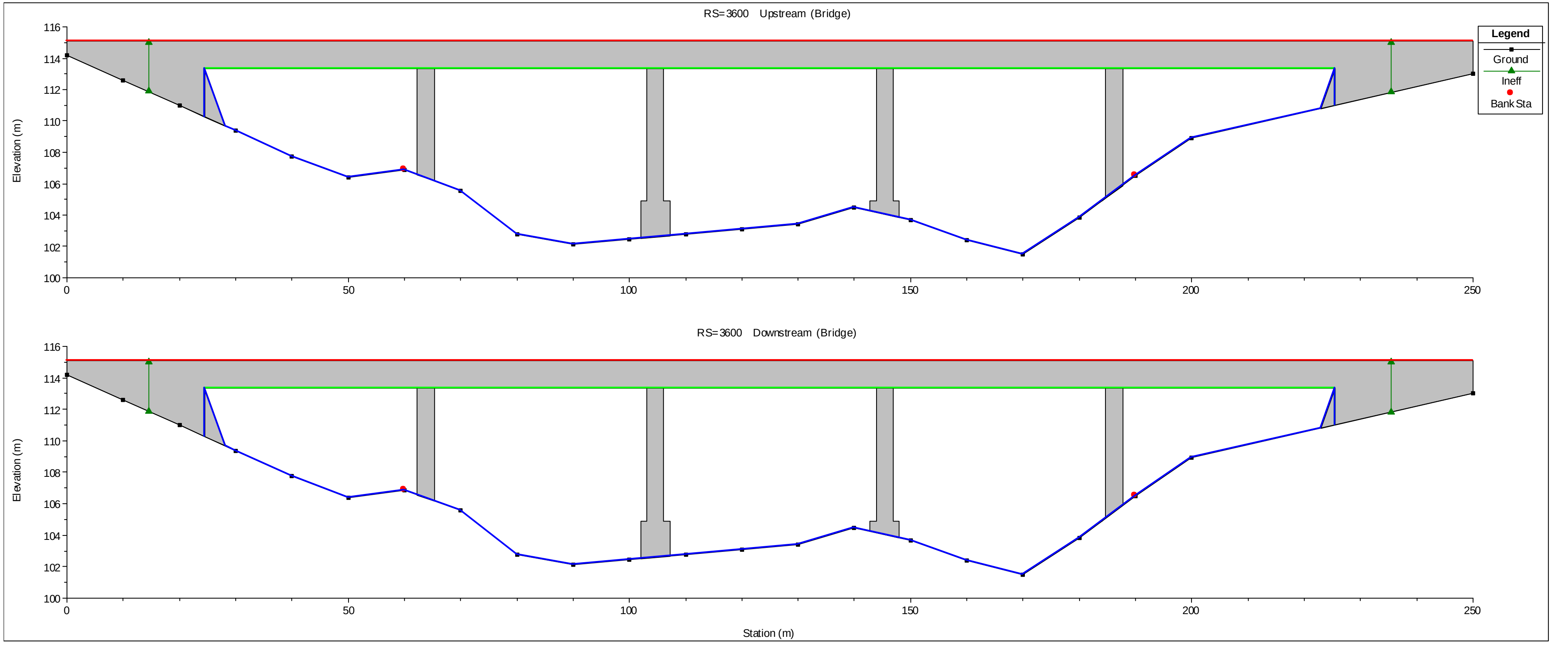

Figure 7d Modelled Hanuman Bridge at Chainage 3600 m

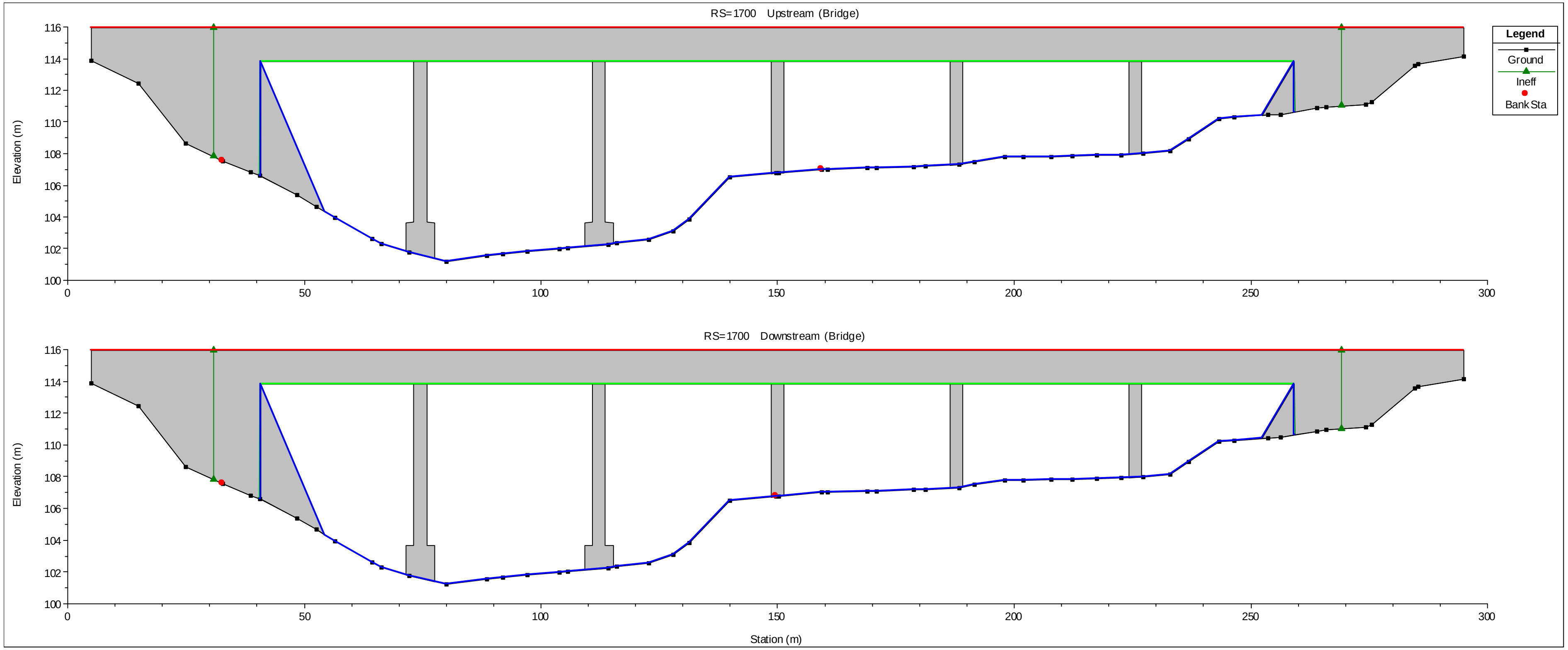

Figure 7e Modelled Nishatganj Bridge at Chainage 1700 m

10. MODEL CALIBRATION

The developed model is calibrated by choosing the value of Manning's coefficient n that reproduces water surface profile observed in the past during passage of the peak flood. The recorded daily maximum water levels of Gomti River at Nimsar, Bhatpurwa, Gaughat, Hanuman Setu and Gomti barrage are available for the month of August, 2008. The maximum flood in the August 2008 was recorded equal to 1190 cumecs at the Gomti Barrage on 29 August, 2008. The recorded water levels at different locations for maximum recorded flood on August 29, 2008 are as follow:

Location	Recorded Water Level
Nimsar	122.28 m
Bhatpurwa	113.21 m
Gaughat	109.97 m
Hanuman Setu	109.01 m
Gomti Barrage	108.60 m

In the present study, the Gomti river from Gomti barrage to 6.8 km upstream of it has been modelled. Except the Hanuman setu, which is located 3600 m upstream of the Gomti barrage the other locations as mentioned above are beyond 6.8 km upstream of the Barrage. Therefore, the model is calibrated by reproducing the water level at Hanuman Setu for known water level at Gomti barrage. The discharge in Gomti river at Gomti barrage was 1190 cumecs and corresponding water level was 108.60 m. When the discharge at Gomti barrage was 3564.81 cumecs the flood discharge in Kukrail nala was 425 cumecs. The proportional discharge in Kukrail nala for 1190 cumecs discharge at Gomti barrage in Gomti river $=425/3564.81\times1190=141.87$ cumecs. The discharge in Gomti river, upstream of chainage 500 m = 1190-141.87= 1048.13 cumecs.

The model was run for 1190 cumecs discharge between chainage 0 to 500 m; 1048.13 cumecs discharge upstream of chainage 500 m and water level at Gomti barrage equal to 108.6 m for varying Manning's coefficients in main channel and flood plain. It was found that for Manning's coefficient = 0.019 in the main channel and 0.03 in flood plain, the computed water level matches well with the recorded water level as shown in Fig. 8. Therefore, n = 0.019 for main channel and 0.03 for flood plain are adopted for further analysis.

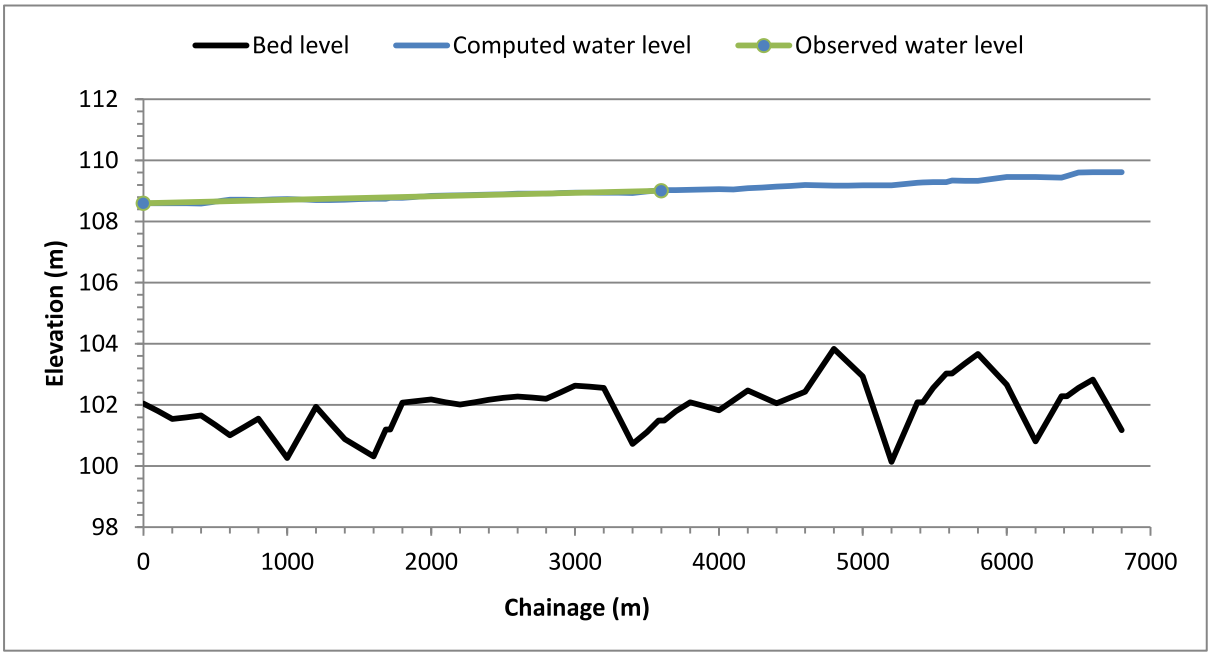

Figure 8 Comparison between computed water level with observed values

11. COMPUTATION OF HFL WITH FLOOD EMBANKMENTS

The ever maximum flood equal to 3564.81 m^3/s was recorded in Gomti river at Gomti Barrage in 1960. The corresponding highest flood level at Gomti barrage was 111.6 m. The recorded HFL in year 1960 at other stations on the Gomti river are given in the Table 3 along with the bed level of the river.

Subsequent to the flood in 1960 in Gomti river, which has created havoc to the Lucknow city, the banks of the Gomti river were raised from Gomti barrage to its upstream up to 7 km. The banks were raised to contain the flood water between the banks for protecting the areas located near the Gomti river from the flood water. No flood of the order of 3564.81 m^3/s has been recorded in the Gomti river after the provision of flood embankments on the both sides of the Gomti river. Therefore, extent of water level in the Gomti river has not been envisaged for the flood discharge 3564.81 m^3/s.

