

## 6.0 Stage-Discharge Relationship for River Sections:

Hourly river stage data during monsoon period for various gauging sections in Barak Valley are used in the study to develop flow simulation model for the river system. A stage discharge relationship for the gauging stations have been developed using nonlinear regression technique. The stage –discharge relationships developed for different gauging stations in the valley are as follows:

Table-6.1 : Stage-Discharge Relationships for various gauging stations:

Name of the River	Gauging Station	Depth vs Discharge Relationships
Barak	Fulertal	$Q = 0.5038y^{3.4265}$
Rukni	Dholai	$Q = 0.5362y^{3.1835}$
Sonai	TulerGram	$Q = 0.7115y^{2.5212}$
Sonai	Moinerkhal	$Q = 6.6468y^{2.1154}$
Barak	Annapunaghat	$Q = 0.8780y^{3.0115}$
Katakhal	Matijuri	$Q = 0.0571y^{3.9116}$
Barak	Badarpurghat	$Q = 0.5823y^{3.248}$
Gumra	Ghumra	$Q = 7.1989y^{1.7705}$
Longai	Fakirabazar	$Q = 0.1317y^{3.2366}$

### 6.1: River System Flood Flow Simulation Model:

The three districts in Bark Valley are drained by the Barak River system; flow in the main river is due to flows from different upstream catchments. In the study area Flows from the upstream catchments unite downstream forming a combined outflow for the river system. A river system having a number of upstream flows may be replaced by an imaginary single channel having a single upstream flow that produces same outflow as observed in the river system (Choudhury 2002,2007). The multiple inflows-single outflow model for the river systems have been calibrated by using computed discharge data for the river system. As described earlier,the drainage system in the study area is segmented into networks with outflow at Annapurnaghat and at Badarpur ghat. Stage data for all gauging stations in the study were collected from CWC office and the hourly rainfall data for the stations in the study area were collected from RMC Guwahati. Considering maximum availability of rainfall

records the flow data for the downstream station at Badarpurghat is scanned to identify major flood events. Three flood events during the period 2000-2010 were selected considering availability of rainfall records. Details of the flood events used in the study are given in the table below.

Table-6.2: Details of the flood Events used in the study

Details Of flood Events Considered																	
Flood Events	Start		End		Peak Flow Depth		Peak Flow Rate		Safe Depth		Safe Discharge		Rainfall Duration				Total Rainfall duration in (h)
	Date	Time	Date	Time	A.P.Ghat	B.P.Ghat	A.P.Ghat	B.P.Ghat	A.P.Ghat	B.P.Ghat	A.P.Ghat	B.P.Ghat	Start		End		
													Date	Time	Date	Time	
Event-1	10-Jul-04	1:00AM	17-Jul-04	12:00AM	16.36	15.93	4048.63	4859.993	20.39	17.20	3300.902	4015	8-Jul-04	1:00AM	19-Jul-04	12:00AM	264
Event-2	19-Jul-04	1:00AM	29-Jul-04	12:00AM	16.69	16.26	4398.26	4870.75	20.39	17.20	3300.902	4015	17-Jul-04	1:00AM	1-Aug-04	12:00AM	336
Event-3	11-Jun-06	1:00AM	21-Jun-06	12:00AM	15.70	15.68	3718.74	4759.86	20.39	17.20	3300.902	4015	9-Jul-04	1:00AM	22-Jul-04	12:00AM	312

Using the recorded for the gauged catchments and computed flow for the ungauged catchment downstream flow at Annapurnaghat and Badarpurghat are simulated on the basis of upstream flows applying the model as given in equation (6.1)

$$Q_{(t+\Delta t)}^D = C_1(\sigma^{1,r} Q_t^1 + \sigma^{2,r} Q_t^2 + \sigma^{3,r} Q_t^{3,r} + \dots \sigma^{n,r} Q_t^{n,r}) + C_2(\sigma^{1,r} Q_t^1 + \sigma^{2,r} Q_t^2 + \sigma^{3,r} Q_t^{3,r} + \dots \sigma^{n,r} Q_t^{n,r}) + C_3 Q_t^D \quad (6.1)$$

Here,  $Q_{(*)}^{(*)}$  = flow from the upstream catchments and  $Q_{(*)}^D$  = flow at the downstream station in the river system. Model parameters for the upper and complete networks were estimated by using genetic algorithm techniques.

### **Model parameters estimation:**

The model parameters  $C_1$ ,  $C_2$ ,  $C_3$  or  $k$  &  $x$  and  $\sigma^{p,r}$  are estimated by minimizing the objective function given by-

$$\text{Min } f = (Q_{\text{comp}} - Q_{\text{obs}})^2 \quad (6.2)$$

Here,  $Q_{\text{comp}}$  = computed downstream discharge and  $Q_{\text{obs}}$  = Observed downstream discharge

### **Upper Network with outflow at Annapurnaghat:**

The upper network consists of flows from both gauged and ungauged catchments; there are six upstream flow stations in the river network with outflow at Annapurnaghat. As there are six upstream stations in the river network to calibrate the simulation model parameters  $C_1$ ,  $C_2$ , and the shift parameters,  $\sigma^{1,r}$  for six upstream flows are estimated using a recorded flood event. In the present study three flood events are used that occurred during the period 2000-2010. The periods of the selected flood events, event-1, event-2 and event-3 are: July 10-17, 2004; July 19-29, 2004 and June 11-21, 2006. The duration of the events are 168hrs, 240hrs and 240hrs respectively. The flood events used in the study are shown in figures: Discharge data of event (1) are used to estimate the model parameters by minimizing the sum of squared error between observed and computed outflow at Annapurnaghat. The estimated model parameters for the upper network are given in the table below.

### **Complete River Network with outflow at Badarpurghat:**

To simulate the flow at Badarpurghat complete river network in the study area is considered. The complete river network consists of nine upstream flows and the downstream outflow is at Badarpurghat. The upstream flows in the river systems are: from the catchments of Jiri, Chiri, Madhura, Ghagra, Jatinga and the river flows recorded at Fulertal, Dholai, Moinerkhal, and Matijuri. Using the same flood event (event-1) model parameters for the complete network are also estimated by using genetic algorithm technique. The estimated parameters for the networks are listed in the Tables given below:

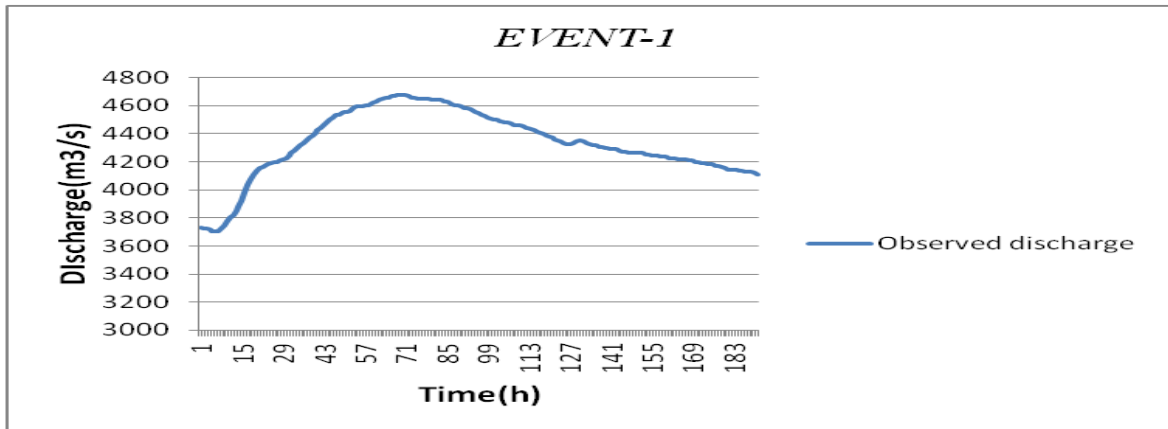


Figure.6.1. represents the flood event from 10<sup>th</sup> – 17<sup>th</sup> July, 2004 at BpGhat.

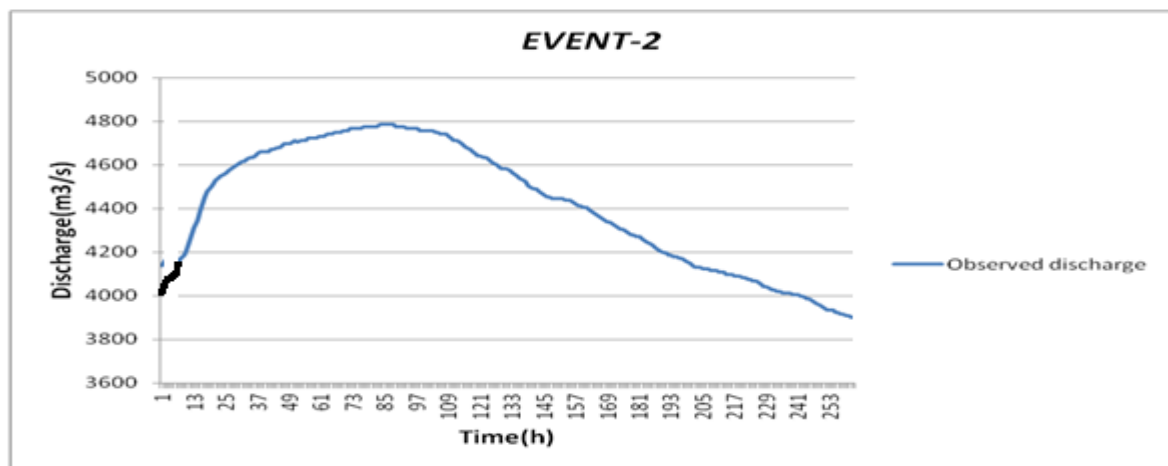


Figure-6.2 Represents the flood event from 19<sup>th</sup> – 29<sup>th</sup> July, 2004 at BpGhat

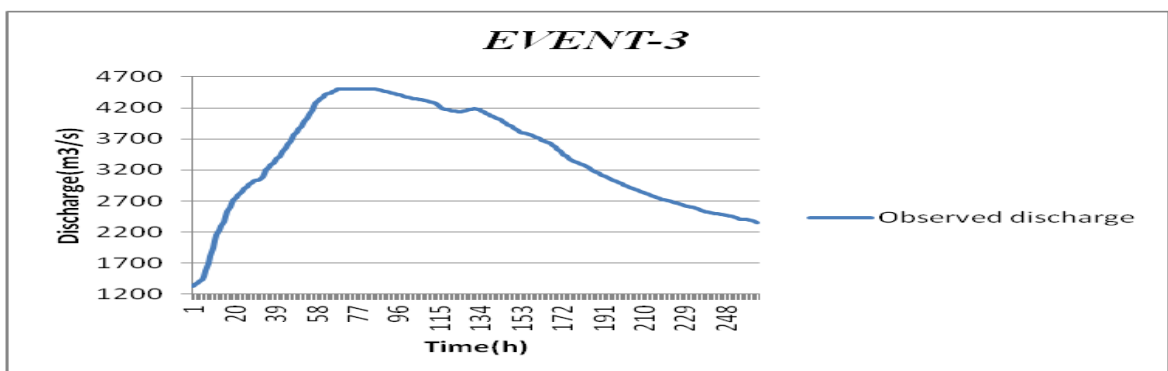


Figure-6.3 The flood event from 11<sup>th</sup> – 21<sup>st</sup> June, 2006 at BpGhat.

Table-6.3- Estimated parameter for the upper network having outflow at Annapurnaghat

<i>UPPERNETWORK-Jiri-Fulertal-Chiri-Dholai-Maniarkhal-Madhura-A.P.ghat</i>										
$\sigma^1$ (Jiri)	$\sigma^2$ (Fulertal)	$\sigma^3$ (Chiri)	$\sigma^4$ (Dholai)	$\sigma^5$ (Mani)	$\sigma^6$ (Madhura)	$C_1$	$C_2$	$C_3$ (A.P. Ghat)	$K$ (hrs)	$x$
0.61	0.71	0.21	1.00	0.57	0.28	0.10	0.11	.80	5	0.1

Table 6.4.-: Estimated parameter for the complete River Network having outflow at Badarpurghat

<i>Complete Network:Rivers:Jiri-Fulertal-Chiri-Dholai-Maniarkhal-Madhura-Jatinga-Matijuri-Ghagra-Badarpurghat</i>													
$\sigma^1$ (Jiri)	$\sigma^2$ (Fulertal)	$\sigma^3$ (Chiri)	$\sigma^4$ (Dholai)	$\sigma^5$ (Mani)	$\sigma^6$ (Madhu)	$\sigma^7$ (Jatinga)	$\sigma^8$ (Matijuri)	$\sigma^9$ (Ghagra)	$C_1$	$C_2$	$C_3$	$k$ (hrs)	$x$
0.10	0.31	0.21	0.72	0.10	0.20	0.13	2.19	0.10	0.09	0.05	0.85	7.0	0.02

Using the estimated parameters in the multiple flow model given by equation (6.1) flood flow at Annapurnaghat and at Badarpurghat are estimated for the flood events as shown in the figures 6.4 to figure 6.9

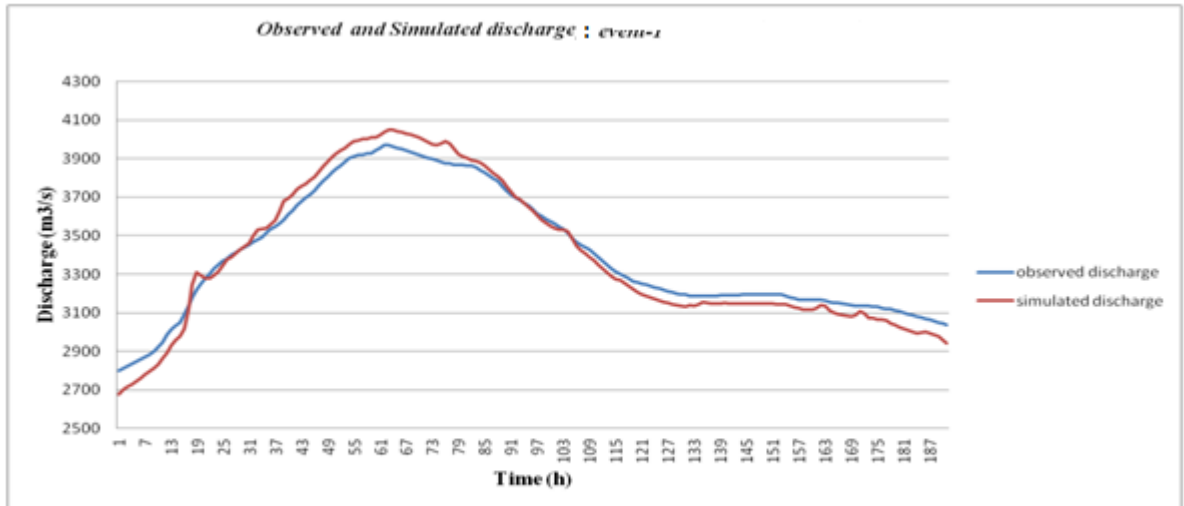


Figure-6.4: Observed and simulated discharge at Annapurnaghat (event-1)

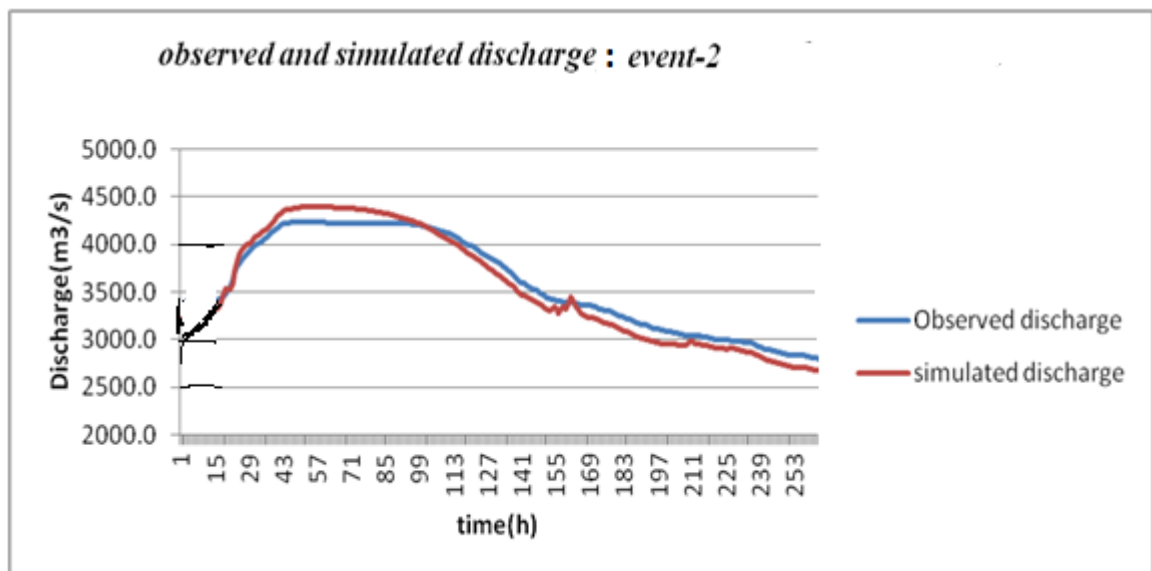


Figure-6.5: Observed and simulated discharge at Annapurnaghat (event-2)