Table 3 Recorded HFL and bed level of river as in year 1960

Chainage (m)	Bed level (m)	HFL (m)	Chainage (m)	Bed level (m)	HFL (m)
6370	100.007	112.232	3000	100.597	111.895
6250	100.121	112.215	2750	100.057	111.875
6000	100.125	112.175	2500	100.67	111.852
5750	100.021	112.156	2250	101.325	111.833
5500	101.545	112.137	2000	101.067	111.805
5250	102.39	112.118	1750	100.02	111.76
5000	102.761	112.08	1500	99.725	111.73
4750	100.555	112.042	1250	102.2	111.705
4500	101.7	112.042	1000	100.932	111.68
4250	100.741	112.004	750	100.374	111.655
4000	100.9	111.985	500	100.007	111.63
3750	102.154	111.985	250	100.916	111.615
3500	100.712	111.947	0	100.931	111.6
3250	100.085	111.928			

In view of this, the model was run with the existing cross-sections & geometry of the Gomti river and for the maximum flood of 3564.81 m^3/s at the Gomti barrage.

Following boundary conditions were considered for running the model

Discharge in the river from Chainage 0 to 500 m = 3564.81 m^3/s

Discharge in the river from Chainage 500 m to 6800 m = 3139.81 m^3/s with the consideration of 425 cumecs flood discharge in Kukrail nala.

Downstream water level at Gomti barrage = 111.60 m

The simulated water surface profile with flood embankments has been compared with recorded HFL in year 1960 without raised banks in Fig. 9. The bed level of the Gomti river measured in 1960 is also shown in Fig. 9 along with the current bed level.

The HFL of the Gomti river has increased due to raising both the banks of the Gomti river. The maximum rise in HFL (Afflux) compared to observed HFL in 1960 due to construction of flood embankments is 1.25 m at Chainage 6800 m i.e., upstream of the Harding bridge (Fig. 10). Afflux due to Railway and Harding bridges are 0.30 m and 0.20 m, respectively (Fig. 10). Such high affluxes are due to undersized length of these bridges compared to other bridges across Gomti river.

Over the year, silting has occurred over the bed of the river and the bed level has gone up by 1.5 m compared to the bed level of the year 1960.

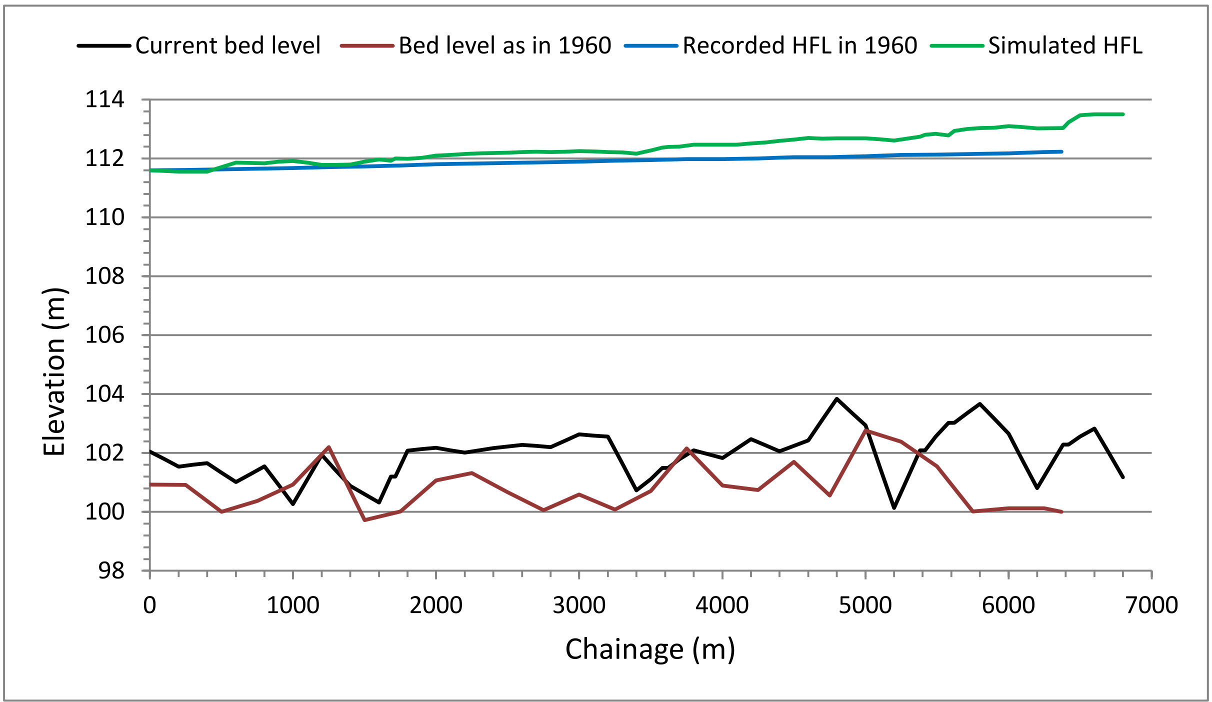

Figure 9 Spatial variations of bed level and HFL

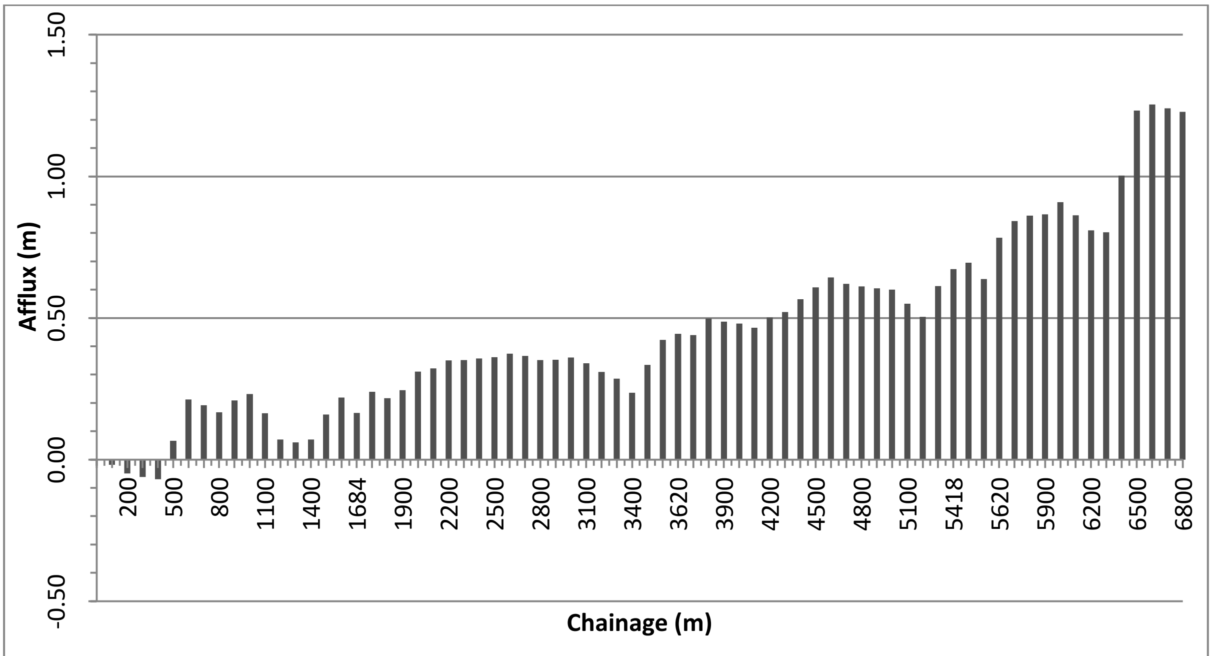

Figure 10 Afflux in Gomti river due to construction of flood embankments

From the above discussion, it can be concluded that due to raising both the banks of the Gomti river, if peak flood of magnitude 3564.81 m^3/s will pass through the river, the HFL shall be 1.25 m higher than the recorded HFL in year 1960 at chainage 6800 m. This could be due to silting of bed and confinement of flood between two raised banks of the river. The elevation of the left and right banks of the Gomti river along with simulated HFL and existing bed level are shown in Fig. 11, which reveals that the simulated HFL is well below the left and right banks level. Hydraulic parameters for peak flow simulation in Gomti river with raised banks are given in Annexure-1.

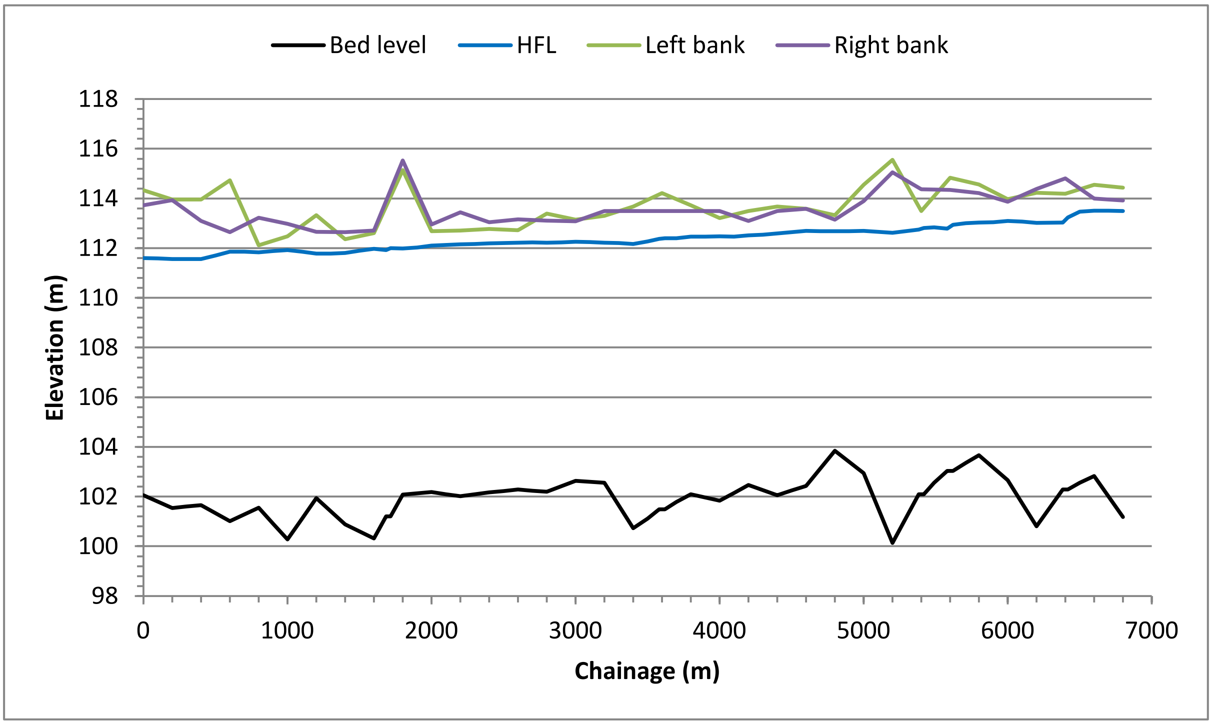

Figure 11 Spatial variation of HFL, bed level and flood embankment of Gomti river

To study the morphological changes of the river due to passage of flood of magnitude 3564.81 m^3/s, the model was run under quasi-unsteady flow for mobile bed. Yang's relationship for the sediment transport was adopted while sediment sorting was carried out using Exner's formulation. Ruby's relationship was adopted for the computation of sediment fall velocity. The model was run for the quasi-unsteady flow to account for the mobility of the river bed. Flow series was provided at chainage 6800 m, while at downstream boundary chainage 0 m, depth of flow was adopted. Equilibrium sediment load was supplied to the mathematical model at the upstream boundary.

The model was run by specifying different time period keeping the discharge the same for the whole run. Values of various other parameter like contraction and expansion coefficients, computational step length etc. were also specified as per the requirement of the mathematical models (Garde and Ranga Raju, 2006).

The changes in bed level after the passage of flood is shown in Fig. 12, which clearly indicates that there would not be any morphological changes in the existing Gomti river on passage of flood of magnitude 3564.81 m^3/s.