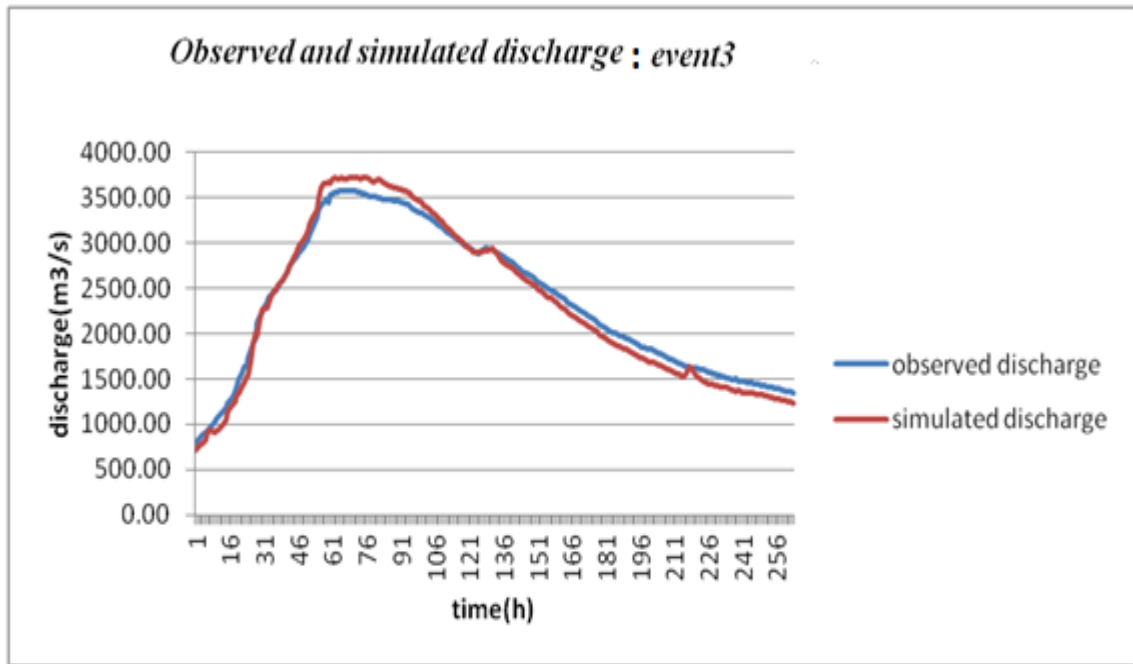


Figure-6.6: Observed and simulated discharge at Annapurnaghat (event-3)

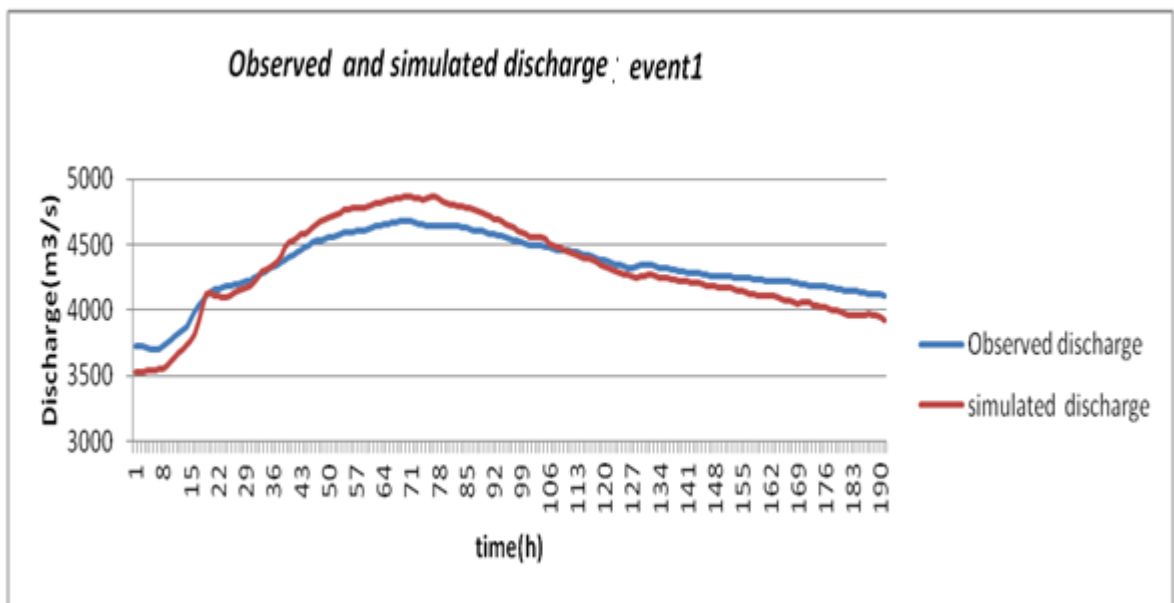


Figure-6.7: Observed and simulated discharge at Badrpurghat (event-1)

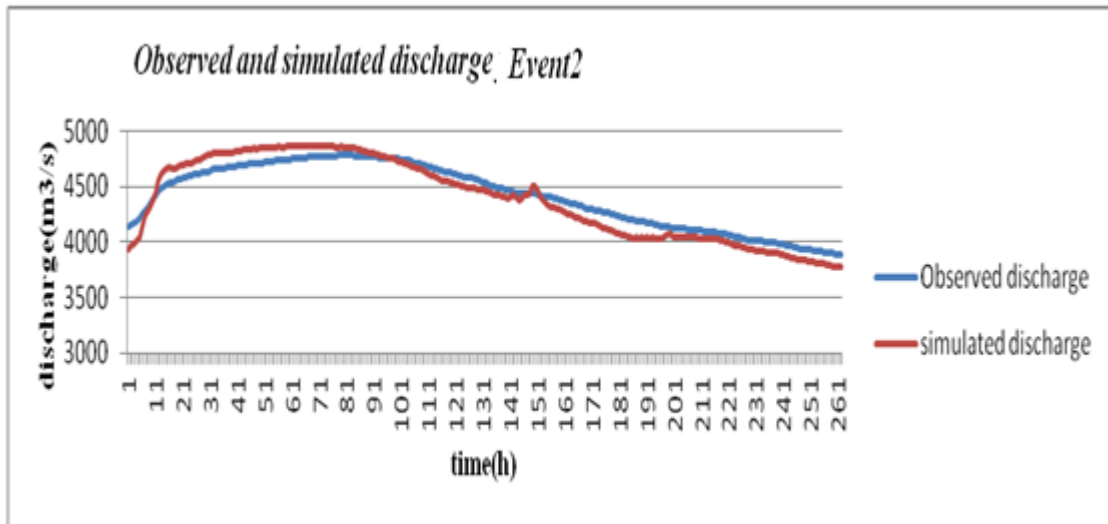


Figure-6.8: Observed and simulated discharge at Badrpurghat (event-2)

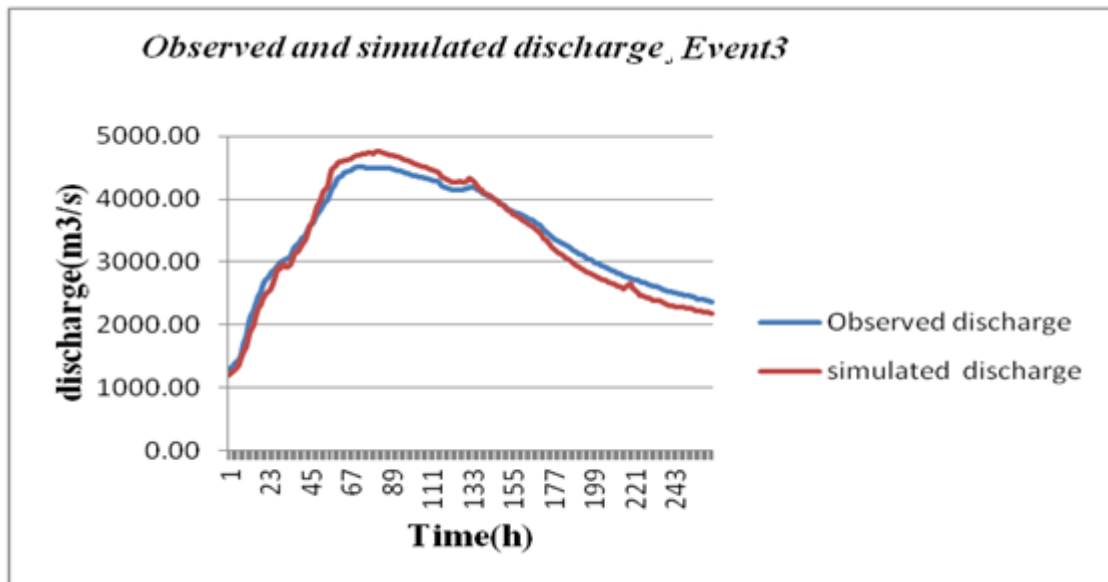


Figure-6.9: Observed and simulated discharge at Badrpurghat (event-3)

## 6.2 Downstream Flood Peak Improvement Analysis:



The simulation model given by equation (6.1) is further used to estimate impacts of tributary flows on the downstream flood flow scenarios. Applying flow simulation model the peak flow reduction indicating improvement in the flood flow at the downstream stations Annapurnaghat and Badarpurghat for completely restricting flows from the ungauged and gauged catchments is studied. The simulation study is conducted by restricting flow in one catchment at a time and restricting flow from two catchments at a time. The results obtained in terms of percentage reduction in the peak flow rate at the downstream station Annapurnaghat and Badarpurghat for event-1 and the average improvement considering selected three events are listed in Tables-6.5 to 6.12 given in the following pages.



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Table-6.5:- Peak flow improvement at Annpurnaghat for restricting flow from single upstream catchment completely ( EVENT 1: FROM 10-JULY TO 17 JULY-2004)

Sl. No	Flow restricted in	Peak Discharge- A.P.Ghat(Obs)	Peak Discharge (With Restricted Flow)	Safe Discharge	D/S Unsafe Discharge Reduction				Flooding Time				Peak Discharge			
					Volume( above safe level m <sup>3</sup> )	Volume( above safe level (Rest)	Improvement (m <sup>3</sup> )	%imprvmt	Total flood time (Hours)	Reduced flood time (Hours)	Improvement (Hours)	%imprvmt	Obs.Peak Discharge above danger level (m <sup>3</sup> /s)	Restricted Peak Discharge above safe level (m <sup>3</sup> /s)	Improvement(m <sup>3</sup> /s)	%imprvmt
1	JIRI	4049	4046	3301	2691828	2680612	11215	0.41	90	90	0	0	748	745	3.11	0.417
2	CHIRI	4049	4041	3301	2691828	2662751	29076	1.08	90	90	0	0	748	740	8.07	1.08
3	DHOLAI	4049	4011	3301	2691828	2555138	136689	5.07	90	87	3	3.33	748	710	37.96	5.078
4	MANIARKHAL	4049	3983	3301	2691828	2457242	234585	8.71	90	87	3	3.33	748	683	65.16	8.715
5	MADHURA	4049	4040	3301	2691828	2659861	31967	1.18	90	90	0	0	748	739	8.88	1.188



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**Table-6.6:- Peak flow improvement at Annapurnaghat for restricting flow from two upstream catchments completely ( EVENT 1: FROM 10-JULY TO 17 JULY-2004)**

Sl. Nol	Flow restricted in	Peak Discharge- A.P.Ghat(Obs)	Peak Discharge (With Restricted Flow)	Safe Discharge	D/S Unsafe flow Reduction				Flooding Time				Flood Peak Discharge			
					Volume( above safe level m <sup>3</sup> )	Volume( above safe level (Rest)	Improvement (m <sup>3</sup> )	%imprvmt	Total flood time (Hours)	Reduced flood time (Hours)	Improvement (Hours)	%imprvmt	Obs Peak Discharge above danger level (m <sup>3</sup> /s)	Restricted Peak Discharge above safe level (m <sup>3</sup> /s)	Improvement(m <sup>3</sup> /s)	%imprvmt
1	jiri& chi	4049	4037	3301	2691828	2651536	40292	1.497	90	90	0	0	748	737	11	1.497
2	jir& dho	4049	4008	3301	2691828	2543923	147904	5.495	90	87	3	3.333	748	707	41	5.495
3	jir&mani	4049	3980	3301	2691828	2446027	245800	9.131	90	87	3	3.333	748	679	68	9.131
4	jir& mad	4049	4037	3301	2691828	2648646	43182	1.604	90	88	2	2.222	748	736	12	1.604
5	chi &dho	4049	4003	3301	2691828	2526062	165766	6.158	90	86	4	4.444	748	702	46	6.158
6	chi&man	4049	3975	3301	2691828	2428166	263662	9.795	90	87	3	3.333	748	674	73	9.795
7	chi&mad	4049	4032	3301	2691828	2630785	61043	2.268	90	88	2	2.222	748	731	17	2.268
8	dho&ma	4049	3946	3301	2691828	2320554	371274	13.79	90	84	6	6.667	748	645	103	13.79
9	dho&mad	4049	4002	3301	2691828	2523172	168656	6.265	90	86	4	4.444	748	701	47	6.265
10	man&mad	4049	3975	3301	2691828	2425276	266552	9.902	90	86	4	4.444	748	674	74	9.902



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**Table-6.7:- Peak flow improvement at BadarpurGhatfor restricting flow from single upstream catchment completely ( EVENT 1: FROM 10-JULY TO 17 JULY-2004)**

Sl. Nol	Flow restricted in	Peak Discharge- B.P.Ghat(Obs)	Peak Discharge (With Restricted Flow)	Safe Discharge	D/S Unsafe flow Reduction				Flooding Time				Flood Peak Discharge			
					Volume( above safe level m <sup>3</sup> )	Volume( above safe level (Rest)	Improvement (m <sup>3</sup> )	%imprvmt	Total flood time (Hours)	Reduced flood time (Hours)	Improvement (Hours)	%imprvmt	Obs Peak.Discharge above danger level (m <sup>3</sup> /s)	RestrictObs Peak Discharge above safe level (m <sup>3</sup> /s)	Improvement(m <sup>3</sup> /s)	%imprvmt
1	Jiri	4860	4857	4015	3041973	3030198	11776	0.38	160	156	4	2.5	845	842	3	0.387
2	Chiri	4860	4854	4015	3041973	3020657	21316	0.70	160	156	4	2.5	845	839	6	0.701
3	Dholai	4860	4841	4015	3041973	2973934	68039	2.23	160	157	3	1.875	845	826	19	2.237
4	Moniar	4860	4852	4015	3041973	3012209	29764	0.97	160	158	2	1.25	845	837	8	0.978
5	Madhu	4860	4855	4015	3041973	3024992	16981	0.55	160	156	4	2.5	845	840	5	0.558
6	Jatinga	4860	4857	4015	3041973	3031787	10186	0.33	160	157	3	1.875	845	842	3	0.335
7	Matijhu	4860	4295	4015	3041973	1009705	2032268	66.80	160	76	84	52.5	845	280	565	66.808
8	Ghagra	4860	4858	4015	3041973	3036250	5723	0.188	160	158	2	1.25	845	843	2	0.188



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**Table-6.8:- Peak flow improvement at BadarpurGhat for restricting flow from two upstream catchments completely ( EVENT 1: FROM 10-JULY TO 17 JULY-2004**

Sl. Nol	Flow restricted in	Peak Discharge- B.P.Ghat(Obs)	Peak Discharge (With Restricted Flow)	Safe Discharge	D/S Unsafe Discharge Reduction				Flooding Time				Flood Peak Discharge			
					Volume( above safe level m <sup>3</sup> )	Volume( above safe level (Rest)	Improvement (m <sup>3</sup> )	%imprvmt	Total flood time (Hours)	Reduced flood time (Hours)	Improvement (Hours)	%imprvmt	Obs.Peak Discharge above danger level (m <sup>3</sup> /s)	Restricted Peak Discharge above safe level (m <sup>3</sup> /s)	Improvement(m <sup>3</sup> /s)	%imprvmt
1	Jiri and Chiri	4860	4851	4015	3041973	3008881	33092	1.09	160	155	5	3.1	844	835.80	9.2	1.1
2	Jiri and Dholai	4860	4838	4015	3041973	2962158	79815	2.62	160	154	6	3.8	844	822.82	22.2	2.6
3	Jiri and Moniarkhal	4860	4848	4015	3041973	3000434	41539	1.37	160	156	4	2.5	844	833.45	11.5	1.4
4	Jiri and Madhura	4860	4852	4015	3041973	3013216	28757	0.95	160	156	4	2.5	844	837.01	8.0	0.9
5	Chiri and Dholai	4860	4835	4015	3041973	2952618	89356	2.94	160	155	5	3.1	844	820.17	24.8	2.9
6	Chiri and Moniarkhal	4860	4846	4015	3041973	2990893	51080	1.68	160	156	4	2.5	844	830.80	14.2	1.7



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7	Chiri and Madhura	4860	4849	4015	3041973	3003676	38298	1.26	160	156	4	2.5	844	834.35	10.6	1.3
8	Dholai and Moniarkhal	4860	4833	4015	3041973	2944170	97803	3.22	160	156	4	2.5	844	817.83	27.2	3.2
9	Dholai and Madhura	4860	4836	4015	3041973	2956953	85020	2.80	160	155	5	3.1	844	821.38	23.6	2.8
10	Moniarkhal and Madhura	4860	4847	4015	3041973	2995228	46745	1.54	160	156	4	2.5	844	832.01	13.0	1.5
11	Jatinga and Matijhuri	4860	4293	4015	3041973	999519	2042454	67.14	160	76	84	52.5	844	277.64	567.3	67.1
12	Jatinga and Ghagra	4860	4856	4015	3041973	3026064	15909	0.52	160	156	4	2.5	844	840.57	4.4	0.5
13	Matijhuri and Ghagra	4860	4294	4015	3041973	1003982	2037991	67.00	160	76	84	52.5	844	278.88	566.1	67.0

Average Improvements in the downstream flood flow in terms of reduction in peak flow rates at Annapurnaghat and Badarpurghat considering flood events-1,2 and 3 are computed and are as given in the following tables 6.9-6.12



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Table-6.9:- Peak flow improvement (Average) at Annpurnaghat for restricting flow from single upstream catchment completely

Flow restricted in	Peak Discharge- A.P.Ghat(Obs)	Peak Discharge (With Restricted Flow)	Safe Discharge	D/S Unsafe Discharge Reduction				Flooding Time				Peak Discharge			
				Volume( above safe level m <sup>3</sup> )	Volume( above safe level (Rest)	Improvement (m <sup>3</sup> )	Av. %imprvmt	Total flood time (Hours)	Reduced flood time (Hours)	Improvement (Hours)	%imprvmt	Obs.Peak Discharge above danger level (m <sup>3</sup> /s)	Restricted Peak Discharge above safe level (m <sup>3</sup> /s)	Improvement(m <sup>3</sup> /s)	Av. %imprvmt
JIRI	4049	4046	3301	2691828	2680613	11215	0.49	90	90	0	0.00	748	745	3	0.49
CHIRI	4049	4041	3301	2691828	2662751	29076	1.25	90	90	0	0.00	748	740	8	1.25
DHOLAI	4049	4011	3301	2691828	2555139	136689	11.83	90	87	3	3.33	748	710	38	11.83
MANIARKHAL	4049	3983	3301	2691828	2457243	234585	10.43	90	87	3	3.33	748	683	65	10.43
MADHURA	4049	4040	3301	2691828	2659861	31967	1.61	90	90	0	0.00	748	739	9	1.61



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Table 6.10: Peak flow improvement (Average) at Annpurnaghat for restricting flow from two upstream catchment completely)

Flow restricted in	Peak Discharge- A.P.Ghat(Obs)	Peak Discharge (With Restricted Flow)	Safe Discharge	D/S Unsafe Discharge Reduction				Flooding Time				Flood Peak Discharge			
				Volume( above safe level m <sup>3</sup> )	Volume( above safe level (Rest)	Improvement (m <sup>3</sup> )	Av. %imprvmt	Total flood time (Hours)	Reduced flood time (Hours)	Improvement (Hours)	%imprvmt	Obs.Peak Discharge above danger level (m <sup>3</sup> /s)	Restricted Peak Discharge above safe level (m <sup>3</sup> /s)	Improvement(m <sup>3</sup> /s)	Av. %imprvmt
jiri& chi	4049	4037	3300.9	2691827	2651536	40292	1.735	90	90	0	0	747.73	737	11.192	1.735
jir& dho	4049	4008	3300.9	2691827	2543923	147904	12.316	90	87	3	3.333	747.73	707	41.085	12.316
jir&mani	4049	3980	3300.9	2691827	2446027	245800	10.91	90	87	3	3.333	747.73	679	68.278	10.91
jir& madhu	4049	4037	3300.9	2691827	2648645	43182	1.858	90	88	2	2.222	747.73	736	11.995	1.858
chi & dho	4049	4003	3300.9	2691827	2526062	165765	13.034	90	86	4	4.444	747.73	702	46.046	13.034
chi& mani	4049	3975	3300.9	2691827	2428166	263661	11.676	90	87	3	3.333	747.73	674	73.239	11.676
chi&madhu	4049	4032	3300.9	2691828	2630785	61043	2.624	90	88	2	2.222	747.73	731	16.956	2.624
dho& mani	4049	3946	3300.9	2691828	2320554	371274	22.256	90	84	6	6.667	747.73	645	103.132	22.256
dho& madhu	4049	4002	3300.9	2691828	2523172	168656	13.204	90	86	4	4.444	747.73	701	46.849	13.204
mani& madhu	4049	3975	3300.9	2691828	2425276	266552	11.799	90	86	4	4.444	747.73	674	74.042	11.799





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**Table-6.11: Peak flow improvement (Average) at Badarpur Ghat for restricting flow from single upstream catchment completely**

Flow restricted in	Peak Discharge- B.P.Ghat(Obs)	Peak Discharge (With Restricted Flow)	Safe Discharge	D/S Unsafe Discharge Reduction				Flooding Time				Flood Peak Discharge			
				Volume( above safe level m <sup>3</sup> )	Volume( above safe level (Rest)	Improvement (m <sup>3</sup> )	Av. %imprvmt	Total flood time (Hours)	Reduced flood time (Hours)	Improvement (Hours)	%imprvmt	Peak Discharge above danger level (m <sup>3</sup> /s)	Restricted Peak Discharge above safe level (m <sup>3</sup> /s)	Improvement(m <sup>3</sup> /s)	Av. %imprvmt
Jiri	4860	4857	4015	3041973	3030198	11776	2.15	160	156	4	3	845	842	3.27	2.05
Chiri	4860	4854	4015	3041973	3020657	21316	1.33	160	156	4	3	845	839	5.92	1.36
Dholai	4860	4841	4015	3041973	2973934	68039	4.14	160	157	3	2	845	826	18.90	4.14
Moniar	4860	4852	4015	3041973	3012209	29764	1.14	160	158	2	1	845	837	8.27	1.04
Madhu	4860	4855	4015	3041973	3024992	16981	1.10	160	156	4	3	845	840	4.72	1.50
Jatinga	4860	4857	4015	3041973	3031787	10186	0.70	160	157	3	2	845	842	2.83	0.70
Matijhuri	4860	4295	4015	3041973	1009705	2032268	66.15	160	76	84	53	845	280	564.52	6.15
Ghagra	4860	4858	4015	3041973	3036250	5723	0.39	160	158	2	1	845	843	1.59	1.39



## Flood Damage Mitigation: Report

Table-6.12: Peak flow improvement (Average) at BadarpurGhat for restricting flow from two upstream catchment completely

Flow restricted in	Peak Discharge-B.P.Ghat(Obs)	Peak Discharge (With Restricted Flow)	Safe Discharge	D/S Unsafe Discharge Reduction				Flooding Time				Flood Peak Discharge			
				Volume( above safe level m <sup>3</sup> )	Volume( above safe level (Rest)	Improvement (m <sup>3</sup> )	Av. %improvement	Total flood time (Hours)	Reduced flood time (Hours)	Improvement (Hours)	%improvement	Peak Discharge above danger level (m <sup>3</sup> /s)	Restricted Peak Discharge above safe level (m <sup>3</sup> /s)	Improvement(m <sup>3</sup> /s)	Av. %imprvmt
Jiri and Chiri	4860	4851	4015	3041973	3008881	33092	1.7	160	155	5	3.1	845	836	9	1.7
Jiri and Dholai	4860	4838	4015	3041973	2962158	79815	3.6	160	154	6	3.8	845	823	22	3.6
Jiri and Moniarkhal	4860	4848	4015	3041973	3000434	41539	2.8	160	156	4	2.5	845	833	12	2.8
Jiri and Madhura	4860	4852	4015	3041973	3013216	28757	2.1	160	156	4	2.5	845	837	8	2.1
Chiri and Dholai	4860	4835	4015	3041973	2952618	89356	4.1	160	155	5	3.1	845	820	25	4.1
Chiri and Moniarkhal	4860	4846	4015	3041973	2990893	51080	3.4	160	156	4	2.5	845	831	14	3.4



### ***Flood Damage Mitigation: Report***

Chiri and Madhura	4860	4849	4015	3041973	3003676	38298	2.7	160	156	4	2.5	845	834	11	2.7
Dholai and Moniarkhal	4860	4833	4015	3041973	2944170	97803	-1.3	160	156	4	2.5	845	818	27	-1.3
Dholai and Madhura	4860	4836	4015	3041973	2956953	85020	5.1	160	155	5	3.1	845	821	24	5.1
Moniarkhal and Madhura	4860	4847	4015	3041973	2995228	46745	3.2	160	156	4	2.5	845	832	13	3.2
Jatinga and Matijhuri	4860	4293	4015	3041973	999519	2042454	49.0	160	76	84	52.5	845	278	567	49.0
Jatinga and Ghagra	4860	4856	4015	3041973	3026064	15909	19.1	160	156	4	2.5	845	841	4	19.1
Matijhuri and Ghagra	4860	4294	4015	3041973	1003982	2037991	48.3	160	76	84	52.5	845	279	566	48.3

Results given in Tables 6.9 through 6.12 shows that the flow from jiri catchment has the least effect on the downstream flow at Annapurnaghat while impacts of flow from the catchment of Dholai on the flow at Annapurnaghat is the highest. Similar results is obtained when flows from two catchments are restricted and it is found that when flow from Dholai and Mainerkhal are restricted it results to maximum reduction in the peak flood flow rate at Annapurnaghat. In the case of Badarpurghat flow from the catchment of Matijuri is found to have maximum impact and flow from the catchment of Mainerkhal has the least impact on the flood flow at Badarpurghat. Again it is seen that when flow from Matijuri and Jatinga or Matijuri and Ghagra are simultaneously restricted maximum reduction in the peak flood flow rate at Badarpurghat is obtained.

### 6.3 Linear Programming (LP) Formulation

Linear Programming model for finding the optimal releases from a number of upstream catchments to have desired flow levels, below danger level at the downstream points are formulated for the upper network with outflow at Annapurnaghat and for the complete network having outflow at Badarpurghat. The model are run for the normal conditions as well as considering effects on discharge rate due to change in the climate in this region. A separate report on assessment of climate change on flows and rainfalls in the region due to change in the climate conducted by IIT Guwahati is appended with this report. The mathematical program is written in standard LP form with all known quantities on the right hand side of the constraints.

$$\text{Maximize } Z = \sum_{t=1}^{T+1} \text{Flow at upstream stations} \quad (6.3)$$

Subject to the flow constraint applicable to a river system:

$$c_1\sigma_1 i_t^1 + c_2\sigma_1 i_{t+1}^1 + c_1\sigma_3 i_t^3 + c_2\sigma_3 i_{t+1}^3 + c_1\sigma_4 i_t^4 + c_2\sigma_4 i_{t+1}^4 + c_1\sigma_5 i_t^5 + c_2\sigma_5 i_{t+1}^5 + c_1\sigma_6 i_t^6 + c_2\sigma_6 i_{t+1}^6 + c_3 q_t = q_{t+1} - c_1\sigma_2 i_t^2 + c_2\sigma_2 i_{t+1}^2 \quad (6.4)$$

and safe flow limits at the downstream stations.

$$q_{t+1} \leq \text{SafeFlow}$$

$$q_t \leq q_{\max} ; t = 1, 2, \dots, T+1$$

Where,  $c_1, c_2, c_3$  are the routing model co efficient.

$\sigma_1, \sigma_2, \dots, \sigma_6$  are the shift factor.

$q_{t+1}$  is the discharge at downstream at time (t+1).

The values of the parameters in equation (6.4) are obtained from the simulation model described earlier. The model is run to maximize flows from a set of upstream catchments with the constraints that the flow at the downstream stations are less than safe flow rates at the corresponding section. The model has been formulated to determine safe flow condition for the downstream locations Annapurnaghat and Badarpurghat in the river system.

## 6.4 Data used

3 Flood Events used in the study,

Event 1- July 10-17, 2004

Event 2- July 19- 29, 2004

Event 3- June 11- 21, 2006

Table- 6.13:- Flood events used in the study

Flood Events Details												
Flood Events	Start		End		Peak Flow Depth		Peak Flow Rate		Safe Depth		Safe Discharge	
	Date	Time	Date	Time	A.P.Ghat	B.P.Ghat	A.P.Ghat	B.P.Ghat	A.P.Ghat	B.P.Ghat	A.P.Ghat	B.P.Ghat
Event-1	10-Jul-04	1:00AM	17-Jul-04	12:00A M	16.36	15.93	4048.63	4859.99 3	20.39	17.2	3300.90 2	4015
Event-2	19-Jul-04	1:00AM	29-Jul-04	12:00AM	16.69	16.26	4398.26	4870.75	20.39	17.2	3300.902	4015
Event-3	11-Jun-06	1:00AM	21-Jun-06	12:00AM	15.7	15.68	3718.74	4759.86	20.39	17.2	3300.90 2	4015

## **6.5 LP Model Results**

The simulation models described earlier and the LP model formulated for the river system are run for various upstream conditions to assess impacts of flood flow at the downstream locations due to changes in the flow conditions at the upstream catchments. The different cases considered in the study and the results obtained are presented below. The model is used to estimate a set of maximum possible peak flow rates for the upstream catchment that creates safe flow at the important D/S locations in the river system. The models is run for two cases, (i) major ungauged catchments are regulated and (ii) major U/S gauged and ungauged catchment flow excepting the main channel flow at Fulertal are controlled.

### **Case-1: Restricted flows from all upstream ungauged Catchments**

The study is conducted to evaluate maximum allowable peak flow rates from the ungauged catchments resulting minimum possible (safe flow) at the downstream station with no regulation of flow in the gauged catchments. In this case the downstream flow rates are constrained to be less than the safe flow at the downstream station and maximum possible peak flow rates in the upstream ungauged catchments considering event-1, event-2 and event-3 are determined applying the LP model. The peak flow rates obtained for the three events are averaged for the catchments to compute maximum possible Peak flow rates from these catchments that produce safe flow at the downstream station Annapurnaghat and Badarpurghat. Results obtained using the optimization models are given in the tables and figures presented below

**Table:6.14- Percentage reduction in peak flow rates in upstream ungauged catchments necessary to create safe flow at Annapurnaghat**

Upstream Stations	% diff. in Peak flow		Remarks
Jiri	53.20	Decrease	Safe flow at downstream Annapurna Ghat & Peak flow reduction by 18.80%
Chiri	50.93	Decrease	
Madhura	50.55	Decrease	
Fulertal	Unregulated		
Dholai			
Maniarkhal			

**Table 6.15-Percentage reduction in peak flow rates for upstream ungauged catchments required to create safe flow at BadarpurGhat**

Stations	% diff. in Peak flow		Remarks
Jiri	63.36	Decrease	Safe flow at downstream Badarpur Ghat & Peak flow reduction by 17.96%
Chiri	88.65	Decrease	
Madhura	88.05	Decrease	
Jatinga	86.18	Decrease	
Ghagra	84.60	Decrease	
Fulertal	Unregulated		
Dholai			
Maniarkhal			
Matiiuri			

**Table-6.16 : Peak flow rates for the Regulated and unregulated catchments upstream of Annapurnaghat (upto Lakshipur) that creates safe flow at Annapurnaghat**

Stations	Peak Flow Rates			Average Peak Flow Rate	Remarks
	Event1	Event2	Event3		
Jiri	1512.02	1380.42	1411.52	1434.66	Safe Flow at downstream Annapurna Ghat;No Regulationof flows at Fulertal, Dholai & Maniarkhal
Chiri	1064.64	974.50	1328.90	1122.68	
Madhura	926.37	830.21	1493.67	1083.41	
Fulertal	5296.44	5662.63	4839.62	5266.23	
Dholai	267.64	473.18	471.39	404.07	
Maniarkhal	584.56	917.18	518.14	673.29	

Table 6.17: Peak flow rates for the Regulated and unregulated catchments upstream of Badarpurghat (upto Lakshipur) that creates safe flow at Badarpurghat.

Stations	Peak FlowRate			Average Peak Flow Rate	Remarks
	Event1	Event2	Event3		
Jiri	817.29	893.62	1650.06	1120.32	Safe Flow at downstream Badarpur Ghat with No Regulation of at Fulertal, Dholai, Maiarkhal & Matijuri
Chiri	251.69	232.77	291.16	258.54	
Madhura	237.44	220.98	300.97	253.13	
Jatinga	225.94	207.29	287.12	240.11	
Ghagra	209.93	206.59	270.51	229.01	
Fulertal	5296.44	5662.63	4839.62	5266.23	
Dholai	267.64	473.18	471.39	404.07	
Maniarkhal	584.56	917.18	518.14	673.29	
Matijuri	1826.13	1515.51	1846.37	1729.34	

The results obtained by using the optimization model shows that for the upper network to have safe flow at d/s Annapurna Ghat the flow rates from the ungauged catchments Jiri, Chiri, Madhura should be below 1434.66, 1122.68, 1083.41 cumecs respectively and the peak flow rates at the unregulated stations Fulertal, Dholai, Maniarkhal are to be less than. 5266, 404 and 673 cumecs respectively. Also, it is seen that safe flow at Badarpurghat occurs when the peak flow rates from the ungauged catchments Jiri, Chiri, Madhura, Jatinga & Ghagra are below 1120.32, 258.54, 253.13, 240.11 & 229.01cumecs respectively with peak flow rate at Fulertal, Dholai, Maniarkhal, Matijuri less than or equal to 5296,267,584,1826 cumecs respectively.It may be obtained from the results given figures 6.10 and 6.11that the selected set of peak flow rates for the upstream gauged and ungauged catchments produces safe flow rates at Annapuranghat and Badarpurghat which are below and close to the respective danger level flow at the corresponding sections.