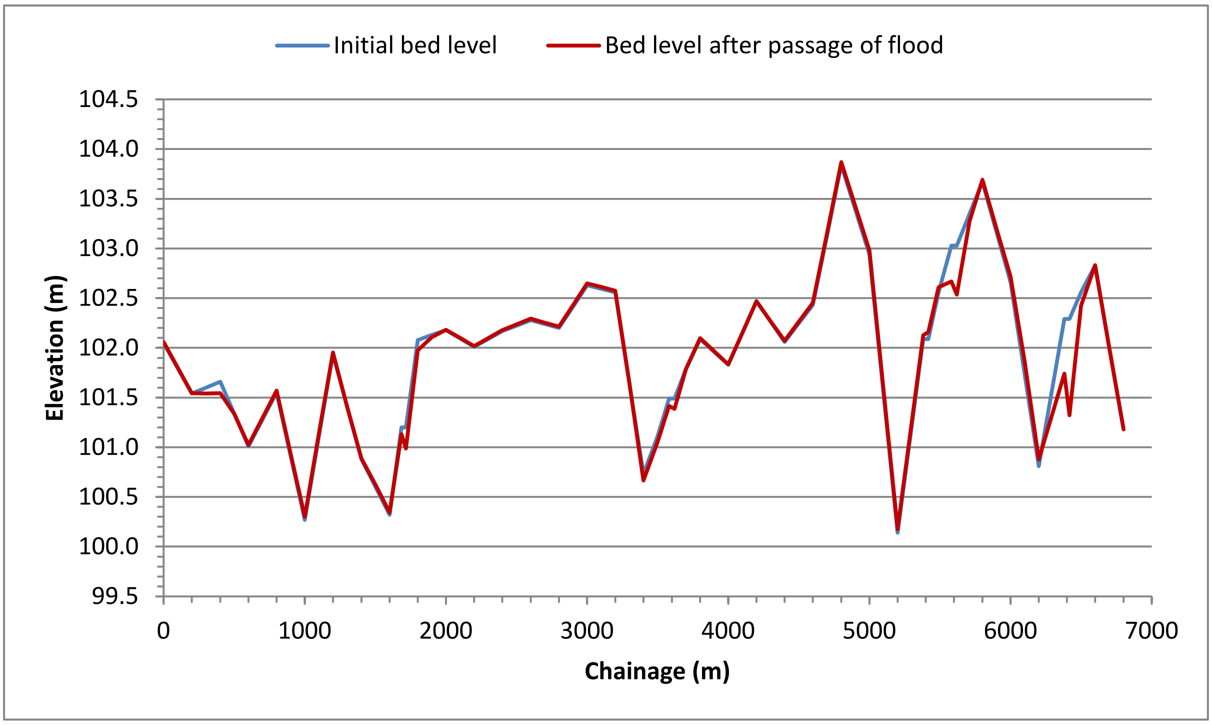

Figure 12 Comparison of bed level of Gomti river after passage of flood with initial bed level

12. SIMULATION OF FLOW UNDER PROPOSED RIVER FRONT DEVELOPMENT

A minimum width of river equal to Lacey's perimeter is generally provided to an alluvial river to attain its regime conditions. In this study also, it was proposed to provide a width of river equal to the Lacey's perimeter to avoid the morphological changes of river from its regime condition. Maximum flood discharge in Gomti river from chainage 500 to 6800 m = 3139.81 m^3/s, however, it is 3564.81m^3/s from Chainage 0 to 500 m due to addition of peak discharge of Kukrail nala = 425 m^3/s into Gomti river.

Lacey water way $P = 4.75\sqrt{Q}$

Taking Q = 3139.81 m^3/s, the value of P is

$P = 4.75\sqrt{3139.81}$ = 266.16 m

The cross-section of the Gomti river from Gomti barrage to 6.8 km upstream of it was examined and found that the width of the river at some station on the river is of the order of 250 m. With the consideration of Lacey's perimeter and existing section of the Gomti river in the study reach, it was proposed to keep minimum width of Gomti river equal to 250 m from Gomti barrage to its 6.8 km upstream. However, at some locations, width is kept slightly less than 250 m in view of existing historical monuments in the flood plain of the river.

To study the effect of reclaimed land for river front development of Gomti river keeping width of river 250 m, the model was run for peak flood equal 3564.81m^3/s from chainage 0 to 500 m; 3139.81 m^3/s from the chainage 500 m to 6800 m; and water level at Chainage 0 equal to 111.6 m.

The values of the hydraulic parameters at different cross sections which have been obtained through mathematical modeling without and with river front development are summarized in Annexure-I. These results have been discussed below.

12.1 Afflux

Comparison of water surface profiles in the river reach from Chainage 0 to 6800 m without and with river front development keeping width of channel 250 m is depicted graphically by Fig.13. It is to be noted that with proposed land reclamation for RFD keeping bed with of river 250 m does not change the water surface noticeably. A negative afflux of the order of 4 cm has been noted from chainage 6500 m to 6800 due to acceleration of flow on account of contraction in flow as the river is wide in this reach and provision of 250 m width of river results in contraction of flow. However, positive afflux of the order of 3 cm has been observed from Chainage 3600 m to 6400 m. Negative affluxes of the order of 2 cm were also obtained from Chainage 500 to 3400 m of river as shown in the Fig. 13.

Thus, afflux in the Gomti river due to the proposed land reclamation for RFD is practically negligible. Therefore, it recommended to for the land acquisition of river keeping the bed width of river 250 m from chainage 0 to 6800 m.

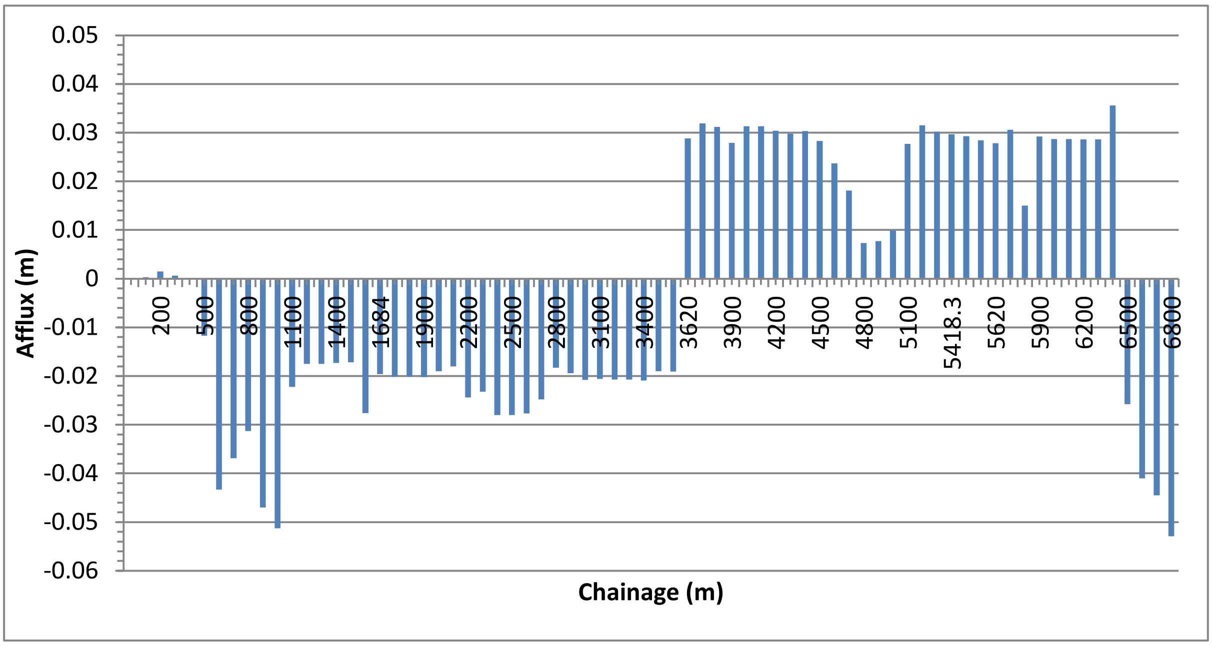

Fig.13 Spatial variation of afflux due to reclamation of land for RFD

12.2 Average Velocity

The changes caused due to proposed RFD on velocity of flow during high flood conditions are depicted in the Figs. 14a-b. In general, velocity with land reclamation for RFD is higher than the velocity without RFD, however, such differences is practically negligible in major length of the Gomti river. An increase in velocity by 20% with RFD from Chainage 6500 m to 6800 m is attributed to the acceleration of flow and lowering the water surface level in this reach. In the other reach of the river also, an increase in velocity with RFD has been noticed as shown in Fig. 14b.