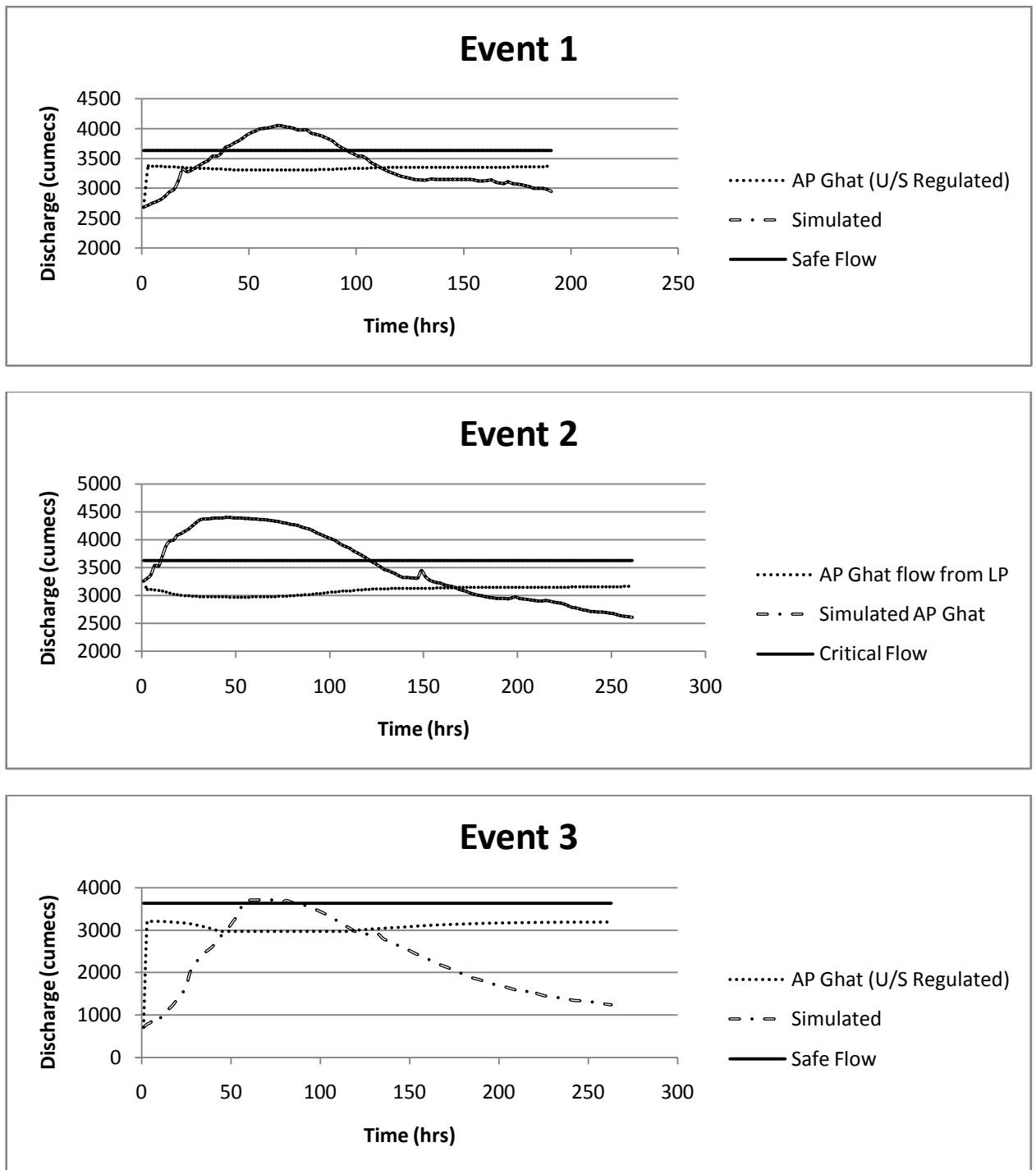


Figure:6.10- Flow at Annapurnaghat: observed flow , safe flow and flow by regulating upstream ungauged catchments flows from Jiri, Chiri and Madhura

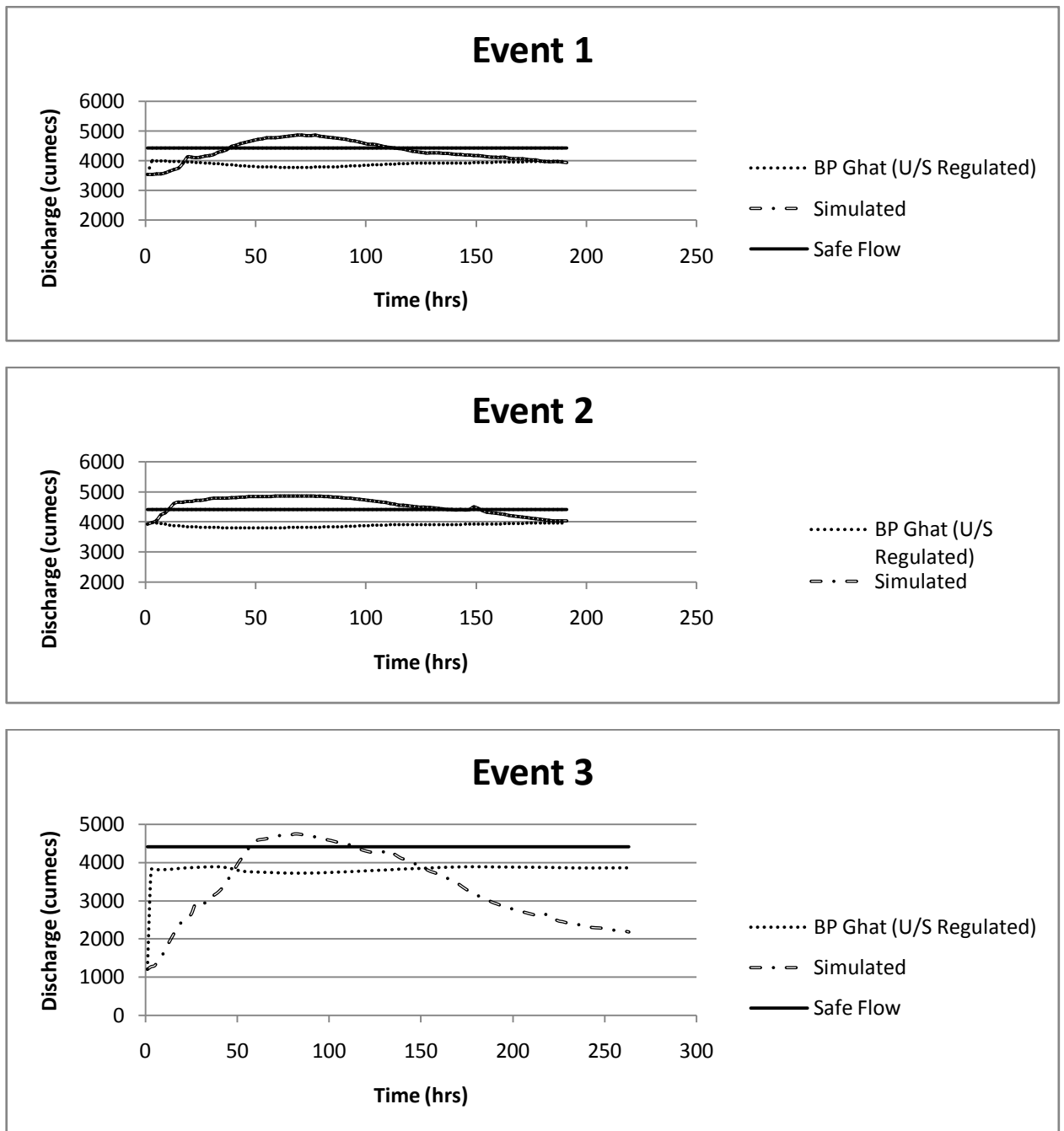


Figure:6.11-Flow at Badarpurghat: observed flow, safe flow and flow by regulating upstream ungauged catchments flows from Jiri, Chiri, Madhura, Jatinga & Ghagra

## Case – 2: Flow Regulations in all upstream catchments/stations excepting main channel flow considering effects of climate change

The effects of regulating flows from all major upstream catchments including gauged and ungauged catchments on the flood scenarios at the downstream station Annapurnaghat and Badarpurghat are evaluated keeping flows from the main channel at Lakhipur unregulated. This is mainly because restricting the main channel flow at Fulertal may not be feasible on many counts. The flow rates for all catchments upstream of Annapurnaghat and Badarpurghat are maximized with the constraint that the downstream flow doesn't exceed the safe flow rates and peak flow rates for these catchments are obtained from the model solution derived using the selected flood events. Peak flow rates obtained for the catchments for flood event-1,2 and three are averaged to find the maximum possible peak flow rates for these catchments that create safe flow at the downstream stations. The model is also run to estimate the maximum allowable peak flow rates for the catchments if there is a rise in the river discharges due to change in the climate. The climate change module study conducted by IIT Guwahati indicated 10 to 20% increase in the rainfall /flow rates due to change in the climate; the effects of increased flow rates are also studied and the results obtained are summarized in Tables-6.18 and 6.19

Table 6.18: Peak flow rates for the gauged and ungauged regulated catchments upstream of Annapurnaghat (upto Lakshipur) with no regulation of flow in the main channel necessary to create safe flow at Annapurnaghat including and not including effects of climate change.

Statio ns	Peak FlowRate									Average Peak Flow Rate			Remarks
	Event1			Event2			Event3			0% increase	10% increase	20% increase	
	0% increase	10% increase	20% increase	0% increase	10% increase	20% increase	0% increase	10% increase	20% increase				
Jiri	2765.00	2765.00	2765.00	2920.09	2920.09	2538.88	2778.56	2778.56	2778.56	2821.22	2821.22	2694.15	Safe Flow at downstr eam Annapur na Ghat
Chiri	517.63	545.55	565.31	461.20	530.98	998.12	552.14	596.77	587.19	510.32	557.77	716.87	
Madh ura	454.34	477.63	493.67	391.10	450.55	814.43	617.81	670.00	658.85	487.75	532.73	655.65	
Dhola i	117.98	118.69	118.73	160.60	172.35	228.00	247.70	246.43	246.03	175.43	179.16	197.59	No flow regulati on in the main channel
Mania rk-hal	192.93	197.71	200.17	248.34	280.08	443.88	197.92	200.89	199.79	213.06	226.23	281.28	
Fulertal	5296.4	5826.1	6355.7	5662.6	6228.9	6795.2	4839.6	5323.6	5807.5	5266.2	5792.9	6319.5	

Table 6.19: Peak flow rates for the gauged and ungauged regulated catchments upstream of Badarpurghat (upto Lakshipur) with no regulation of flow in the main channel necessary to create safe flow at Badarpurghat including and not including effects of climate change

Station s	Peak Flow Rate									Average Peak Flow Rate			Remar ks
	Event1			Event2			Event3			0% increase	10% increase	20% increase	
	0% increase	10% increase	20% increase	0% increase	10% increase	20% increase	0% increase	10% increase	20% increase				
Jiri	1044.41	1011.96	976.74	764.15	766.21	764.85	944.69	952.79	960.49	917.75	910.32	900.70	
Chiri	252.65	250.02	247.44	273.10	270.26	267.45	309.68	307.78	305.91	278.48	276.02	273.60	
Madhu r-a	248.18	245.53	242.92	266.98	264.17	261.37	314.04	312.17	310.33	276.40	273.96	271.54	
Dholai	133.37	133.36	133.35	202.77	200.92	199.05	217.05	216.84	216.64	184.40	183.71	183.01	
Maniar khal	197.55	195.52	193.47	243.06	240.52	237.98	220.60	219.41	218.22	220.40	218.48	216.56	No flow regulat ion in the main channe l
Jatinga	243.94	241.31	238.70	257.96	255.23	252.50	307.73	305.82	303.94	269.88	267.45	265.04	
Ghagr a	236.70	234.11	231.53	257.44	254.71	251.99	298.24	296.34	294.44	264.13	261.72	259.32	
Matijur i	305.90	301.57	297.25	263.48	261.46	259.43	659.81	659.07	658.34	409.73	407.37	405.01	
Fulertal	5296.44	5826.08	6355.73	5662.63	6228.89	6795.15	4839.62	5323.58	5807.54	5266.23	5792.85	6319.47	

Tables-6.18 and 6.19 show the maximum peak flow rates for the upstream catchments that producesafe flow at the potential downstream damage stations. The results show that the allowable peak flow rate for the catchments decreases marginally due to increase in the river discharges forchanges in the

climate in next 50-60 years. Though the peak outflow rate for the upstream catchments necessary to maintain safe flow rate at the D/s stations are only marginally decreased but, the requirement of additional storage arrangement in the catchments to account for the changes in the climate would be comparatively large as the said storage arrangements must hold the additional volume coming due to increase in the inflow rates which is predicted to be around 10-20% in next 50 to 60 years. Results given in the tables 6.16 and 6.17 indicates the allowable maximum peak flow rates for the catchments when only some of the upstream catchments are regulated while, the results given in the table 6.18 and 6.19 are the maximum peak flow rates if all upstream catchments except the main channel are regulated. It may be seen that in both the cases considered in the study safe flow at the potential D/S locations is resulted and in the second case (table 6.18 and 6.19) D/S flow is much lesser than the safe limit due to higher reduction in the u/s peak flow rates. Considering the results given in Table-6.19 under the heading "0% increase" and the figures 6.12-6.17 it can be seen that the set of peak flow rate selected for the upstream catchments produces safe flow at both Annapurnaghat and Badarpurghat well below the corresponding danger limit and change marginally if upstream flows increases by 10% to 20% due to climate change. It may be mentioned here that though by regulating all upstream catchments as given by Table 6.19 increased safety at the downstream damage sections can be assured however considering the requirements of storage facilities in the upstream catchments required this option may not much preferable over the earlier solution obtained in case-I.

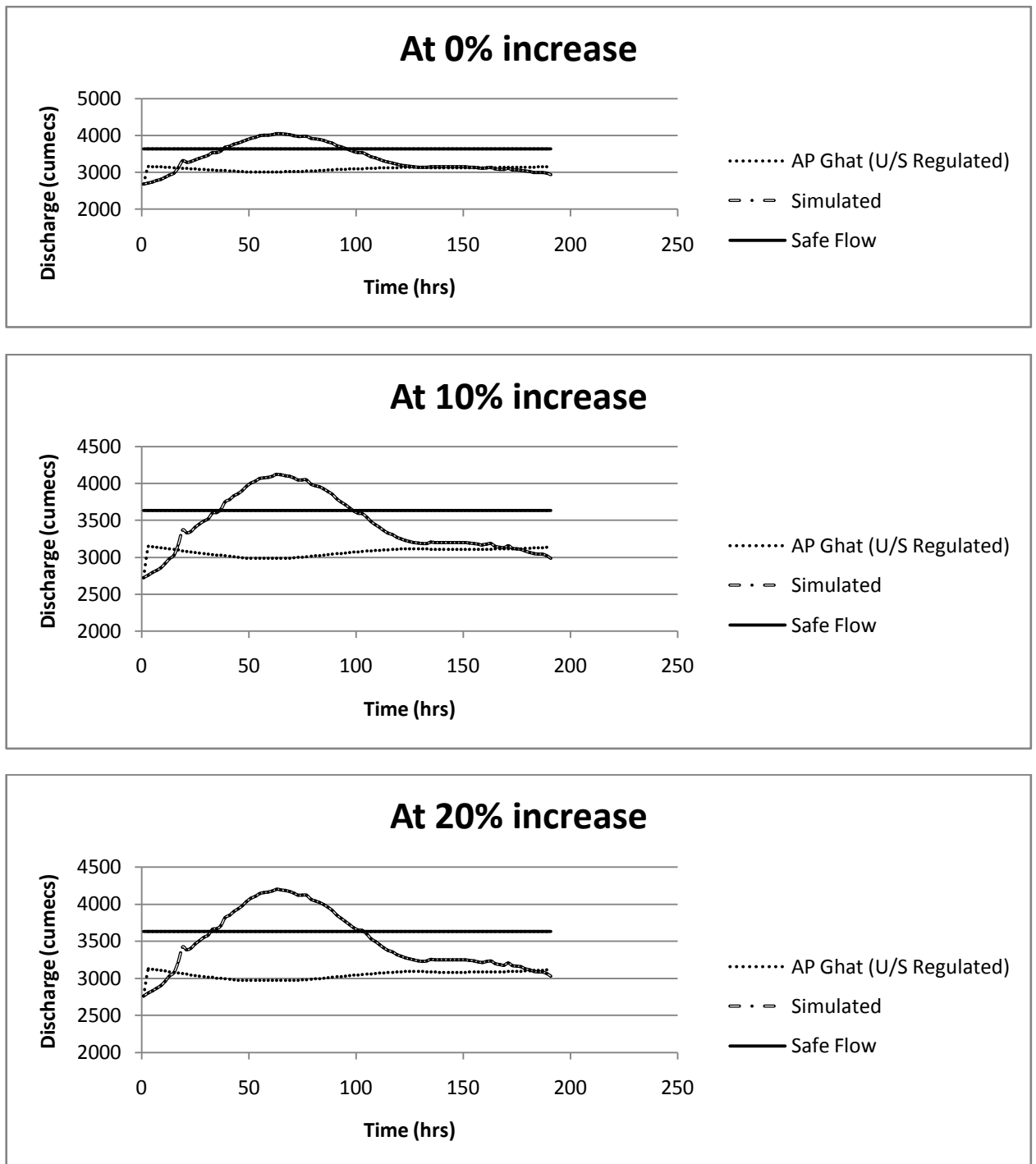


Fig:6.12 Flow at Annapurna Ghat (Event-1) including and not including effects of climate change: U/S flow regulation-all catchment

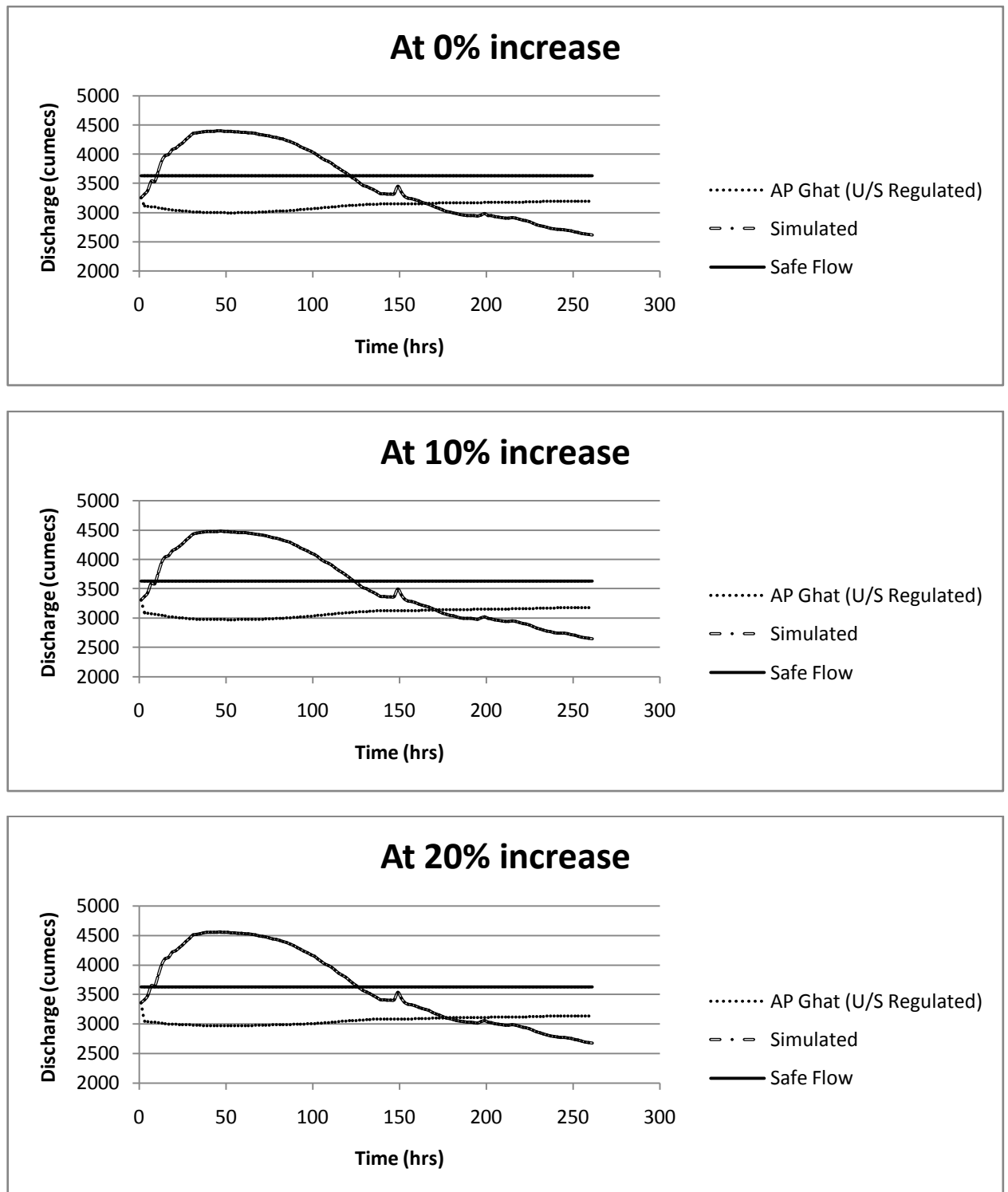


Fig:6.13 Flow at Annapurna Ghat (Event-2) including and not including effects of climate change: U/S flow regulation-all catchment



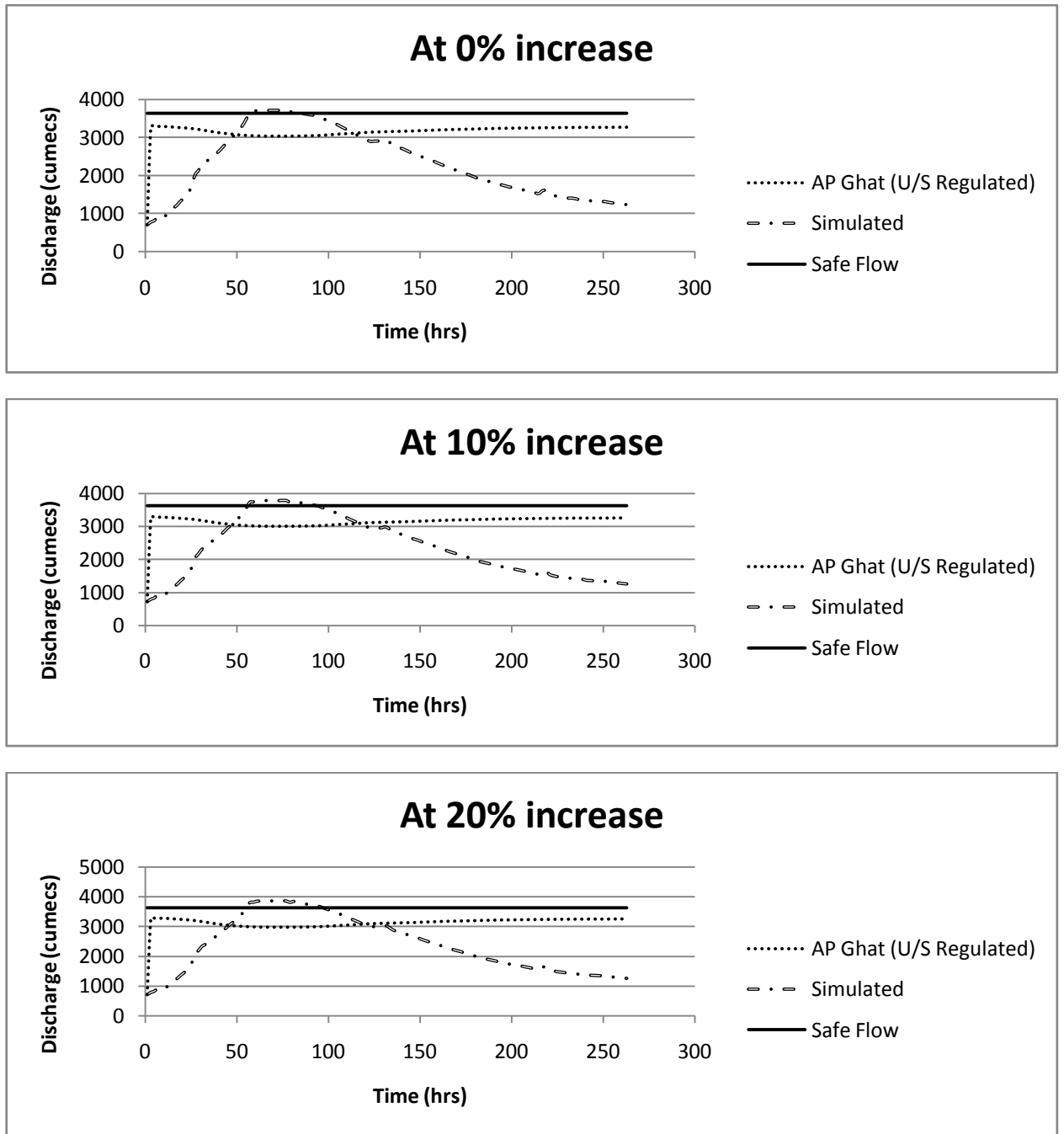


Fig:6.14 Flow at Annapurna Ghat (Event-3) including and not including effects of climate change: U/S flow regulation-all catchment

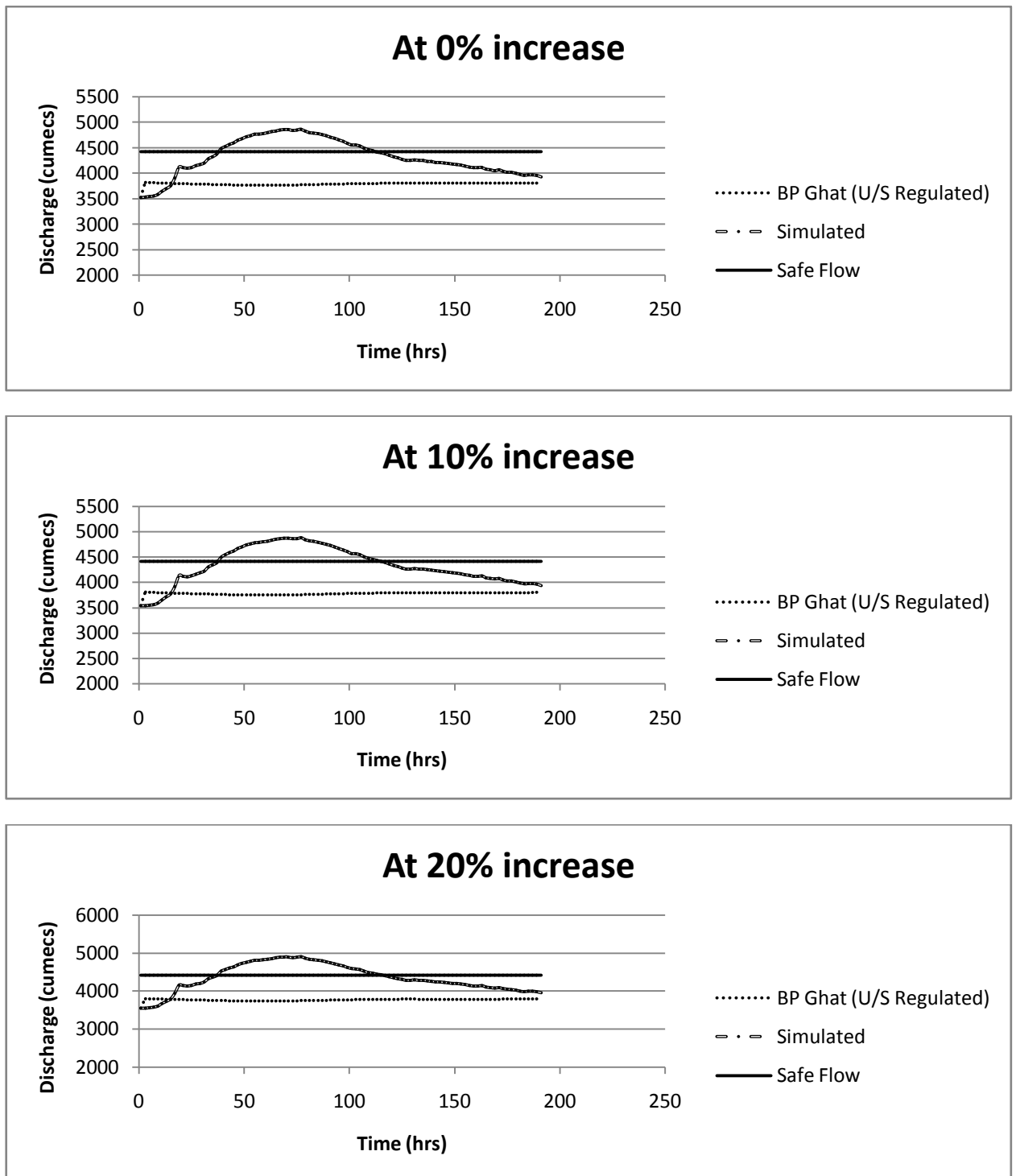


Fig:6.15 Flow at Badarpur Ghat (Event-1) including and not including effects of climate change: U/S flow regulation-all catchment

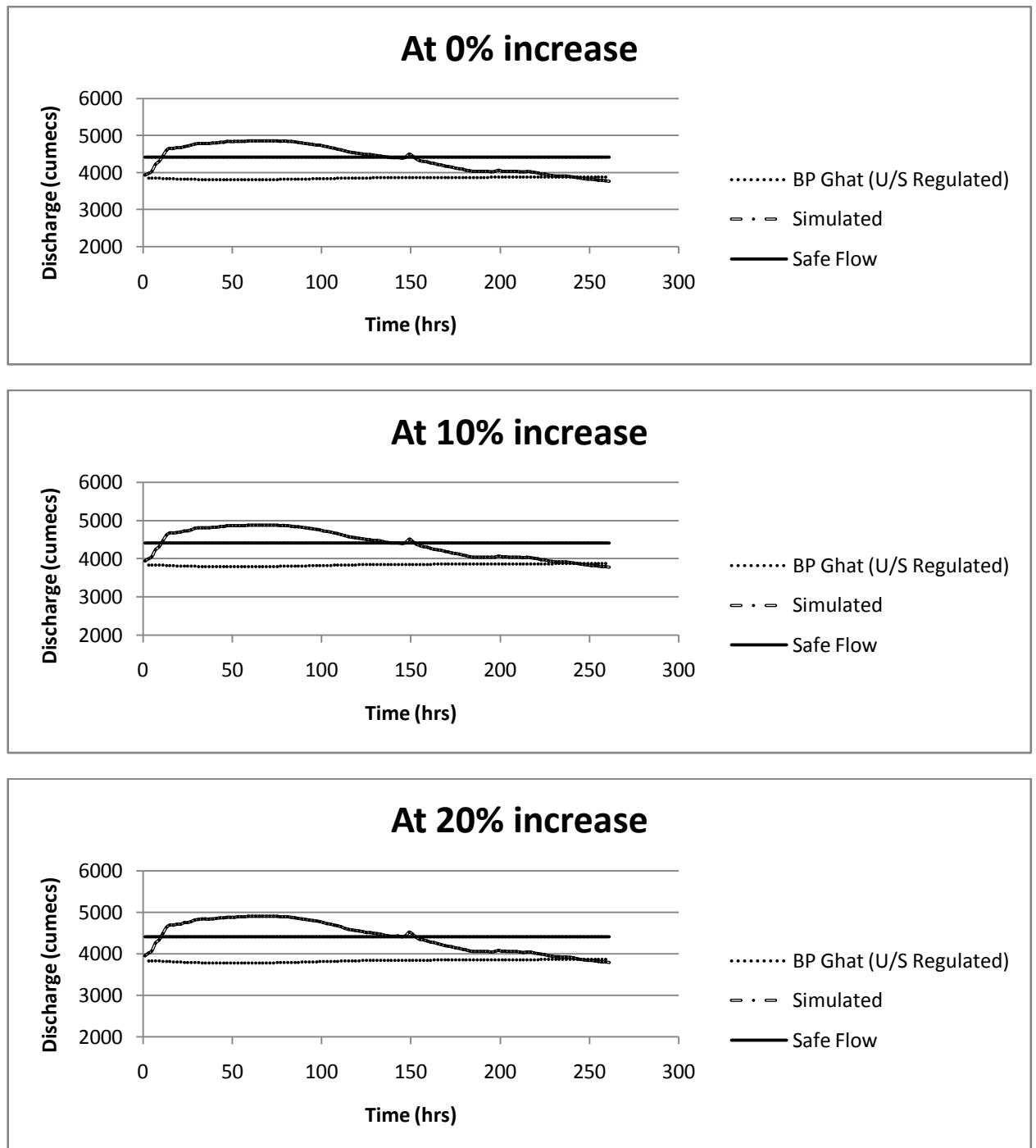


Fig:6.16 Flow at Badarpur Ghat (Event-2) including and not including effects of climate change: U/S flow regulation-all catchment

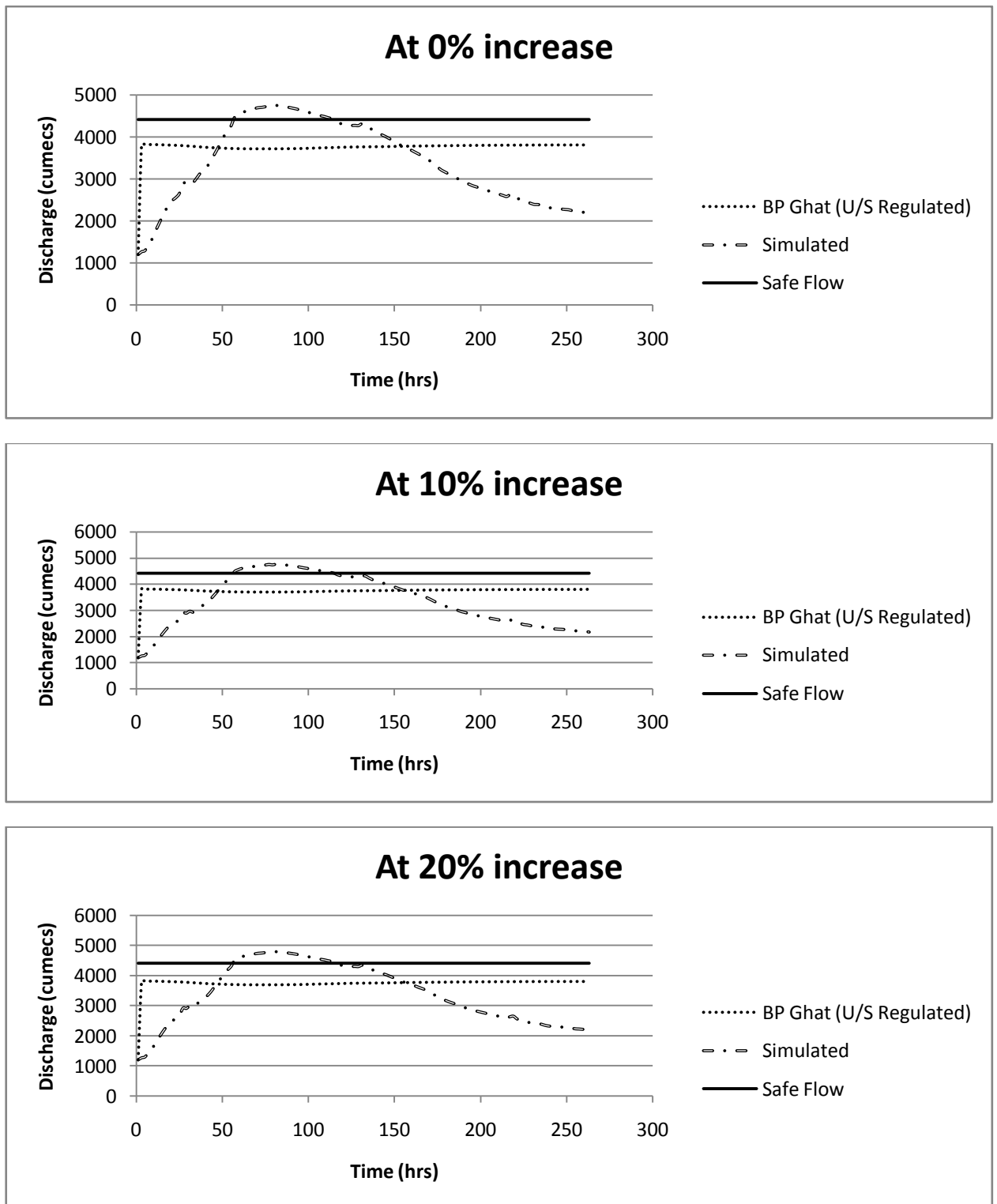


Fig:6.17 Flow at Badarpur Ghat (Event-3) including and not including effects of climate change: U/S flow regulation-all catchment