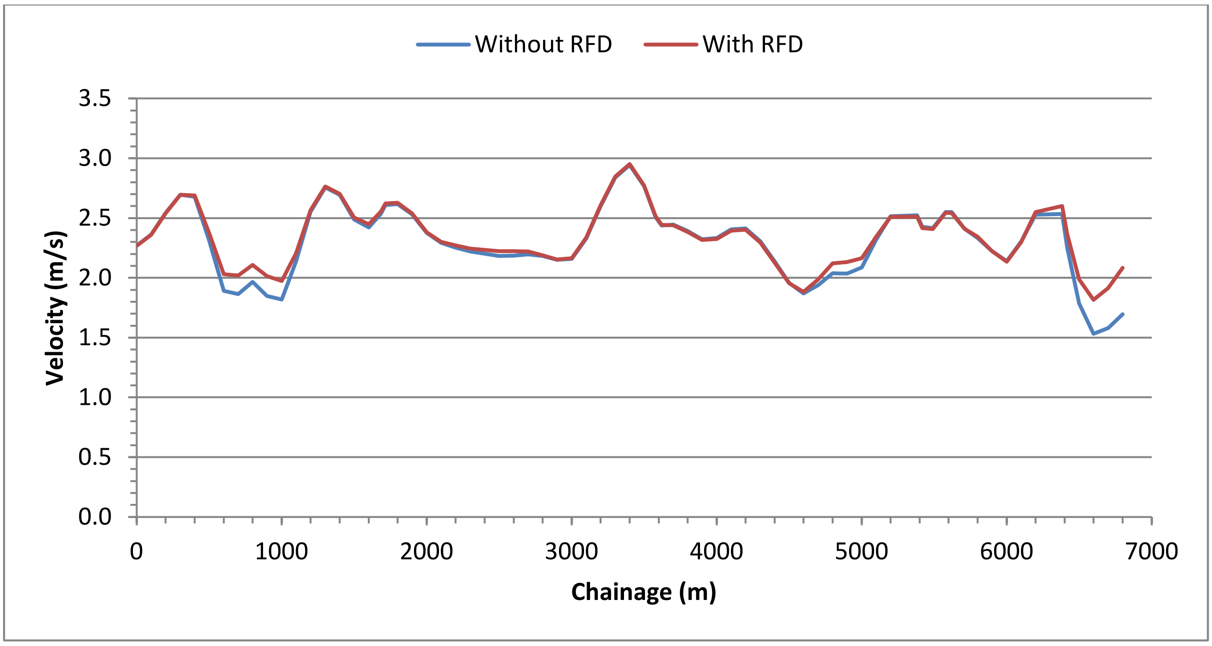

Fig. 14(a) Spatial variation of average velocity with and without RFD

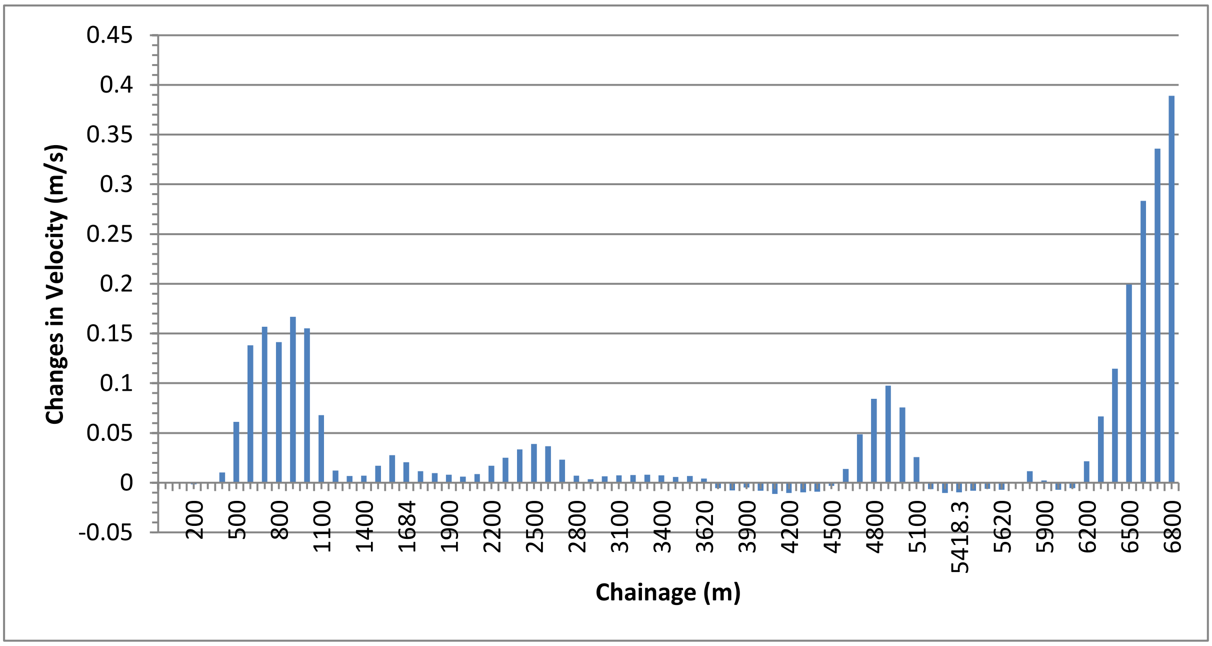

Fig. 14(b) Difference in average velocity with and without RFD

12.3 Average Bed Shear Stress

The changes in bed shear stress during high flood conditions on account of the proposed river front development are depicted in the Figs. 15a,b. It can be seen from this figures that shear stress with proposed river front development has increased by about 30% in the reach from Chainage 6500 m to 6800 m. This is conformal to the lowering of water level and increase in velocity in this reach. In the other reach of the river also, an increase in bed shear stress with RFD has been noticed as shown in Fig. 15b.

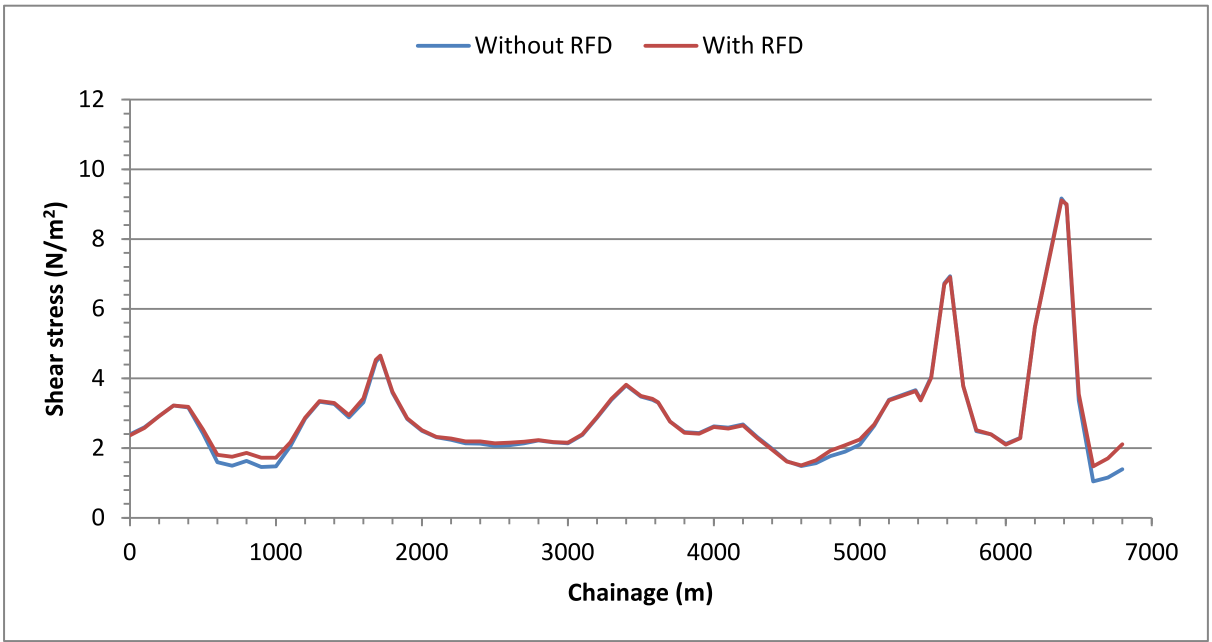

Fig.15(a) Spatial variation of bed shear stress with and without bridge

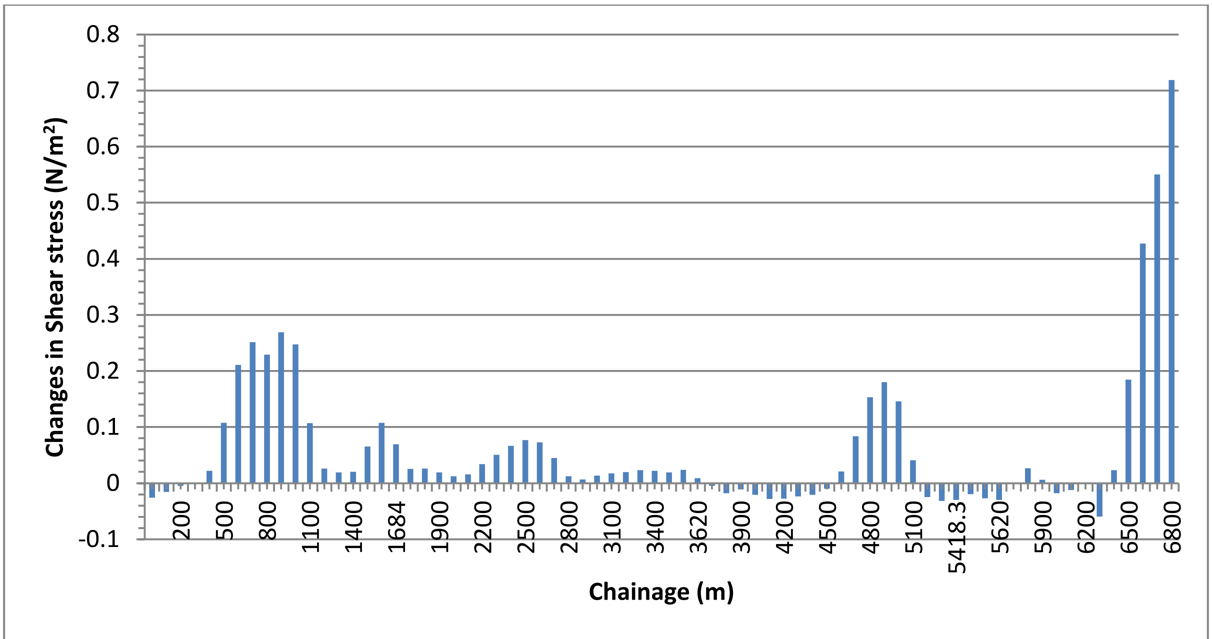

Fig. 15(b) Difference in bed shear stress with and without RFD

12.4 River Bed Level

Insignificant changes in the general bed levels of river have occurred due to river front development as shown in the Fig. 16. Small amount of degradation that has occurred in the upper reach could be attributed to increases in shear stress and velocity in this reach. The maximum aggradation or degradation due to river front development is of the order of 6 cm in some reaches. From practical consideration, there is no change in bed level of the Gomti river on account of river front development.

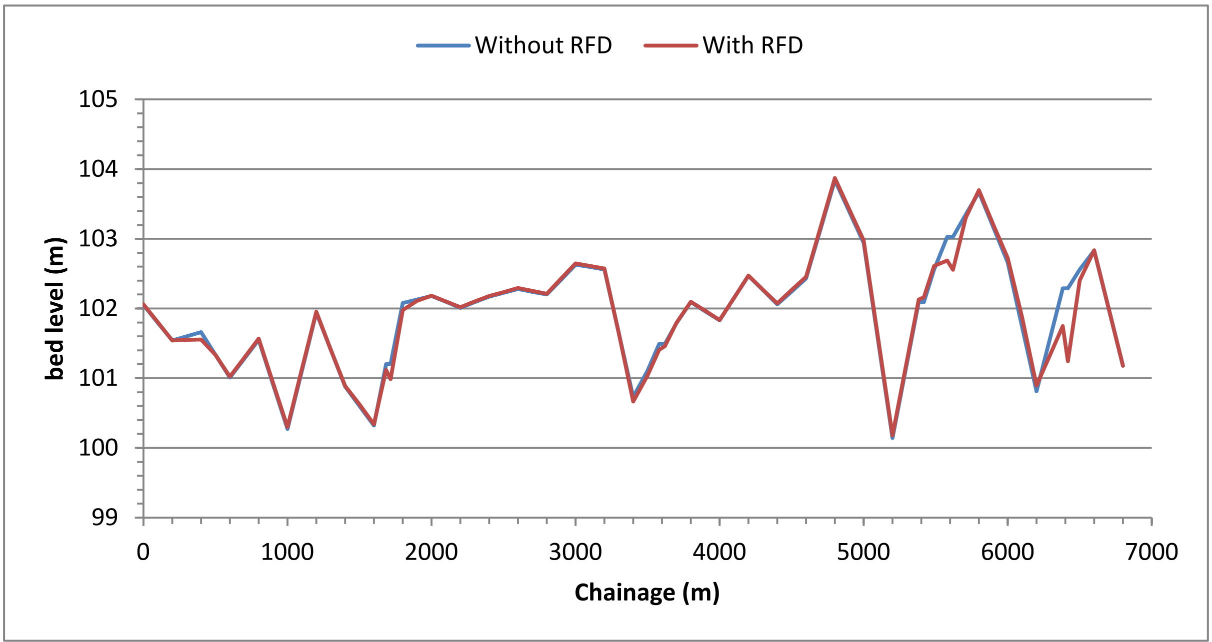

Fig. 16 Spatial variation of bed level with and without RFD

12.5 Width of River

The width of the Gomti river under the river front development of Gomti river is kept 250 m, however, at some locations, it is kept slightly less than 250 m in view of historical Monuments in the flood plain of the river. The recommended minimum width of the Gomti river is given in Table 4.

A three-dimensional view of Gomti river under the river front development showing the existing bridges, flood embankments, reclaimed land etc. is shown in Fig. 17.

Table 4 Width of Gomti river & extent of raising the banks level

Chainage (m)	**Existing width of river** (distance between flood embankments) (m)	**Proposed width of river** (m)	**Extent of raising the banks level** (m)*	
			Left bank	Right bank
6800	382	250	0.52	1.03
6600	399	250	0.41	0.96
6400	325	250	0.58	-0.04
6200	Harding Bridge	Harding Bridge	0.32	0.17
6000	260	250	0.66	0.76
5800	272	250	-0.01	0.33
5600	244	250	-0.37	0.12
5400	Railway Bridge	Railway Bridge	0.84	-0.04
5200	Daligang Bridge	Daligang Bridge	-1.42	-0.91
5000	310	250	-0.35	0.31
4800	315	250	0.87	1.05
4600	308	250	0.64	0.64
4400	273	250	0.46	0.63
4200	250	230	0.55	0.94
4000	259	230	0.79	0.50
3800	267	250	0.27	0.50
3600	Hanuman Setu	Hanuman Setu	-0.28	0.43
3400	193	215	-0.03	0.14
3200	206	245	0.40	0.20
3000	254	250	0.59	0.65
2800	268	250	0.31	0.59
2600	283	250	0.98	0.54
2400	284	250	0.89	0.62
2200	282	250	0.93	0.20
2000	268	250	0.90	0.63
1800	Nishatganj Bridge	Nishatganj Bridge	-1.67	-2.06
1600	287	250	0.84	0.73
1400	214	250	0.92	0.64
1200	213	250	-0.06	0.60
1000	362	250	0.89	0.39
800	292	250	1.19	0.09
600	343	250	-1.41	0.67
400	249	250	-0.90	-0.04
200	283	250	-0.90	-0.87
0	269	250	-1.23	-0.63

*Negative values indicate surplus height of banks beyond the required bank levels.