## 7.0 River System Sediment Flow Analysis:

In the present study to simulate sediment flow along the main river course that receives sediment flows from different catchment integrated water-sediment flow model for the river system is calibrated. For the upper and lower river systems the integrated water-sediment model given by equation 7.1 and 7.2 are calibrated using the water discharge and sediment discharge /concentration data collected for the gauging sites from CWC Shillong.

$$C_{s,(t+\Delta t)}^d = \alpha_d \left[ c_1 \left( \sum_{p=1}^n \sigma^{u,p} \left( \frac{C_{s,t}^{u,p}}{\alpha_{u,p}} \right)^{\frac{1}{\beta_{u,p}}} \right) + (1 - c_1 - c_3) \left( \sum_{p=1}^n \sigma^{u,p} \left( \frac{C_{s,(t+\Delta t)}^{u,p}}{\alpha_{u,p}} \right)^{\frac{1}{\beta_{u,p}}} \right) + c_3 \left( \frac{C_{s,t}^d}{\alpha_d} \right)^{\frac{1}{\beta_d}} \right]^{\beta_d} \quad (7.1)$$

$$Q_{s,(t+\Delta t)}^d = \alpha_d \left[ c_1 \left( \sum_{p=1}^n \sigma^{u,p} \left( \frac{Q_{s,t}^{u,p}}{\alpha_{u,p}} \right)^{\frac{1}{(\beta_{u,p}+1)}} \right) + (1 - c_1 - c_3) \left( \sum_{p=1}^n \sigma^{u,p} \left( \frac{Q_{s,(t+\Delta t)}^{u,p}}{\alpha_{u,p}} \right)^{\frac{1}{(\beta_{u,p}+1)}} \right) + c_3 Q_{s,t}^d \alpha_d^{\beta_d+1} \right]^{\beta_d+1} \quad (7.2)$$

Where

$C_{s,t}^{u,p}, Q_{s,t}^{u,p}$  = Equivalent sediment concentration & sediment discharge at p due to sediment discharges at n different locations.

$\sigma^{u,p}$  = shift factor associated with the transfer of flow from u to p

$C_{s,t}^u$  = sediment concentration at point p

$Q_{s,t}^{u,p}$  = Sediment discharge at point p

$\alpha_u, \beta_u$  = Rating curve parameters &  $\alpha_u$  has the dimension of sediment density &  $\beta_u$  is an exponent.

The model parameters in equation (7.1) and (7.2) are estimated using genetic algorithm. Multi-objectives optimization tool NSGA-II is used to estimate the model parameters in the water-sediment integrated model by minimizing sum of the squared deviations between downstream observed and computed water discharge, sediment discharge and sediment concentrations in the river system.

## Upper network with Downstream sediment outflow station at Annapurnaghat

In the upper network, Fulertal & Dholai are the upstream section with Annapurna Ghat as the downstream section. Based on the size of network, 10 model parameters are required to be estimated in this network. Applying simulation models, these model parameters are estimated using first set of inflow-outflow data and three objective functions  $f(1)$ ,  $f(2)$  &  $f(3)$  minimizing the sum of squared error between observed and predicted sediment concentration, sediment and water discharge. The model parameters estimated for this network are shown in TABLE: 6.13. Using these estimated model parameters the downstream sediment discharge and sediment concentration values are predicted. The models performance are tested using standard statistical criterion "root mean squared error" & "coefficient of correlation"

TABLE-7.1 Model Parameters for Upper Network

$\beta^{d=B,P \text{ Ghat}}$	0.3899
$\beta^2=\text{Matijhuri}$	0.3897
$\alpha^2=\text{Matijhuri}$	0.9487
$\sigma^2=\text{Matijhuri}$	0.8903
$\beta^1=A,P \text{ Ghat}$	0.4264
$\alpha^1=A,P \text{ Ghat}$	0.5282
$\sigma^1=A,P \text{ Ghat}$	0.9893
$\alpha^{d/s-B,P \text{ dhat}}$	0.6118
$C_3$	0.74969
$C_2$	0.11205
$C_1$	0.13827
$X$	0.01477
$K$	3.54736

As the models are applied in the multiple river reaches, equivalent inflow is used in the models to obtain the model parameters. Sediment concentration, sediment discharge and water discharge at downstream section are computed based on the equivalent inflow only. Effect of each of the tributaries on the downstream section is assessed by restricting the sediment flow of the tributaries. Restriction of tributary sediment flow may is done one by one at a time and two at a time. Observed and simulated sediment concentration/sediment discharge at the downstream locations Annapurnaghat

and Badarpurghat obtained by applying the models given in equation (7.1) and (7.2) are presented in the following figures

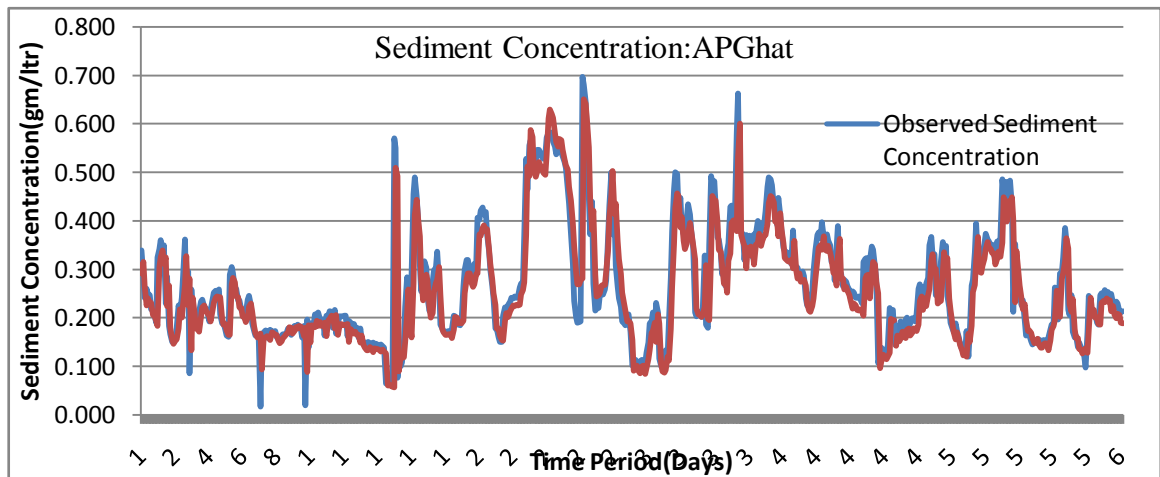


FIGURE: 7.1 Observed Sediment Concentration & simulated sediment concentration in upper network

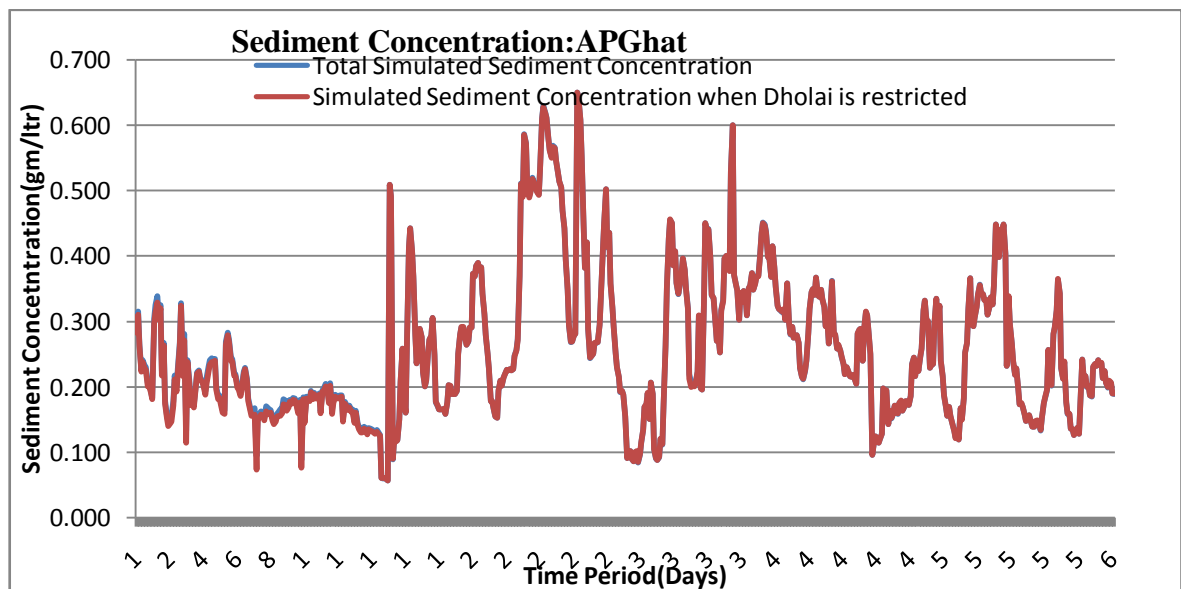


FIGURE. 7.2 Sediment Concentration at AP Ghat for no sediment flow from Dholai catchments

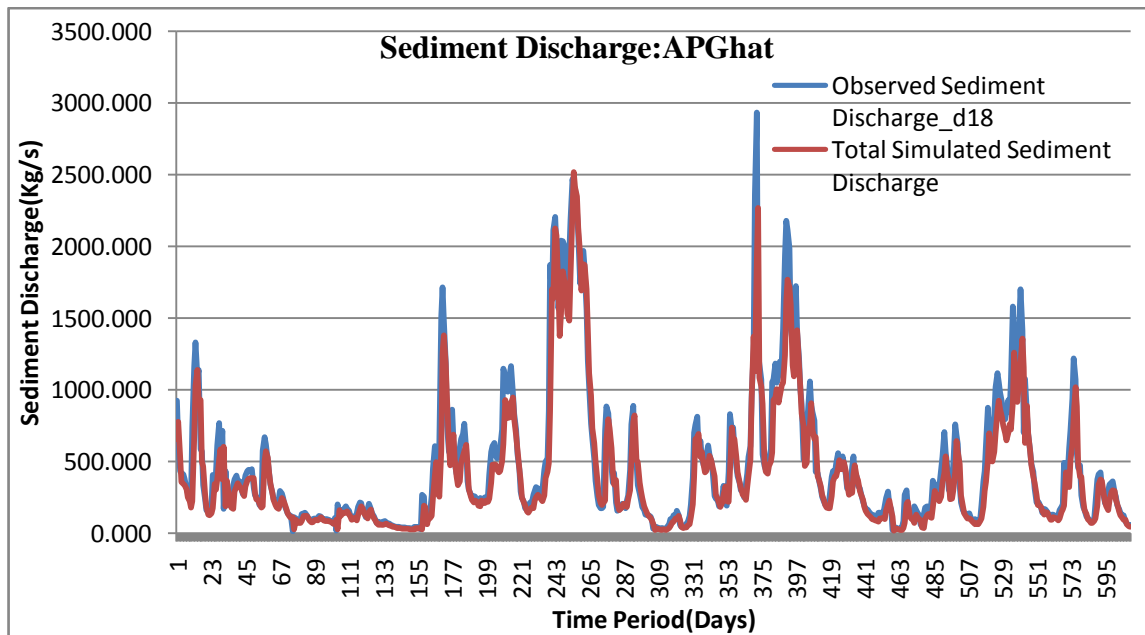


FIGURE.7.3 Observed Sediment and simulated sediment discharge at AP Ghat in upper network

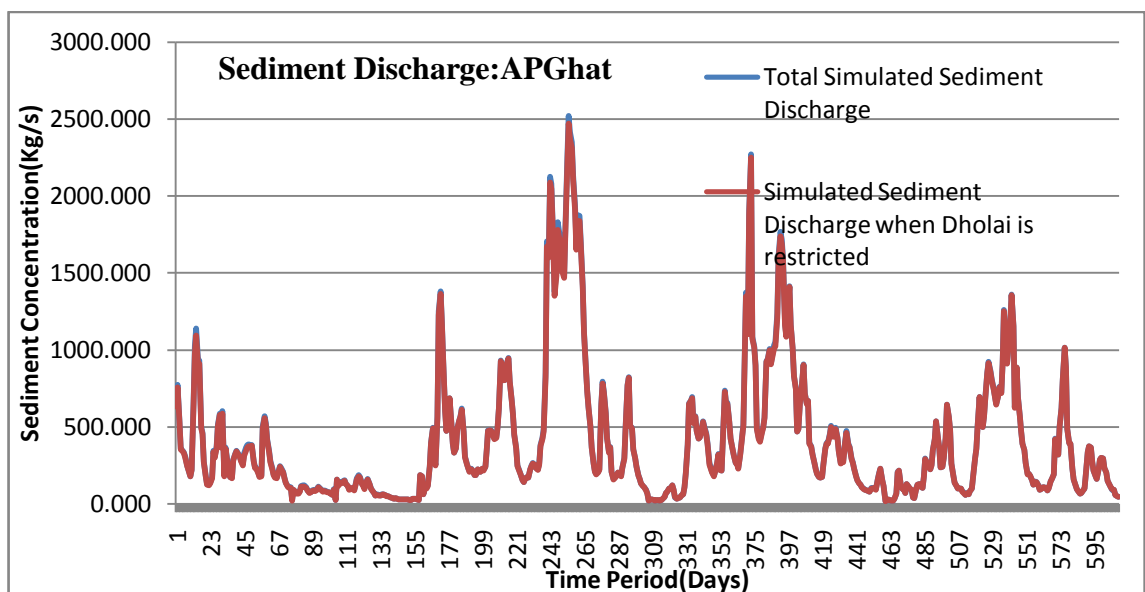


FIGURE 7.4 Sediment Discharge at Annapurnaghat for no sediment flow from Dholai

### Complete River System with outflow at Badarpurghat:

In the larger river network, Fulertal, Dholai & Matijhuri are the upstream sections with Badarpur Ghat as the downstream section. Based on the size of the network, 13 model parameters are required to be estimated to define the sediment flow simulation model for the network. The model



parameters are estimated using a set of inflow-outflow data & tested on other set of inflow-outflow data series. The model parameters estimated for this network are shown in table-7.2:

Table-7.2 Model parameters for complete River system

Sl. No	Network	Lower Network
	U/S	1.Fulertal 2..Dholai 3.Matijhuri
	D/S	B.P Ghat
	K	6.0186
	X	0.1034
	C <sub>1</sub>	0.19029
	C <sub>2</sub>	-0.02070
	C <sub>3</sub>	0.83041
	Q <sub>d/s-B.P ghat</sub>	0.1266
	Q <sub>1=Fulertal</sub>	1.7079
	Q <sub>1=Fulertal</sub>	2.1693
	β <sub>1=Fulertal</sub>	0.8164
	Q <sub>2=Dholai</sub>	0.7521
	Q <sub>2=Dholai</sub>	2.5317
	β <sub>2=Dholai</sub>	0.9943
	B <sub>3=Matijhuri</sub>	0.4912
	A <sub>3=Matijhuri</sub>	3.3252
	B <sub>3=Matijhuri</sub>	1.9913
	β <sub>d=B.P Ghat</sub>	1.0001

Sediment concentration, sediment discharge & water discharge at the downstream stations are computed by using estimated parameters & compared with respective observed values. To assess the relative impacts of sediment flow from different tributaries sediment flow from the tributaries are restricted and the resulting peak sediment discharge/concentration at the downstream locations is derived from the model results. The sediment discharge and sediment concentration graphs obtained by restricting sediment flows from the catchments are shown in the figures 7.5 to 7.9 given in the next pages.

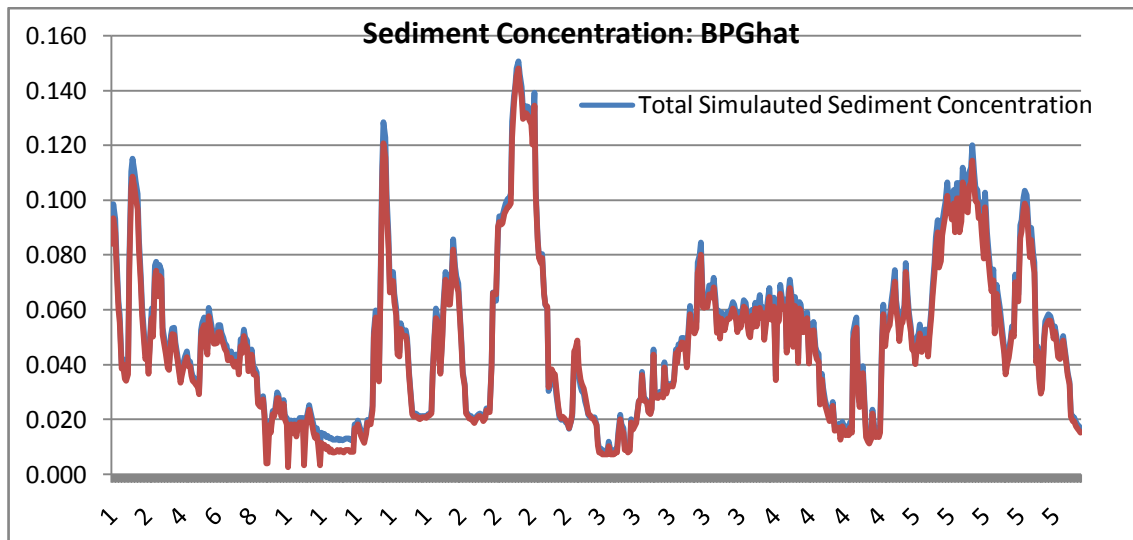


FIGURE.7.5 sediment concentration for no sediment flow from Dholai

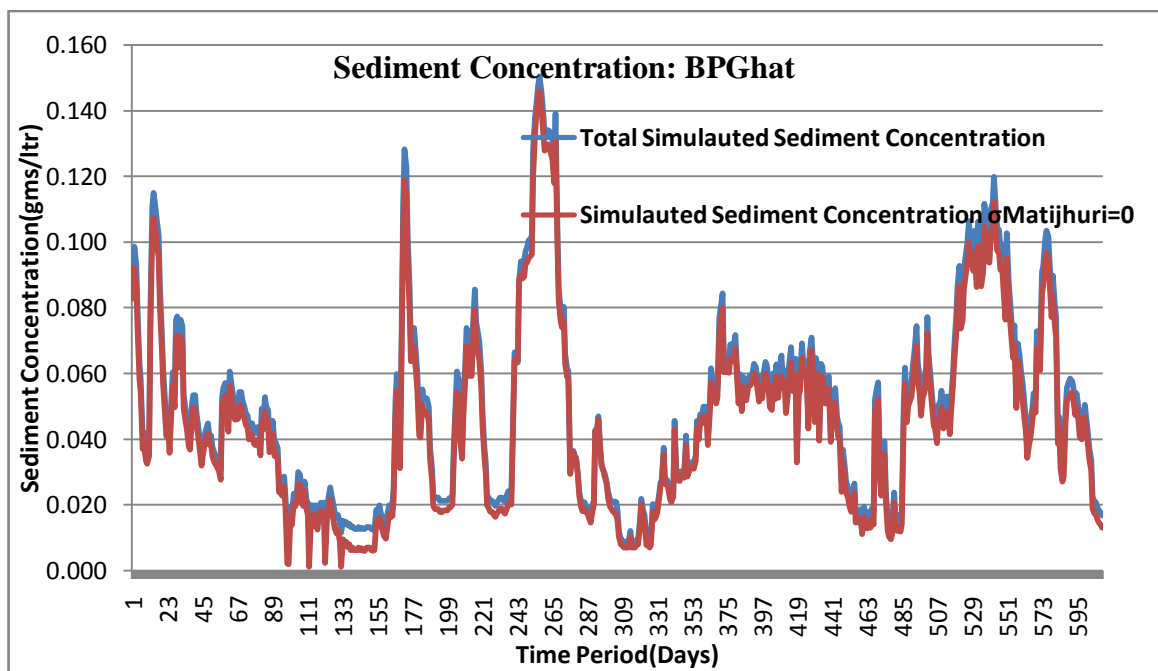


FIGURE-7.6 Sediment concentration for no sediment flow from Madhura,

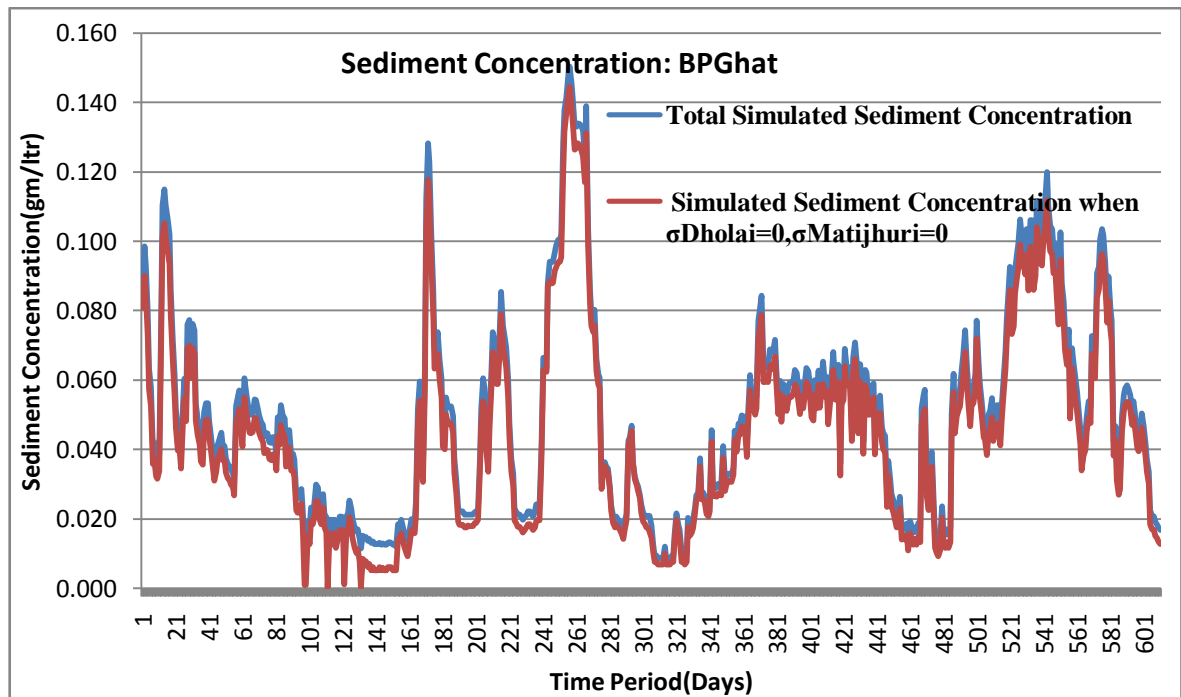


FIGURE 7.7. Observed sediment concentration and concentration at BPGhat for no sediment flow from Dholai and Madhura subcatchments

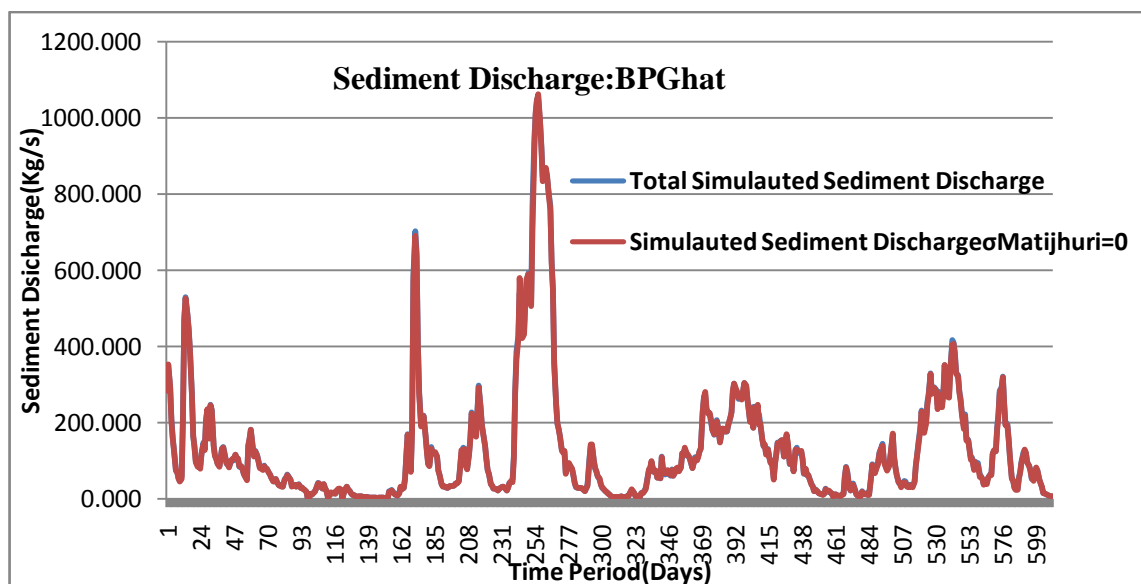


FIGURE-7.8 . Sediment discharge for no sediment flow from Matijuri

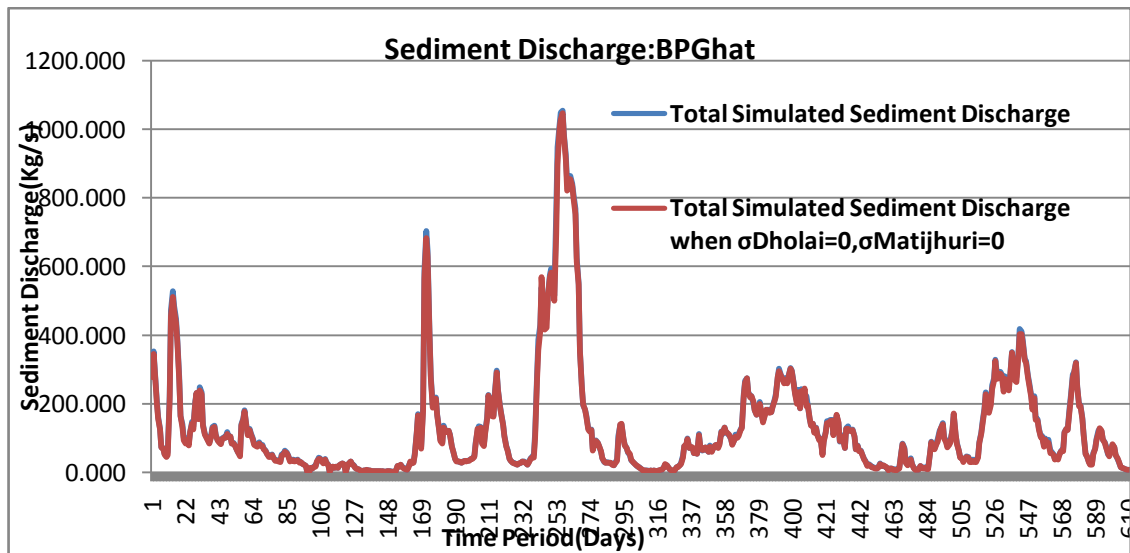


FIGURE-7.9 Sediment discharge for no sediment flow from Matijuri and Dholai sub-catchments.

Table-7.3 :- Impact of sediment flow from upstream catchments at Badarpurghat

Sediment Concentration						Sediment Discharge				
	Observed Sediment Concentration-B.P GHAT	Dholai restricted	Matijhuri restricted	Improvement due to Dholai restriction	Improvement due to Matijhuri restriction	Observed Sediment discharge-B.P GHAT	Dholai restricted	Matijhuri restricted	Improvement due to Dholai restriction	Improvement due to Matijhuri restriction
Peak values	0.164	0.145	0.143	0.018	0.020	1090.60	1038.41	1045.60	52.19	44.9968
Sediment Load (kg)						86210.90	78010.86	78066.36	8200.03	8144.535

Table-7.4:- Impact sediment flow from upstream catchments at Annapurnaghat

Sediment Concentration				Sediment Discharge		
	Observed Sediment Concentration-A.P Ghat	Restricted	Improvement	Observed Sediment Discharge	Restricted	Improvement
Peak values	0.697	0.281	0.416	718.607	220.2834	498.324
Sediment Load(kg)	-	-	-	286569.7	246840.9	39728.87

As indicated in the above tables the relative contribution of sediment from the Matijuri catchments is more compared to the other catchments considered in the study. It is found that for no sediment flow from the Matijuri catchments the sediment load at Badarpurghat reduces by 10.46 % and the peak sediment concentration decreases by 12.36%. In the case of Dholai sub catchment the improvement in sediment load at Badarpurghat is around 9.23% and reduction in peak sediment concentration rate is 9.25%.

## 8.0. Flood forecasting in the river system

The downstream flow top width and downstream discharge in a river reach can be forecasted using upstream levels/ discharge rates. In the present study a hybrid Muskingum models is used to forecast downstream discharge rates and flow top width in the river system on the basis of flow depths measured at several upstream locations. The multiple flow routing model given in equation 6.1 is rewritten to describe the downstream flow top width in terms of upstream flow depth at several upstream stations as given in equation 8.1

$$T_{(t+\Delta t)}^{(d)} = \left( \left( c_1 (\sigma^{1,r} Q_t^{1,u} + \sigma^{2,r} Q_t^{2,u} + \dots + \sigma^{n,r} Q_t^{n,u}) + (1 - c_1 - c_3) (\sigma^{1,r} Q_{t+\Delta t}^{1,u} + \sigma^{2,r} Q_{t+\Delta t}^{2,u} + \dots + \sigma^{n,r} Q_{t+\Delta t}^{n,u}) + c_3 (\alpha_d T_t^{\beta_d}) \right) / \alpha_d \right)^{1/\beta_d} \quad (8.1)$$

Here,  $T_{(t+\Delta t)}^{(d)}$  denotes downstream flow top width,  $t$ ,  $t+\Delta t$  represent the time-period.  $c_1$ ,  $c_2$ ,  $c_3$  are the routing coefficients.  $Q_t^{1,u}$  = Instantaneous water discharge ( $\text{m}^3/\text{s}$ ) at upstream section 1 at time  $t$ .  $\alpha_{(d)}$ ,  $\beta_{(d)}$  = rating curve parameters reflecting water discharge characteristics for the downstream section and  $T_t^{(d)}$  = Instantaneous flow top width at a section at time  $t$  at the downstream section. Eqn (8.1) gives the hybrid multiple inflows Muskingum model incorporating discharge and flow top width variables for a river system. The model is highly non- linear involving a number of parameters. The model relates discharges separated by a time interval  $\Delta t$  for various upstream and the downstream stations in a river system, satisfy continuity requirements adhering to the Muskingum principle of flow movement in river reaches. The model allows directly estimating downstream flow top width on the basis of water discharges for different upstream stations.

Model parameters in equation (8.1) could be estimated by minimizing the difference between the observed and the computed downstream flow top width values. Equation (8.1) being the modified form of the Muskingum model given by equation (6.1), a parameter set for a river system may be identified to best satisfy both the models. Based on the models given by equations (6.1) and (8.1) downstream discharge and flow top width prediction model for a river system can be written as

$$Q_{t+\Delta t'}^d = c_1' Q_t^{e,u,r} + c_3' Q_t^d \quad (8.2)$$

$$T_{t+\Delta t'} = \left( \left( c_1' (\sigma^{1,r} Q_t^{1,u} + \sigma^{2,r} Q_t^{2,u} + \dots + \sigma^{n,r} Q_t^{n,u}) + c_3' (\alpha_d T_t^{\beta_d}) \right) / \alpha_d \right)^{1/\beta_d} \quad (8.3)$$

For a river reach having estimated Muskingum model parameters  $k$ ,  $x/c_1, c_3$ ; shift parameter  $\sigma^{p,r}$ , and the rating parameters  $\alpha_d, \beta_d$  for the downstream section, equations (8.2) and (8.3) can be defined and used to obtain downstream water discharge and flow top width estimated  $\Delta t'$  time unit ahead.

Discharge and flow top width forecasting models for the Barak river system are calibrated using 241 pairs of inflow, outflow and common downstream flow top width data for the river system. Water discharge data for four gauging stations Fulertal, Tulergram, Matjuri and Badarpurghat collected from CWC, Shillong are used in forecasting downstream discharge and flow top width at Badarputghat. Observed flow top width data at Badrapurghat are obtained by using DEM and applying ArcGIS tool. The hybrid model incorporating water discharge and flow top width variables is used to obtain estimate and two hours ahead forecast for discharge and flow top width at the downstream section in the river system. To determine flow top widths at the downstream section corresponding to a set of recorded flow depths in the river system, flow top width across the downstream section is measured using the DEM. Correlation coefficients between flow top width and discharge, flow top width and depth of flow at the downstream station are found to be 0.965 and 0.935 respectively. The correlation coefficient values show that top width of flow has relationships with discharge and depth of flow at a section. The hybrid model parameters for the river system are estimated by applying genetic algorithm minimizing sum of the squatted deviation between observed and predicted flow rate and flow top width at Badrapurghat. The estimated model parameters for Barak river system are listed in Table-8.1

**Table 8.1 . Hybrid multiple inflows Muskingum model performances**

Performance measures	Simulation mode		Forecasting mode	
	Discharge (m <sup>3</sup> /s)	Top width (m)	Discharge (m <sup>3</sup> /s)	Top width (m)
CORR	0.99	0.90	0.94	0.89
RMSE	139.58	148.73	132.54	158.64
CE	0.93	0.88	0.89	0.86
MAE	83.46	88.71	73.51	90.65
Model Parameters	$k=8.9\text{hrs}, x=0.113, \alpha_d=4.39, \beta_d=1.01, \sigma^{F,r}=1.11, \sigma^{T,r}=-0.077, \sigma^{M,r}=0.786$			

*Superscript F, T and M represent Phulertol, Tulargram and Matijuri respectively*

Using the estimated parameters downstream flow rate and downstream flow top width at Badarpurghat is predicted/estimated by using recorded discharge for four upstream stations in the river system. The estimated and 2 hours ahead predicted flow rate and flow top at Badrapurgaht are shown in figure 8.1 and 8.2. Model performances both in simulation and forecasting mode measured using statistical criteria are given in table 8.1. The results obtained show that performances of the hybrid model in forecasting flow top width and flow rate at Badarpurghat by using upstream flow rates is satisfactory and the model can be used to forecast the downstream flow conditions on the basis flow information received for a number of upstream stations in the river system. It may be mentioned here that the flow top width prediction model allows directly predicting the downstream possible water spread area in a river system in advance on the basis of upstream flow records and is useful in issuing flood warning and mitigating flood damages.