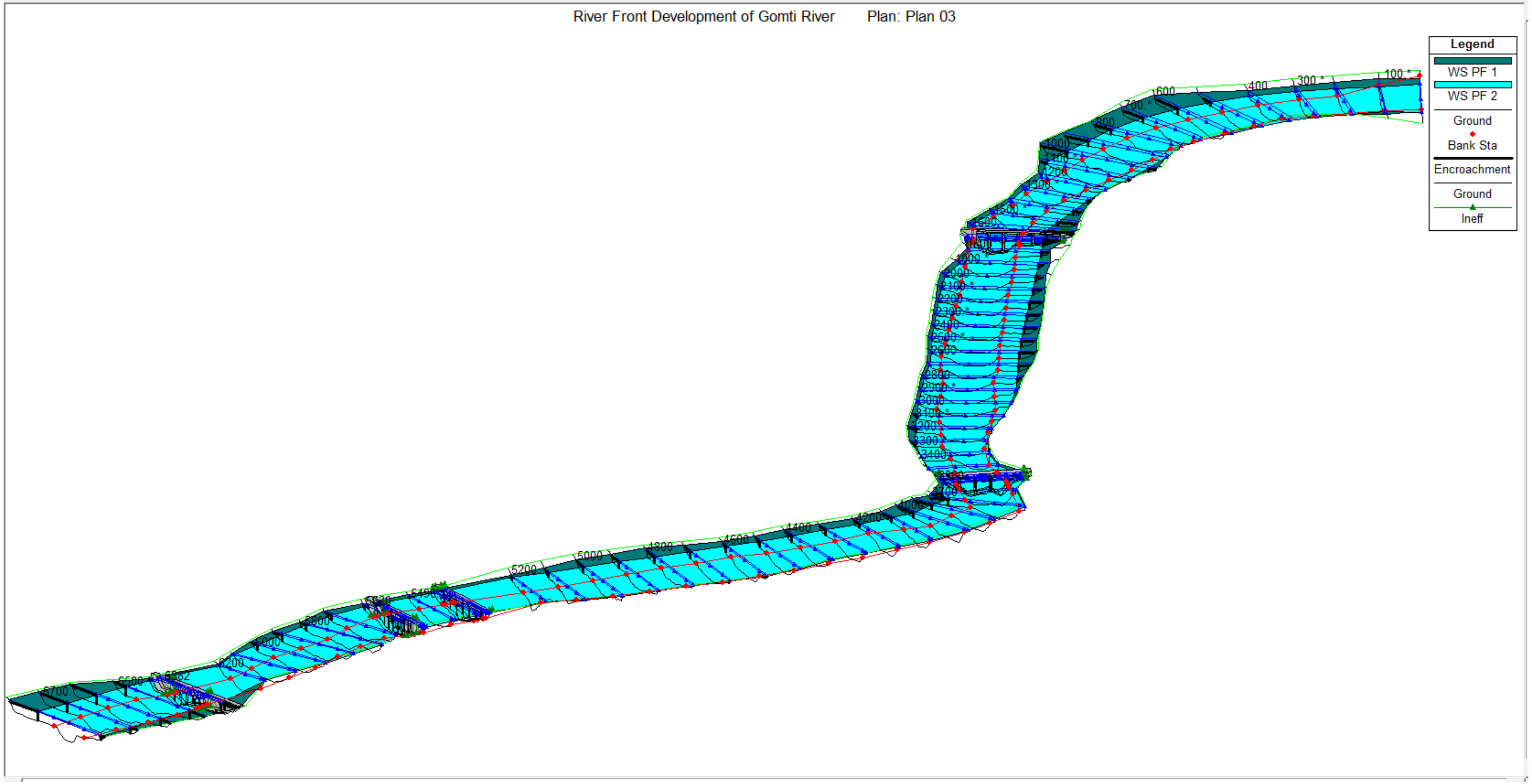

Figure 17 3D view Gomti river under river front development

12.6 Free Board

The available free board has been computed using the top level of both existing flood embankments and simulated HFL under river front development. Those free boards available at left and right banks are shown in Fig. 18.

As per IS 12094:2000 guidelines, minimum free board of 1.5 m over design HFL including the backwater effect, if any should be provided for the rivers carrying design discharge upto 3000 cumecs, for higher discharge or for aggrading flashy rivers a minimum free board of 1.8 meters over the design HFL shall be provided. This should be checked also for ensuring a minimum of about 1.0 m free board over the design HFL corresponding to 100 year return period. In view of above, 1.5 m free board is suggested in this case. The extent of raising the left and right banks to accomplish 1.5 m free board under design flood & river front development above the existing banks level is given in Table 4.

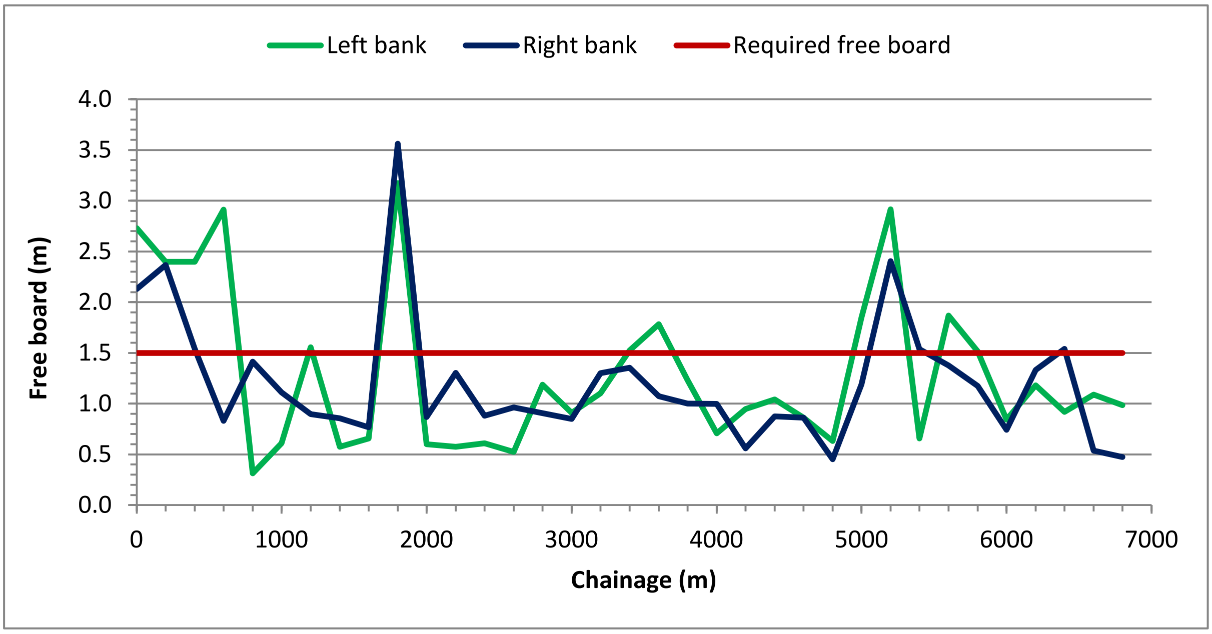

Figure 18 Spatial variation of available and required freeboard

13. WORKING PLAN FOR RECLAMATION OF LAND FOR RFD

For the facilitation of flow through the Gomti river, the plan form of the river is worked out and the same is shown in the attached drawing. The salient's feature of the plan form is described in Table 5.

Table 5 Suggested changes with respect to plan form of the Gomti

Reaches	*Suggested changes*
Chainage 500-1100m	Left bank be shifted towards river by 30 m Right bank be shifted towards river by 15 m
Chainage 1300-2000m	Right bank be shifted towards river by maximum shift 30 m
Chainage 1180-1580m	Left bank be shifted away from river with maximum shift 65 m
Chainage 3200-3460m	Right bank be shifted away from river by 30 m
Chainage 3800-4400m	Left bank be shifted towards river by 30 m
Chainage 4400-5100m	Left bank be shifted towards river by 50 m
Chainage 5600-6200 m	Left bank be shifted towards river by 25 m
Chainage 6400-6600m	Right bank be shifted towards river by 90 m
Chainage 6400-6800m	Left bank be shifted towards river by 100 m

The required top widths of the river at highest flood level at various changes are given in the Table 4. No construction work shall be carried out that protrudes towards the river in its width given in Table 4. Such protrusion should not be from the bed of the river as well. However, 25 m wide pucca promenades at natural surface level of the river may be developed along both the banks within 250 m width. A width of 200 m of the river shall be kept mobile for facilitation of bed aggradation & degradation.

Cross-section of Gomti river at chainages 6600 m and 4800 m under the river front development are shown in Figs. 19 and 20, respectively as illustration.

The land that can be reclaimed is indicated in the attached drawing, while in reaches from chainage 3200-3460 m and Chainage 1180-1580 m, land should be made available to the river for facilitation of flood water without obstruction as mentioned in the Table 5.

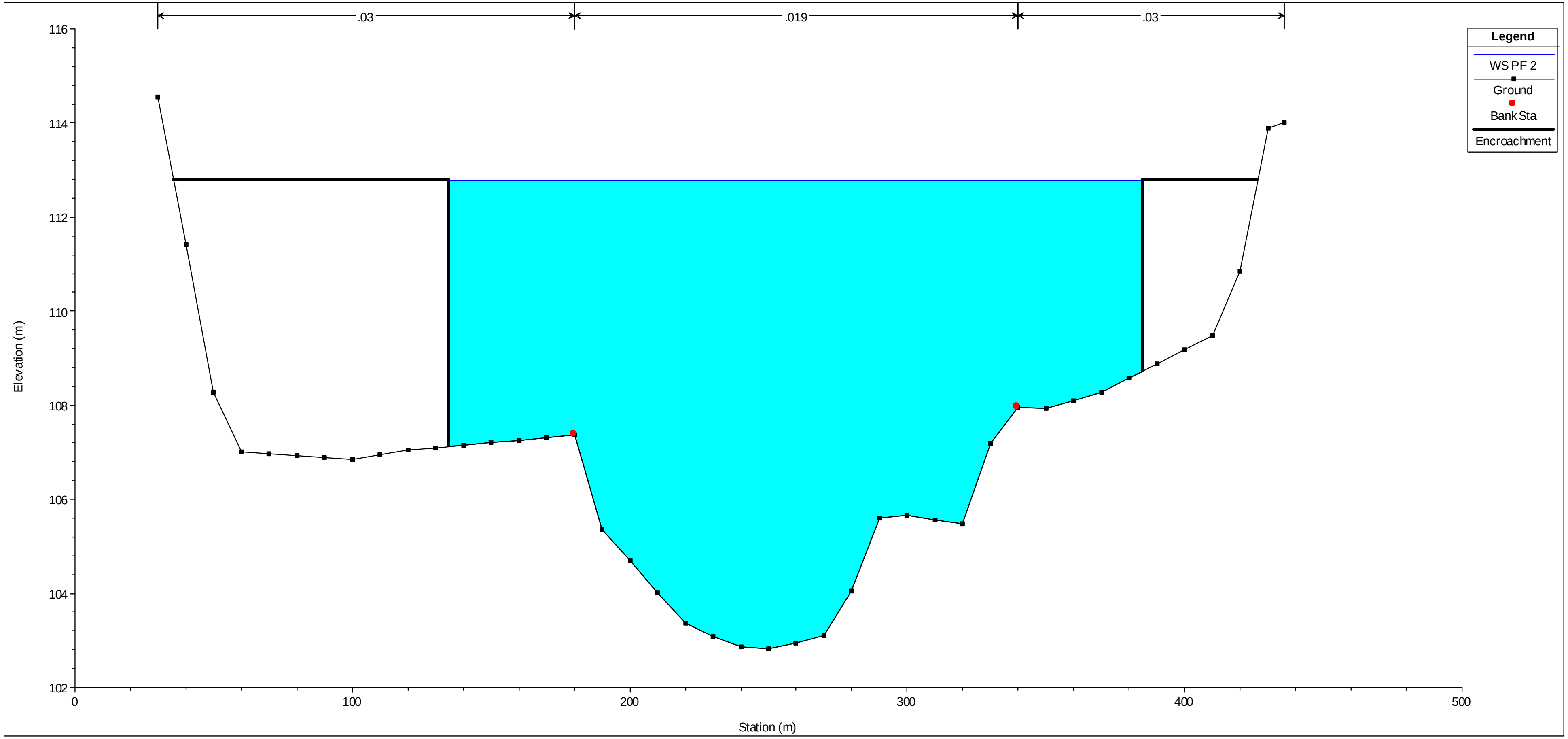

Figure 19 Cross-section of Gomti river at chainage 6600 m under river front development

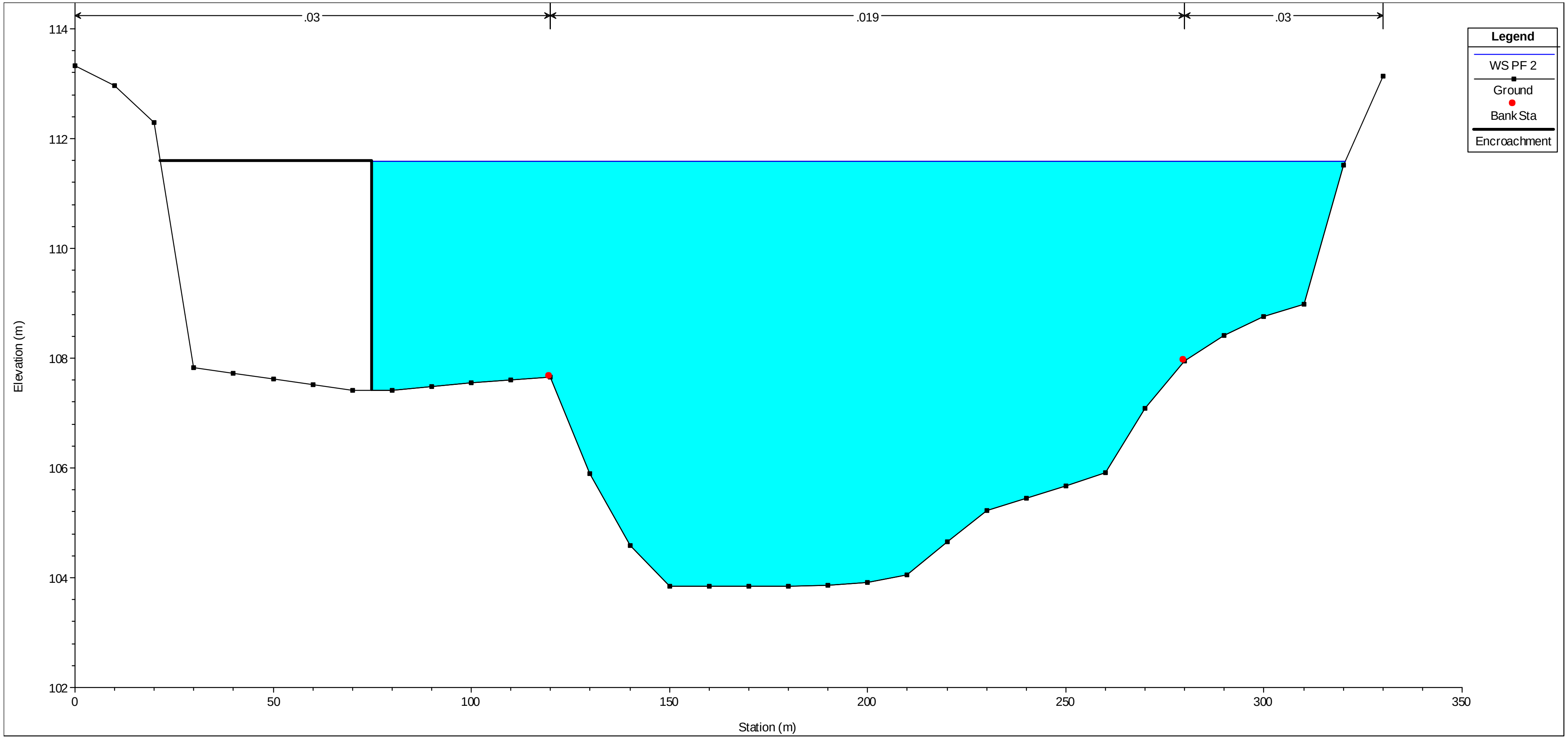

Figure 20 Cross-section of Gomti river at chainage 4800 m under river front development

14. EFFECT OF RIVER FRONT DEVELOPMENT ON HYDRAULIC STRUCTURES

There are six hydraulic structures across the Gomti river in the reach under consideration for the river front development. These six structures are Gomti barrage, Nishatganj bridge, Hanuman bridge, Daliganj bridge, Railway bridge and Harding bridge. In view of changes in the hydraulic parameters of the Gomti river on account of river front development, the adequacy of the structures under changed hydraulic conditions are checked below:

(a) Gomti Barrage

It is proposed to develop river front of Gomti river upstream of the Gomti barrage. The length of barrage from abutment to abutment is 202.60 m, however, under the river front development a width of river 250 m is to be maintained in the reach under consideration. Thus there would not be any increase in the unit discharge of the river at the Gomti barrage. Further, the flow in the river is subcritical flow which results in no changes in water level at barrage due to changes upstream of it. No morphological changes on the Gomti river have been found due to river front development. In view of above points, it is clear that the river front development will not cause any damage to the Gomti barrage.

The safety of the bridges across the Gomti river in the reach under consideration has been checked from the scour consideration.

(b) Nishantganj Bridge

Data pertaining to Nishatgan bridge are as follow:

Located at chainage	= 1700 m
Simulated HFL	= 111.98 m
Abutment to abutment length	= 218.50 m
Number of piers	= 5
Diameter of pier	= 2.7 m
Diameter of well foundation	= 6 m

Clear water way L = 218.50-5×(2.7+6)/2 = 196.75 m

Discharge intensity q= Q/L =3139.81/196.75 = 15.96 $m^3/s/m$

Founding level = 83.45 m

The maximum scour level below the HFL is computed by using IRC procedure (IRC:5-1998 and IRC:78-2000) of scour computation involving q_{design} i.e. $D_{se} = 1.35 \times (q^2 / f)^{1/3}$ as the waterway of the bridge is less than the Lacey's waterway (Lacey's water way = 266.16 m in this case). Here *f* is the silt factor, *q* is design flood discharge intensity. As per IRC: 78-2000, discharge for scour computation is increased by an amount depending on the catchment area of the river. In the present case, the catchment area of the river Gomti at the barrage is equal to 8725 km^2, for which recommended increase in discharge is 22%. Thus design q = 1.22*15.96 =19.47 $m^3/s/m$.

The maximum depth of scour below HFL

$$= 2 \times 1.35 \times (19.47^2 / 1.0)^{1/3}$$

$$= 19.54 \text{ m}$$

Accordingly, minimum depth of founding level below HFL for the proposed bridge as per IRC: 5- 1998 and IRC 78: 2000 is

= 1.33 × maximum scour level below HFL

= 1.33 × 19.54 = 26.00 m

Hence founding level based on scour considerations = 111.98 (HFL) – 26.00 = +85.98 m, which is higher than the founding level of the bridge i.e., 83.45 m, hence the bridge is safe from the scour consideration.

(c) Hanuman Bridge

Data pertaining to Hanuman bridge are as follow:

Located at chainage = 3600 m

Simulated HFL = 112.43 m

Abutment to abutment length = 191.11 m

Number of piers/wall = 4

Other details of bridge like diameter of pier; diameter of well foundation; discharge intensity q; founding level etc. were not made available to the writer, therefore, scour computations were not carried out.

(d) Daliganj Bridge

Data pertaining to Daliganj bridge are as follow:

Located at chainage = 5400 m

Simulated HFL = 112.83 m

Abutment to abutment length = 210.15 m

Number of piers = 6

Diameter of pier = 4 m

Diameter of well foundation = 7.5 m

Clear water way L = 210.15-6×(4+7.5)/2 = 175.65 m

Discharge intensity q= Q/L =3139.81/175.65= 17.88 $m^3/s/m$

Founding level = 80.5 m

Design intensity of discharge = 1.22×17.88 = 21.81 $m^3/s/m$

The maximum depth of scour below HFL

$$= 2\times1.35\times(21.81^2/1.0)^{1/3}$$

$$= 21.08 \text{ m}$$

The minimum depth of founding level below HFL

= 1.33 × maximum scour level below HFL

= 1.33 × 21.08 = 28.03 m

Hence founding level based on scour considerations = 112.83 (HFL) – 28.03 = +84.80 m, which is higher than the founding level of the bridge i.e., 80.50 m, hence the bridge is safe from the scour consideration.

(e) Railway Bridge

Data pertaining to Railway bridge are as follow:

Located at chainage = 5600 m

Simulated HFL = 112.96 m

Abutment to abutment length = 125.88 m

Number of piers/wall = 6

Diameter of pier = 2.49 m

Diameter of well foundation = 4.88 m

Clear water way L = 125.88-6×(2.49+4.88)/2 = 103.77 m

Discharge intensity q= Q/L =3139.81/103.77 = 30.26 $m^3/s/m$

Founding level = 92.23 m

Design intensity of discharge = 1.22×30.26 = 36.91 $m^3/s/m$

The maximum depth of scour below HFL

$$= 2\times1.35\times(36.91^2/1.0)^{1/3}$$

= 29.93 m

The minimum depth of founding level below HFL

= 1.33 × maximum scour level below HFL

= 1.33 × 29.93 = 39.81 m

Hence founding level based on scour considerations = 112.96 (HFL) – 39.81 = +73.15 m, which is lower than the founding level of the bridge i.e., 92.23 m, hence the bridge is unsafe from the scour consideration.

(f) Harding Bridge (Arch type)

Data pertaining to Harding bridge are as follow:

Located at chainage = 6400 m

Simulated HFL = 113.27 m

Abutment to abutment length = 125.276 m

Number of piers/wall = 4

Diameter of pier = 2.75 m

Diameter of well foundation = 4.268 m

Clear water way L = 125.276-4×(2.75+4.268)/2 = 111.24 m

Discharge intensity q= Q/L =3139.81/111.24 = 28.23 $m^3/s/m$

Founding level = 94.7 m

Design intensity of discharge = 1.22×28.23 = 34.44 $m^3/s/m$

The maximum depth of scour below HFL

$$= 2 \times 1.35 \times (34.44^2 / 1.0)^{1/3}$$

$$= 28.58 \text{ m}$$

The minimum depth of founding level below HFL

= 1.33 × maximum scour level below HFL

= 1.33 × 28.58 = 38.01 m

Hence founding level based on scour considerations = 113.27 (HFL) – 38.01 = +75.26 m, which is lower than the founding level of the bridge i.e., 94.70 m, hence the bridge is unsafe from the scour consideration.

Adequacy of the existing five bridges across Gomti river upstream of the Gomti barrage have been evaluated from the scour consideration. Nishatganj and Daliganj bridges were found safe as their existing foundation is lower than the required founding level. However, such computation could not be carried out for Hanuman Setu due to unavailability of its general arrangement drawing.

The length of Railwaly as well as the Harding bridges is of the order of 125 m compared to 210 m (approx.) length of Nishatganj bridge, Hanuman setu and Daliganj bridge. The undersized length of Railway & Harding bridges has resulted in high unit discharge and high scour depth. The existing founding levels of the Railway & Harding bridges are at higher level compared to the required level thereby these bridges are unsafe from the scour consideration. The founding levels of the Nishatganj and Daliganj bridges are 83.45 m and 80.50 m respectively, while for Railway and Harding bridges are 92.33 m and 94.7 m, respectively, which is approximately 11.5 m higher.

The Railway and Harding bridges were constructed before 1960 and sustained the ever maximum flood of the Gomti river in 1960. It is to be noted that during that flood, the flood water had spread over the banks of the river - mainly towards the left bank as evident from the Fig. 21. The bridges could not fail due to partial flow of flood water through the bridges. Now the flood embankments have been constructed along both the banks of the river which shall confine the flood water in the Gomti river resulting in deep scour and likely failure of these bridges.

The following measures may be taken up to safeguard these bridges:

(c) The length of the Railway and Harding bridges shall be increased by a suitable distance.

(d) Retrofitting shall be provided to control the scour near the bridge pier and abutment in the form of riprap, collar etc.

A detail study along with soil investigation at these bridge sites is required for carrying out the above measures.