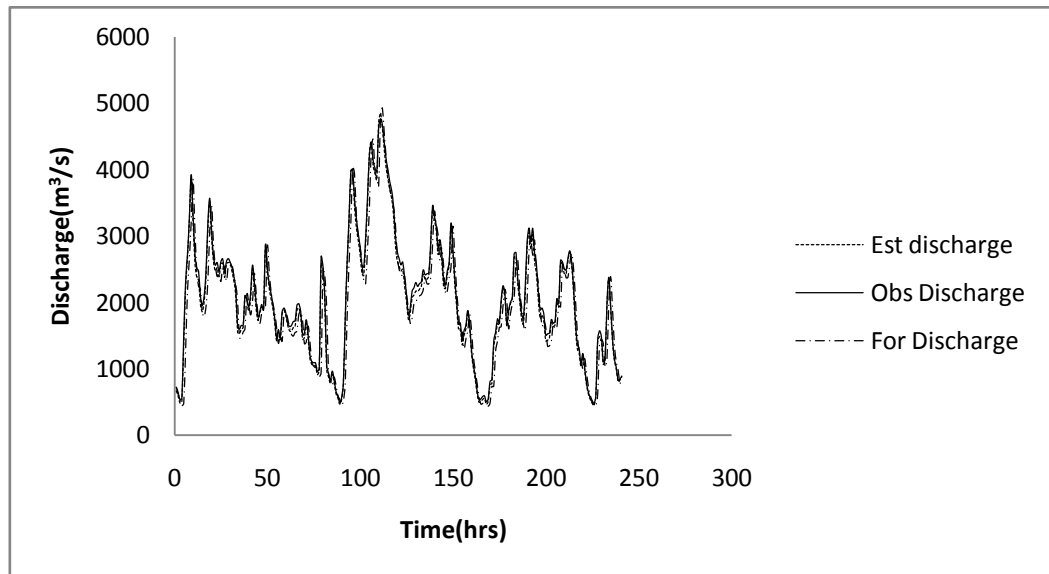


Figure 8.1. Observed, estimated and 2 hours ahead forecasts of downstream flow rates at Badarpurghat

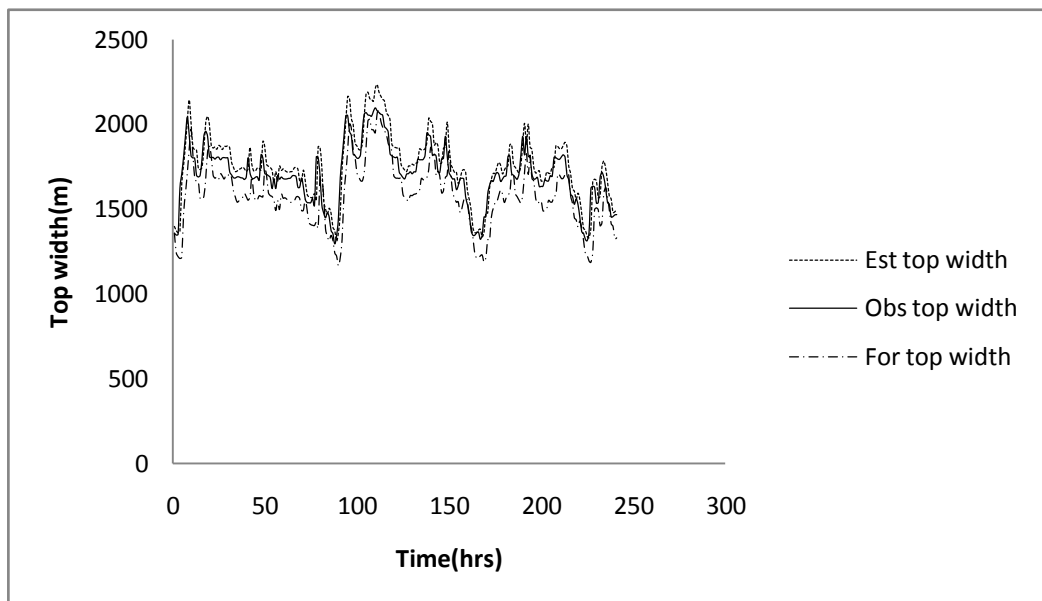


Figure 8.2. Observed, estimated and 2 hours ahead forecasts of downstream flow top width at Badarpurghat

## **9.0 Conclusions & Recommendations:**

In the present study attempt has been made to determine the extent of flow regulations required in the upstream catchments to have safe flow at important downstream damage locations in the river system in Barak valley. There are a number of gauged and ungauged catchments in the study area and downstream flow simulation model incorporating flows from all the upstream gauged and ungauged catchments have been developed for the river system. To determine the existing flow capacity of the sections in the tributary river systems as well as in the main river the sections are surveyed at a regular interval and at all critical sections along a river course and the required channel parameters and other sectional details such as flow area, top width etc are determined/computed. Expected maximum rainfall intensity for different return periods for the study area is obtained by applying L-moment techniques for the homogeneous zone identified by applying fuzzy C-means based clustering techniques.

Three flood events considering availability of rainfall records in the study area are selected and used to conduct flood movement analysis for the river system. Stage-discharge relationships for all gauging stations are developed applying regression technique and are used to express the flow depths measured at a gauging station in terms of the discharge value. Flow contributions from the ungauged catchments are obtained by using GIUH approach. Digital elevation model, stream network and slope map for the important catchments in the study area are developed using GIS technique; the stream networks are ordered using Strahler stream ordering law. Important morphological parameters for the tributary river systems required for developing the GIUH models are derived using the DEM, stream network, slope map and data obtained by direct field measurements. The IUHs obtained for the catchments are lagged using s-curve technique to derive 1-hour unit hydrograph. Contributions from the important ungauged catchments are determined by using 1-hour unit hydrograph for the catchments and the rainfall excess for the storm events during the selected flood periods. Flow contributions from the gauged and ungauged catchments are integrated using equivalent inflow for a number of upstream catchments as applicable to the river networks in the study area. Sediment flow simulation model for the river

system are developed using the sediment concentration and sediment discharge data collected for the river system. The model is used to assess the relative contributions of the catchments in sediment load in the river reaches. Downstream flow rate and flow top width forecasting models have been developed for the river system that can be applied to forecast downstream flow conditions well in advance on the basis of upstream flow rates recorded at several upstream sections. Linear Programming model is formulated for the river networks having outflow at Annapurnaghat and Badarpurghat to determine effects of upstream flows on the downstream flows. The model is applied for two cases: (i) when upstream flows from the major ungauged catchments are regulated (ii) when flows from all upstream catchments are regulated. The effects of climate change on the flow rates are incorporated in the LP model and for the changed climatic conditions flow controls required in all major catchments upstream of the potential damage sections at Annapurnaghat and Badarpurghat are evaluated. The study shows that

- 1) For the river system in the study area flow from the jiri catchment has the minimum impact and the flows from the Dholai catchment has the most significant impact on the flood flow at Annapuranghat computed in terms of reductions in the peak flow rates. The percentage reduction in the peak flow rate that can be achieved by controlling flows from any one of the upstream catchments in the river system may not be sufficient in keeping flood flow rate at Annapurnaghat below safe limit. The study further show that the most significant reduction in the peak flow rate at Annapurnaghat is obtained by controlling flows from the catchments of Dholai and Mainerkhal together.

In the case of Badarpurghat flow from the catchment of Matijuri is found to have maximum influence on the peak flow rate at Badarpurghat and effect of Mainerkhal is found to be the least among all the tributary flows considered in the study. It is further revealed that significant improvements in terms of reduction in peak flood flow rates at Badrapurghat can be achieved by controlling flows either from Matijuri and Jatinga or Matijuri and Ghagra catchments as demonstrated by the study results. It may be mentioned here that the degree of flood peak reduction achievable is dependent on the degree of flow control implemented at the identified upstream single/dual catchments.

The study indicates the importance of the upstream sub catchments in controlling flood damages in the potential downstream locations and the requirement of storage facilities in the said upstream catchments for achieving the desired effects on the downstream locations need to be further estimated /evaluated

2) Assessment of flow controls in more than two upstream catchments show that safe flow rates at the important downstream stations can be maintained by partial regulation of flows from the upstream catchments. The study conducted to assess improvements in flood flow by controlling only the upstream ungauged catchments shows that a set of flow sequences for the regulated unaguged catchments Jiri, Chiri and Madhura with peak flow rates 1434, 1122, 1083 cumecs respectively and peak flow rates for the unregulated gauged catchments/stations Fulertal, Dholai, Maniarkhal as 5266, 404 and 673 cumecs respectively resulted safe flow at Annapurnaghat close to the critical limit. Also it can be concluded from the study that peak flow rates less than 1120.32, 258.54, 253.13, 240.11, 229.01, 5296, 267, 584, 1826 cumecs respectively for the catchments/stations Jiri, Chiri, Madhura, Jatinga & Ghagra, Fulertal, Dholai, Maniarkhal and Matijuri respectively creates safe flow at Badarpurghat as well as at Annapurnaghat with flow rates for both the sections close to the respective safe flow limit. The model generated peak flow rates for the upstream sections resulting safe flow at the downstream stations close to the danger limit is important as it indicates minimum possible storages in the upstream catchments and exercising minimum possible flow controls for the catchments to have safe flow at the downstream stations. The results obtained in the study are based on the peak flow rates for the catchments, time to peak flow are not considered in the model. The results give an idea about the maximum possible outflow rates for the selected catchments and the actual requirements of storages in the individual catchments may be further estimated on the basis of the present findings.

3) The study shows that substantial improvements in the flood flow rate at the downstream stations Annapurnaghat and Badarpurghat can be expected by controlling flows in the upstream catchments. As indicated in the results

given in the tables 6.19 it is seen that when all upstream catchments have some degree of control measures it results to downstream peak flow rates much below the safe limit at Badarpurghat and also at Annapurnaghat. In this case though substantial reduction in the flood flow rate at the downstream stations can be obtained by controlling flows in all upstream catchments as indicated in the results this option may not be much preferable considering financial and other implications.

- 4) The study conducted to assess impacts of the climate change quantifies the requirement for additional storages in the respective catchments. The study shows that when river discharges increase by 10-20% due to change in the climate having almost same level of flow from the major upstream catchments as indicated by the respective peak flow rates given in table 6.19 safe flood flow both at Annapurnaghat and Badarpurghat well below the danger level can be obtained. However, in that case storage requirements for the selected upstream catchments will be higher compared to the storage requirements for no changes in the climate and no increment in the river discharges.
- 5) The sediment flow simulation study conducted using sediment data available from CWC show that the relative contribution of sediment from the Matijuri catchments is more compared to the other catchments considered in the study. It is found that for no sediment flow from the Matijuri catchments the sediment load at Badarpurghat reduces by 10.46 % and the peak sediment concentration decreases by 12.36%. In the case of Dholai sub catchment the improvement in sediment load at Badarpurghat is around 9.23% and reduction in peak sediment concentration rate is 9.25%.
- 6) The study shows that water discharge-flow top width hybrid model is useful in Barak river system and can be applied to forecast downstream flow rates and flow top width on the basis of flow rates recorded at several upstream sections. Direct prediction of flow top width at a section by using current upstream flow rates and simple channel system parameters is important as the predicted flow top width gives advance information on the possible spread of flow, the risk of flooding and the extent of flooding at the downstream section.

7. Based on the survey works, field trips and laboratory works conducted to assess existing flow capacity of the channel systems, functioning of the sluice gates in the districts of Cachar, Karimjang and Hailakandi and status of existing embankments along the river courses etc. the following observations/recommendations forwarded that may be considered for further study and / implementation for improving overall flood condition in the valley

**Karimganj District:****A. River Kushiya**

- (i) On field investigation, it has been observed that there is severe erosion on the left bank of river kushiya at Haritkar Jobinpur, Bakarshal (near B.O.P camp in karimganj town area), Deopur, Chandsrikona, Shenulbag, Jagannathi, Sadanashi, Lxmibazar area and is causing economic losses to the local populace. Suitable anti erosion measures may be under taken to protect these places from erosions.
- (ii) There is a problem of water logging in Karimganj town which is mainly during high stages in the river Kushiya. During high stages in the river Kushiya surface drainage is retarded with occasional back flow from the river Kushiya. An additional sluice gate preferably in areas near Chanbazar may help much in regulating the accumulated water as well as in protecting the greater Karimganj town area from drainage congestion.

On executing the above mentioned works a vast area of approximately equal to 200 sq km including a total population of 3.00 lakhs in Karimganj district will be benefitted. Also National Highway NH-44, NH-154, Assam- Tripura Railway Line, Border Outpost (BOP) CAMP at Indo-Bangladesh Border and many other Government and public utilities will be saved from flood inundation and erosion.

**B. River Longai**

- (i) A vast area in Karimganj district is inundated by the river Longai. Though, there are embankments at places along the river course the existing embankment needs further raising and strengthening to protect the villages along the river course namely, Morangaon and Koncharchat, Ptherkandi Bazar area, Village Muraure, Bahadurpur , Salepur, Teoghor, Charrarbazar etc on right bank of river Longai and

villages namely Nalibari, Katebari, Kolkolighat, Khankar, Muraure etc on left bank of river Longai along with anti-erosion works.

- (ii) To reduce flood related damages and water logging in Nilambazar and Nilambazar-Krishnanagar area in southern part of Karimganj District additional sluice gates are required to regulate the flows. The new sluice gate may suitably be installed at P.W.D Colony, Kalibari area, at village Abdullapur and at Ganghai area to get rid of water logging in southern Karimganj District.
- (iii) One number of sluice gate over Churia Jhumjhum Channel near village Muraure in Karimganj district needs to be modernized and reconstructed for proper functioning.

On completion of the above works, the total urban and rural area of approximately equal to 1000 sq km including important National Highway NH-44, Assam- Tripura Railway line, vast cultivable land and many other Government and public utilities will be saved from flooding. A total population of approximately 3.00 lakhs is expected to be benefitted.

### **Hailakandi District:**

A vast area in the Hailakandi district is inundated by river Katakhal. Most of the existing sluice gates are not fully functional and are making the flood problem further complicated. The following improvement works is necessary and may be taken up to improve the flood conditions in Hailakandi district.

#### **I) IMPROVEMENT IN THE FUNCTIONING OF SLUICE GATES**

**POLA SLUICE :-** Located on Pola channel, draining runoff to the R/ Borak. It has 4 nos shutters. It is partially functional. To make it fully functional, it needs repairing of 2 no shutters including guide channels and as well as raising and strengthening of guide bund and recouping of river side apron etc.

**HATIA DIVERSION SLUICE:-** Located on Dholeswari river, draining runoff to river Dholeswari from the Bakri haor area. It has 4 nos of shutters and is partly functional. To make it fully functional, it needs repair of 2 no shutters including all guide channels.

HATIA SLUICE:- Located on R/ Dhaleswari . It has single shutter. It is non functional at present. Its shutter is fully damaged including guide channel, counter weight is also not existing and is fully non functional.

LALATOL SLUICE:- Located on R/ Katakhal. It has 2 nos shutters. It is partially functional. Repairing of Shutters is necessary to make it functional.

## II) Raising and Strengthening of Existing embankments:

The river katakhal is inundating a vast area in Hailakandi District almost every year. To save these areas from flooding rising and strengthening work of existing dyke along the river course is necessary. Raising and strengthening work of the dyke along left bank of the river katakhal from Matijuri bridge to Narainpur bazar will be useful in saving vast areas from flood inundation and may be taken up on urgent basis.

III) In Ashia Beel area waterlogging is caused due to blockage in Jita Nadi creating difficulties, losses and flood congestion. Flow capacity of the watercourse is reduced severely due to several factors. Clearing of the blockages in the channel course to improve draining of surface flow into the river Dhaleshwari will be helpful in improving the overall flood condition in the area.

### Cachar District:

I) There is severe drainage congestion in the southern part of Silchar city and in the adjoining areas mainly due to reduced flow carrying capacity of the channel systems. The Rangirkhari channel is the major carrier channel with outfall at the River Ghagra and is draining most parts of the Silchar city as well as Mahisabeel of Bethukandi area. Flow carrying capacity of the Rangirkahri channel needs to be improved by removing encroachments etc. for efficient drainage. Further, the channel course may be defined and made fixed to avoid future encroachment and modification of flow area of the important channel. There is a sluice gate in the channel with outfall at Ghagra which is not sufficient for removal of the drained water into the Ghara river efficiently; an



additional sluice gate with pupping facility may be installed at a suitable location to enhance removal of water drained by the channel. Installation of additional sluice gate in the Rangirkhari channel will be helpful in discharging huge volume of accumulated water thereby clearing drainage congestion in the southern part of Silchar city as well as in the adjoining areas.

- II) Construction of sluice gate at Kandhigram area along left bank of river Barak on the dyke from Badarpur to Bhanga is required to improve drainage congestion in an area of approximately 5.0 sq km.
- III) Raising and strengthening of embankment along Sonai River is required at places. Flood management works to protect the village Nandigram on the left bank of river Sonai; raising and strengthening of embankments from Berabak to Kagdohr will save approximately 800 hectares of land areas and more than 2.0 lakhs of people will be benefitted apart from saving the National highway connecting Silchar to Aizwal.

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