Figure 21 Harding bridge during 1960 flood in Gomti river

15. IMPACT OF RIVER FRONT DEELOPEMNT ON DRAINS

There are 26 numbers of major and minor nalas in Lucknow that outfall in the Gomti River. Among them Kukrail nala and G.H. Canal are the two major drains. The later outfalls into Gomti river downstream of the Gomti barrage from left side, while Kukrail nala outfalls into the river at about 500 m upstream of Gomti barrage from right side. There are 16 nalas that outfall into Gomti river in a reach from Gomti barrage to 6.8 km upstream of it. Details of these nalas are given in Table 6. The flow rate of these nalas during non-monsoon is also given in the Table 6.

Table 6 Details of nalas discharging into Gomti river from Chainage 0 to 6.8 km

S/ No	Barrel Number	Nala	Chainage (km)	Bank of river	HFL (m)	Flow (MLD)
1	23	NER U/S	6.5	Right	105.85	1.64
2	25	Mohan Mikins	6.5	Left	107.82	6.95
3	1	Daliganj-1	5.8	Left	107.59	6.35
4	13	NER D/S	5.925	Right	105.85	1.15
5	2	Daliganj-2	5.6	Left	107.1	3.53
6	14	Vazirganj	5.34	Right	106.24	61.4
7	15	Ghasiyari Mandi	5.1	Right	106.1	19.94
8	3	Arts College	5	Left	107.13	2.25
9	16	China Bazar	4.2	Right	106.1	3.15
10	4	Hanuman Setu	4	Left	107.3	4.1
11	17	Law Plas	3.6	Right	107.1	4.07
12	5	D.G.P.S	3.35	Left	107.4	7.32
13	6	Kedarnath	2.9	Left	107.5	3.08
14	7	Nishatgsng	2.6	Left	107.6	1.42
15	18	Japling Road	1.25	Right	106.51	16.22
16		Kukrail Nala	0.50	left		

The HFL of these nalas at its outfall to Gomti river is higher than the HFL of Gomti river during flood, therefore, pumping stations are provided to pump the water from the nalas to Gomti river. However, no such pumping is required during the lean flow in Gomti river during non-monsoon as they pass the flow into river through gravity flow.

As such there is no significant difference in HFL of Gomti river in its reach under consideration due to river front development compared to the existing condition. Therefore, there shall not be any impact on the nalas after the river front development.

16. CONCLUSIONS

Based on the study carried out in this report, the following conclusions can be derived.

(a) The design flood discharge in Gomti river at barrage has been estimated 3654.81 m^3/s, while for Kukrail nala, the peak discharge is taken 425 m3/s. The HFL at Gomti barrage for discharge equal to 3654.81 m^3/s is 111.6 m.

(b) With the consideration of Lacey's perimeter and existing section of the Gomti river in the study reach, it is proposed to keep minimum width of Gomti river at its HFL equal to 250 m, however, at some locations, it is kept slightly less than 250 m in view of historical Monuments in the flood plain of the river as given in Table 4.

(c) If peak flood of magnitude 3564.81 m^3/s will pass through the river, the HFL shall be 1.25 m higher than the recorded HFL in year 1960 at chainage 6800 m. Affluxes due to Railway and Harding bridges are 0.30 m and 0.20 m, respectively. Such high affluxes are due to inadequate length of these bridges.

(d) Over the year, silting has occurred over the bed of the river and the bed level has gone up by 1.5 m compared to the bed level of the river in year 1960.

(e) Comparison of water surface profiles in the river reach from Chainage 0 to 6800 m without and with river front development reveals that with proposed land reclamation for RFD does not change the water surface noticeably. A negative afflux of the order of 4 cm has been noted from chainage 6500 m to 6800 due to acceleration of flow on account of contraction in flow.

(f) Simulated velocity with land reclamation for RFD is higher than the velocity without RFD, however, such differences is practically negligible in major length of the Gomti river.

(g) The bed shear stress shall increase by 30% (approx.) in the reach from Chainage 6500 m to 6800 m with proposed river front development. In the other reaches of the river as well, an increase in bed shear stress with RFD has been noticed. There shall be negligible morphological changes in the Gomti river under the proposed river front development.

(h) No construction work shall be carried out that protrudes towards to the river in its proposed width. Such protrusion should not be from the bed of the river as well. However, 25 m wide pucca promenades at natural surface level of the river may be developed along both the banks within the proposed width of the river. A width of 200 m of the river shall be kept mobile for facilitation of bed aggradation & degradation.

(i) The land that can be reclaimed is indicated in the attached drawing, while in reaches from chainage 3200-3460 m and Chainage 1180-1580 m, land should be made available to the river for facilitation of flood water without any obstruction.

(j) The top levels of the flood embankments are not adequate as the available free board is less than the required 1.5 m free board. The extent of raising the left and right banks to accomplish 1.5 m free board under design flood & river front development above the existing banks level are given in Table 4.

(k) There are six hydraulic structures across the Gomti river in the reach under consideration for the river front development. These six structures are Gomti barrage, Nishatganj bridge, Hanuman bridge, Daliganj bridge, Railway bridge and Harding bridge. In view of changes in the hydraulic parameters of the Gomti river on account of river front development, the adequacy of the structures under changed hydraulic conditions has been checked.

(l) The proposed river front development will not cause any damage to the Gomti barrage.

(m) Nishatganj and Daliganj bridges are safe from scour consideration as their existing foundation is lower than the required founding level.

(n) The existing founding levels of the Railway & Harding bridges are at higher level compared to the required level thereby these bridges are unsafe from the scour considerations. The following measures may be taken up to safeguard these bridges:

  (i) The length of the Railway and Harding bridges shall be increased by a suitable distance.

(ii) Retrofitting shall be provided to control the scour near the bridge pier and abutment in the form of riprap, collar etc.

(o) There are sixteen drains/nalas that outfall into Gomti river in a reach from Gomti barrage to 6.8 km upstream of it. The HFL of these nalas at their outfall into Gomti river is higher than the HFL of Gomti river during flood.

(p) As such, there is no significant difference in HFL of Gomti river in its reach under consideration due to river front development compared to the existing condition. Therefore, the impacts of river front development on the capacity of existing drains to discharge into the river system shall be negligible.

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Annexure-1

HYDRAULIC PARAMETERS FOR FLOOD SIMULATION IN GOMTI RIVER WITH AND WITHOUT RIVER FRONT DEVELOPMENT

(A) Hydraulic parameters for flood simulation in Gomti river without river front development

	River	Reach	Stations	Initial bed (m)	Final Bed level (m)	HFL(m)	Flow (m^3/s)	Velocity (m/s)	Shear Stress (N/m^2)	EG Slope (m/m)
1	Gomti River	0-6800 m	6800	101.18	101.18	113.50	3139.81	1.694	1.393	6.58E-05
2	Gomti River	0-6800 m	6700.*	102.01	102.01	113.50	3139.81	1.579	1.153	5.69E-05
3	Gomti River	0-6800 m	6600	102.83	102.83	113.50	3139.81	1.533	1.049	5.34E-05
4	Gomti River	0-6800 m	6500.*	102.56	102.42	113.47	3139.81	1.787	3.367	1.75E-04
5	Gomti River	0-6800 m	6418	102.29	101.32	113.23	3139.81	2.251	8.972	4.36E-04
6	Gomti River	0-6800 m	6382	102.29	101.74	113.03	3139.81	2.534	9.167	4.78E-04
7	Gomti River	0-6800 m	6200	100.81	100.88	113.02	3139.81	2.528	5.485	2.51E-04
8	Gomti River	0-6800 m	6100.*	101.73	101.86	113.06	3139.81	2.304	2.295	1.12E-04
9	Gomti River	0-6800 m	6000	102.66	102.72	113.10	3139.81	2.140	2.119	1.08E-04
10	Gomti River	0-6800 m	5900.*	103.17	103.20	113.05	3139.81	2.222	2.392	1.37E-04
11	Gomti River	0-6800 m	5800	103.67	103.69	113.03	3139.81	2.332	2.485	1.60E-04
12	Gomti River	0-6800 m	5710.*	103.35	103.28	113.00	3139.81	2.409	3.782	2.16E-04
13	Gomti River	0-6800 m	5620	103.03	102.54	112.94	3139.81	2.550	6.937	3.43E-04
14	Gomti River	0-6800 m	5580	103.03	102.67	112.79	3139.81	2.550	6.731	3.43E-04
15	Gomti River	0-6800 m	5490.*	102.56	102.61	112.83	3139.81	2.415	4.045	2.13E-04
16	Gomti River	0-6800 m	5418.3	102.09	102.16	112.80	3139.81	2.426	3.399	1.78E-04

17	Gomti River	0-6800 m	5381.7	102.09	102.13	112.74	3139.81	2.522	3.665	1.93E-04
18	Gomti River	0-6800 m	5200	100.14	100.18	112.61	3139.81	2.515	3.390	1.71E-04
19	Gomti River	0-6800 m	5100.*	101.54	101.58	112.65	3139.81	2.318	2.643	1.43E-04
20	Gomti River	0-6800 m	5000	102.94	102.98	112.69	3139.81	2.087	2.102	1.22E-04
21	Gomti River	0-6800 m	4900.*	103.39	103.42	112.69	3139.81	2.034	1.904	1.11E-04
22	Gomti River	0-6800 m	4800	103.84	103.87	112.68	3139.81	2.037	1.773	1.01E-04
23	Gomti River	0-6800 m	4700.*	103.13	103.16	112.68	3139.81	1.940	1.567	8.40E-05
24	Gomti River	0-6800 m	4600	102.43	102.45	112.69	3139.81	1.868	1.482	7.24E-05
25	Gomti River	0-6800 m	4500.*	102.24	102.26	112.65	3139.81	1.958	1.624	8.17E-05
26	Gomti River	0-6800 m	4400	102.06	102.07	112.60	3139.81	2.136	1.979	1.04E-04
27	Gomti River	0-6800 m	4300.*	102.27	102.27	112.54	3139.81	2.305	2.313	1.23E-04
28	Gomti River	0-6800 m	4200	102.47	102.47	112.51	3139.81	2.412	2.680	1.40E-04
29	Gomti River	0-6800 m	4100.*	102.15	102.15	112.47	3139.81	2.406	2.589	1.46E-04
30	Gomti River	0-6800 m	4000	101.83	101.83	112.47	3139.81	2.333	2.627	1.36E-04
31	Gomti River	0-6800 m	3900.*	101.96	101.97	112.47	3139.81	2.321	2.429	1.26E-04
32	Gomti River	0-6800 m	3800	102.09	102.10	112.47	3139.81	2.391	2.462	1.25E-04
33	Gomti River	0-6800 m	3700.*	101.79	101.79	112.40	3139.81	2.446	2.767	1.40E-04
34	Gomti River	0-6800 m	3620	101.49	101.39	112.40	3139.81	2.438	3.302	1.65E-04
35	Gomti River	0-6800 m	3580	101.49	101.42	112.37	3139.81	2.507	3.389	1.71E-04
36	Gomti River	0-6800 m	3500.*	101.11	101.05	112.27	3139.81	2.767	3.475	1.69E-04
37	Gomti River	0-6800 m	3400	100.73	100.66	112.17	3139.81	2.944	3.796	1.76E-04
38	Gomti River	0-6800 m	3300.*	101.65	101.65	112.21	3139.81	2.838	3.389	1.66E-04
39	Gomti River	0-6800 m	3200	102.56	102.57	112.22	3139.81	2.599	2.872	1.47E-04
40	Gomti River	0-6800 m	3100.*	102.60	102.61	112.24	3139.81	2.327	2.379	1.30E-04
41	Gomti River	0-6800 m	3000	102.63	102.65	112.25	3139.81	2.158	2.139	1.19E-04
42	Gomti River	0-6800 m	2900.*	102.41	102.43	112.23	3139.81	2.149	2.169	1.19E-04
43	Gomti River	0-6800 m	2800	102.20	102.21	112.22	3139.81	2.182	2.221	1.20E-04
44	Gomti River	0-6800 m	2700.*	102.24	102.25	112.23	3139.81	2.197	2.142	1.13E-04
45	Gomti River	0-6800 m	2600	102.28	102.29	112.22	3139.81	2.186	2.080	1.07E-04
46	Gomti River	0-6800 m	2500.*	102.23	102.24	112.20	3139.81	2.183	2.066	1.07E-04

47	Gomti River	0-6800 m	2400	102.17	102.18	112.19	3139.81	2.200	2.129	1.09E-04
48	Gomti River	0-6800 m	2300.*	102.09	102.10	112.17	3139.81	2.220	2.141	1.11E-04
49	Gomti River	0-6800 m	2200	102.01	102.02	112.16	3139.81	2.253	2.240	1.14E-04
50	Gomti River	0-6800 m	2100.*	102.09	102.10	112.12	3139.81	2.292	2.310	1.20E-04
51	Gomti River	0-6800 m	2000	102.18	102.18	112.10	3139.81	2.375	2.500	1.32E-04
52	Gomti River	0-6800 m	1900.*	102.13	102.11	112.02	3139.81	2.530	2.832	1.50E-04
53	Gomti River	0-6800 m	1800	102.08	101.98	111.99	3139.81	2.617	3.588	1.85E-04
54	Gomti River	0-6800 m	1716	101.20	100.99	112.00	3139.81	2.609	4.633	2.36E-04
55	Gomti River	0-6800 m	1684	101.20	101.13	111.92	3139.81	2.536	4.470	2.33E-04
56	Gomti River	0-6800 m	1600	100.32	100.34	111.97	3139.81	2.420	3.317	1.68E-04
57	Gomti River	0-6800 m	1500.*	100.60	100.62	111.90	3139.81	2.488	2.885	1.45E-04
58	Gomti River	0-6800 m	1400	100.88	100.89	111.80	3139.81	2.696	3.271	1.64E-04
59	Gomti River	0-6800 m	1300.*	101.41	101.41	111.78	3139.81	2.757	3.329	1.70E-04
60	Gomti River	0-6800 m	1200	101.94	101.95	111.78	3139.81	2.553	2.845	1.48E-04
61	Gomti River	0-6800 m	1100.*	101.10	101.14	111.86	3139.81	2.140	2.060	1.02E-04
62	Gomti River	0-6800 m	1000	100.27	100.30	111.92	3139.81	1.818	1.473	6.94E-05
63	Gomti River	0-6800 m	900.*	100.91	100.93	111.89	3139.81	1.848	1.458	7.28E-05
64	Gomti River	0-6800 m	800	101.55	101.57	111.84	3139.81	1.965	1.637	8.36E-05
65	Gomti River	0-6800 m	700.*	101.28	101.30	111.85	3139.81	1.864	1.498	7.70E-05
66	Gomti River	0-6800 m	600	101.01	101.02	111.86	3139.81	1.892	1.596	8.18E-05
67	Gomti River	0-6800 m	500.*	101.34	101.34	111.71	3564.81	2.313	2.425	1.25E-04
68	Gomti River	0-6800 m	400	101.66	101.54	111.56	3564.81	2.679	3.166	1.67E-04
69	Gomti River	0-6800 m	300.*	101.60	101.54	111.56	3564.81	2.695	3.223	1.70E-04
70	Gomti River	0-6800 m	200	101.54	101.54	111.56	3564.81	2.542	2.922	1.55E-04
71	Gomti River	0-6800 m	100.*	101.80	101.80	111.58	3564.81	2.361	2.598	1.44E-04
72	Gomti River	0-6800 m	0	102.05	102.06	111.60	3564.81	2.268	2.394	1.40E-04

(B) Hydraulic parameters for flood simulation in Gomti river with river front development

	River	Reach	Stations	Initial bed (m)	Final Bed level (m)	HFL(m)	Flow (m3/s)	Velocity (m/s)	Shear Stress (N/m2)	EG Slope (m/m)
1	Gomti River	0-6800 m	6800	101.18	101.18	113.45	3139.81	2.083	2.111	1.00E-04
2	Gomti River	0-6800 m	6700.*	102.01	102.01	113.46	3139.81	1.915	1.703	8.44E-05
3	Gomti River	0-6800 m	6600	102.83	102.83	113.46	3139.81	1.816	1.476	7.55E-05
4	Gomti River	0-6800 m	6500.*	102.56	102.40	113.45	3139.81	1.987	3.551	1.84E-04
5	Gomti River	0-6800 m	6418	102.29	101.24	113.27	3139.81	2.365	8.996	4.31E-04
6	Gomti River	0-6800 m	6382	102.29	101.75	113.06	3139.81	2.601	9.107	4.74E-04
7	Gomti River	0-6800 m	6200	100.81	100.89	113.05	3139.81	2.550	5.484	2.50E-04
8	Gomti River	0-6800 m	6100.*	101.73	101.87	113.09	3139.81	2.299	2.283	1.11E-04
9	Gomti River	0-6800 m	6000	102.66	102.72	113.13	3139.81	2.133	2.101	1.07E-04
10	Gomti River	0-6800 m	5900.*	103.17	103.20	113.07	3139.81	2.224	2.399	1.37E-04
11	Gomti River	0-6800 m	5800	103.67	103.70	113.05	3139.81	2.343	2.511	1.61E-04
12	Gomti River	0-6800 m	5710.*	103.35	103.30	113.03	3139.81	2.410	3.782	2.16E-04
13	Gomti River	0-6800 m	5620	103.03	102.56	112.96	3139.81	2.543	6.907	3.41E-04
14	Gomti River	0-6800 m	5580	103.03	102.69	112.81	3139.81	2.544	6.704	3.41E-04
15	Gomti River	0-6800 m	5490.*	102.56	102.61	112.86	3139.81	2.407	4.025	2.12E-04
16	Gomti River	0-6800 m	5418.3	102.09	102.16	112.83	3139.81	2.416	3.369	1.76E-04
17	Gomti River	0-6800 m	5381.7	102.09	102.13	112.77	3139.81	2.512	3.634	1.91E-04
18	Gomti River	0-6800 m	5200	100.14	100.18	112.65	3139.81	2.509	3.365	1.69E-04
19	Gomti River	0-6800 m	5100.*	101.54	101.58	112.68	3139.81	2.344	2.684	1.45E-04
20	Gomti River	0-6800 m	5000	102.94	102.98	112.70	3139.81	2.163	2.248	1.29E-04
21	Gomti River	0-6800 m	4900.*	103.39	103.42	112.69	3139.81	2.132	2.084	1.21E-04
22	Gomti River	0-6800 m	4800	103.84	103.87	112.69	3139.81	2.121	1.927	1.10E-04
23	Gomti River	0-6800 m	4700.*	103.13	103.16	112.70	3139.81	1.988	1.651	8.83E-05
24	Gomti River	0-6800 m	4600	102.43	102.45	112.72	3139.81	1.882	1.503	7.32E-05
25	Gomti River	0-6800 m	4500.*	102.24	102.27	112.68	3139.81	1.955	1.614	8.10E-05
26	Gomti River	0-6800 m	4400	102.06	102.07	112.63	3139.81	2.127	1.958	1.02E-04

27	Gomti River	0-6800 m	4300.*	102.27	102.27	112.57	3139.81	2.295	2.289	1.22E-04
28	Gomti River	0-6800 m	4200	102.47	102.47	112.54	3139.81	2.402	2.652	1.38E-04
29	Gomti River	0-6800 m	4100.*	102.15	102.15	112.50	3139.81	2.395	2.561	1.44E-04
30	Gomti River	0-6800 m	4000	101.83	101.84	112.50	3139.81	2.325	2.606	1.34E-04
31	Gomti River	0-6800 m	3900.*	101.96	101.97	112.50	3139.81	2.316	2.418	1.25E-04
32	Gomti River	0-6800 m	3800	102.09	102.10	112.50	3139.81	2.384	2.444	1.24E-04
33	Gomti River	0-6800 m	3700.*	101.79	101.79	112.43	3139.81	2.441	2.762	1.39E-04
34	Gomti River	0-6800 m	3620	101.49	101.46	112.43	3139.81	2.442	3.311	1.66E-04
35	Gomti River	0-6800 m	3580	101.49	101.41	112.35	3139.81	2.514	3.412	1.72E-04
36	Gomti River	0-6800 m	3500.*	101.11	101.04	112.26	3139.81	2.773	3.494	1.70E-04
37	Gomti River	0-6800 m	3400	100.73	100.67	112.14	3139.81	2.952	3.819	1.77E-04
38	Gomti River	0-6800 m	3300.*	101.65	101.65	112.19	3139.81	2.846	3.412	1.68E-04
39	Gomti River	0-6800 m	3200	102.56	102.57	112.20	3139.81	2.607	2.891	1.48E-04
40	Gomti River	0-6800 m	3100.*	102.60	102.61	112.22	3139.81	2.334	2.396	1.32E-04
41	Gomti River	0-6800 m	3000	102.63	102.65	112.23	3139.81	2.165	2.152	1.20E-04
42	Gomti River	0-6800 m	2900.*	102.41	102.43	112.21	3139.81	2.153	2.176	1.20E-04
43	Gomti River	0-6800 m	2800	102.20	102.21	112.20	3139.81	2.189	2.233	1.21E-04
44	Gomti River	0-6800 m	2700.*	102.24	102.25	112.20	3139.81	2.220	2.187	1.16E-04
45	Gomti River	0-6800 m	2600	102.28	102.29	112.20	3139.81	2.223	2.152	1.11E-04
46	Gomti River	0-6800 m	2500.*	102.23	102.24	112.17	3139.81	2.222	2.142	1.11E-04
47	Gomti River	0-6800 m	2400	102.17	102.18	112.16	3139.81	2.234	2.196	1.13E-04
48	Gomti River	0-6800 m	2300.*	102.09	102.10	112.15	3139.81	2.245	2.191	1.14E-04
49	Gomti River	0-6800 m	2200	102.01	102.02	112.14	3139.81	2.270	2.274	1.16E-04
50	Gomti River	0-6800 m	2100.*	102.09	102.10	112.10	3139.81	2.300	2.325	1.21E-04
51	Gomti River	0-6800 m	2000	102.18	102.18	112.08	3139.81	2.381	2.513	1.33E-04
52	Gomti River	0-6800 m	1900.*	102.13	102.11	112.00	3139.81	2.538	2.851	1.52E-04
53	Gomti River	0-6800 m	1800	102.08	101.98	111.97	3139.81	2.627	3.614	1.86E-04
54	Gomti River	0-6800 m	1716	101.20	100.98	111.98	3139.81	2.621	4.659	2.38E-04
55	Gomti River	0-6800 m	1684	101.20	101.12	111.90	3139.81	2.556	4.539	2.36E-04
56	Gomti River	0-6800 m	1600	100.32	100.34	111.94	3139.81	2.448	3.424	1.74E-04

57	Gomti River	0-6800 m	1500.*	100.60	100.62	111.88	3139.81	2.505	2.951	1.49E-04
58	Gomti River	0-6800 m	1400	100.88	100.89	111.78	3139.81	2.703	3.291	1.66E-04
59	Gomti River	0-6800 m	1300.*	101.41	101.41	111.76	3139.81	2.764	3.349	1.72E-04
60	Gomti River	0-6800 m	1200	101.94	101.95	111.76	3139.81	2.565	2.871	1.49E-04
61	Gomti River	0-6800 m	1100.*	101.10	101.13	111.84	3139.81	2.208	2.167	1.07E-04
62	Gomti River	0-6800 m	1000	100.27	100.30	111.87	3139.81	1.974	1.720	8.14E-05
63	Gomti River	0-6800 m	900.*	100.91	100.93	111.84	3139.81	2.015	1.727	8.66E-05
64	Gomti River	0-6800 m	800	101.55	101.57	111.81	3139.81	2.107	1.866	9.56E-05
65	Gomti River	0-6800 m	700.*	101.28	101.30	111.82	3139.81	2.020	1.750	8.93E-05
66	Gomti River	0-6800 m	600	101.01	101.02	111.82	3139.81	2.030	1.806	9.30E-05
67	Gomti River	0-6800 m	500.*	101.34	101.34	111.69	3564.81	2.375	2.532	1.31E-04
68	Gomti River	0-6800 m	400	101.66	101.55	111.56	3564.81	2.689	3.187	1.68E-04
69	Gomti River	0-6800 m	300.*	101.60	101.55	111.56	3564.81	2.695	3.223	1.70E-04
70	Gomti River	0-6800 m	200	101.54	101.54	111.56	3564.81	2.540	2.917	1.55E-04
71	Gomti River	0-6800 m	100.*	101.80	101.80	111.58	3564.81	2.360	2.582	1.43E-04
72	Gomti River	0-6800 m	0	102.05	102.06	111.60	3564.81	2.269	2.369	1.38E-04