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Using Satellite Images to Analyze Technically Sukkur Barrage During Flood in Pakistan

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Abstract: Flood 2010 began in late July, resulting from heavy monsoon rains in Khyber Pakhtunkhwa, Punjab, Balochistan and Sindh in Pakistan. Over all Pakistan's one-fifth area was affected by flood. According to Government data, flood directly affected about 20 million people, mostly by destruction of property, livelihood and infrastructure with a death toll of close to 2000. Indus Basin Irrigation system is one of the world's largest Irrigation system and the largest system in Pakistan. It covers Area of 17.2 Mha. Indus river basin irrigation system has three major reservoirs, sixteen barrages, two head works, two siphons across major rivers, 12 inter river link canals and 44000irrigation canal mileage. Sindh irrigation system lies below Guddu barrage, the first barrage in Sindh, enters Sindh province at a R.L. of (75m 246ft) above mean sea level. After Flood 2010, it was important to study the region of sukkur and sukkur barrage to control high flood with safe flow to avoid massive destruction. Almost one fifth portion of Pakistan was submerged in Flood water. For future planning it is important to take precautionary measures and avoid destructions at sukkur barrage. Sukkur Barrage has network based on seven canals (9923 km) 6166 miles long, feeding the largest irrigation system in the world, with more than 7.63 million acres of irrigated land which is approximately 25 percent of total canal irrigated area of the country. Structure of barrage is based on 66 spans, each 60 feet and weighing 50 tons. Here, Goal of research study is to present a hypothetical flood in Indus River at point of Sukkur barrage with potential changes in geometry of river in premises of Sukkur barrage. To measure technical analysis of sukkur barrage a computer based model is prepared through HEC RAS software. software is capable to moderate the satellite image and modify it according to contour's of area and imbedding Computer Added Design in model to analyze impact of flood 2010 at Sukkur Barrage. levees are also generated in model to overcome the problem of overtopping of flood water. Analysis shows results same as satellite images were taken during flood and impact of velocity pressure (showing water particle tracing) at gates were also measured as depositing of silt at upstream of barrage.

Keywords: IRIS, Flood 2010, GIS, Sukkur Barrage, Computer Based Model, Data, Technical Analysis, Results and Suggestions

1. Introduction

Indus Basin Irrigation system is one of the world's largest Irrigation system and the largest system in Pakistan. Itcovers Area of 17.2 Mhastarting from Lake Masrooraand then falls in to Arabian Sea. Regarding to river water storage and diversion the Indus river basin irrigation system has three major reservoirs, sixteen barrages, two head works, two siphons across major rivers, 12 inter river link canals and 44000 irrigation canal mileage.

In Sindh agriculture acts as an industry, Indus plains lies below Guddu barrage, the first barrage in Sindh, enters Sindh province at an elevation of (75m 246ft) above mean sea level and passes through major parts of the Sindh province before discharging into Arabian Sea. In Sindh, the only source of irrigation water is from Indus River. The climate of southern part of Pakistan is tropicaland arid as maximum temperature exceeds 45°C in summer, whereas, lake evaporations stands at 2800mm at Thatta. Average gradient was observed from sea level as flat with rate of 12.5 cm/km (eight inches/mile), Indus provides irrigation system to major portion of Sindh almost 41 percent. The total Gross Commanded area of Sindh and Baluchistan which depends on Indus is 5.92 Mha whereas, the only Cultivable command Area is 5.43 Mha. The major crops grown in Sindh are rice, cotton, maize, ground nut etc. in Kharif and wheat, gram, barley, pottatos, tobacco and sugarcane in Rabi. Besides this, Sindh also produces horticultural crops such as: mangoes, bananas, dates and chilies.

Sindh has also diversion capacity of 111 billion cubic meter (BCM) which is equivalent to 90 million Acre Feet (MAF) [1]. Indus basin irrigation system consist of six major rivers namely: Indus, Chenab, Jhelum, Ravi, Beas and Sutlaj. According to the Indus water accord signed between Pakistan and India in 1960, the three eastern rivers - Ravi, Beas and Sutlej - were allotted to India while three western rivers - Indus, Jhelum and Chenab - were allotted to Pakistan.

1.1. Water Ability of the Indus Basin Irrigation System

There are three main sources of water availability in the Indus basin.

The average annual flow of western rivers of Indus basin is approximately 142 million acres feet MAF. About 104 MAF of this water is diverted for irrigation purposes and about 35 million acre feet outflows to the Arabian sea.

Another source of water is the rain fall. Irrigated areas of Indus basin receive on average 40 million acres feet of water annually. Rain fall of Sindh province is 100 to 180 mm per year and evaporation rate is between 1000 to 2000 mm.

The third source of water is the ground water. It provides approximately 40 percent of crop water requirements of the country [2].

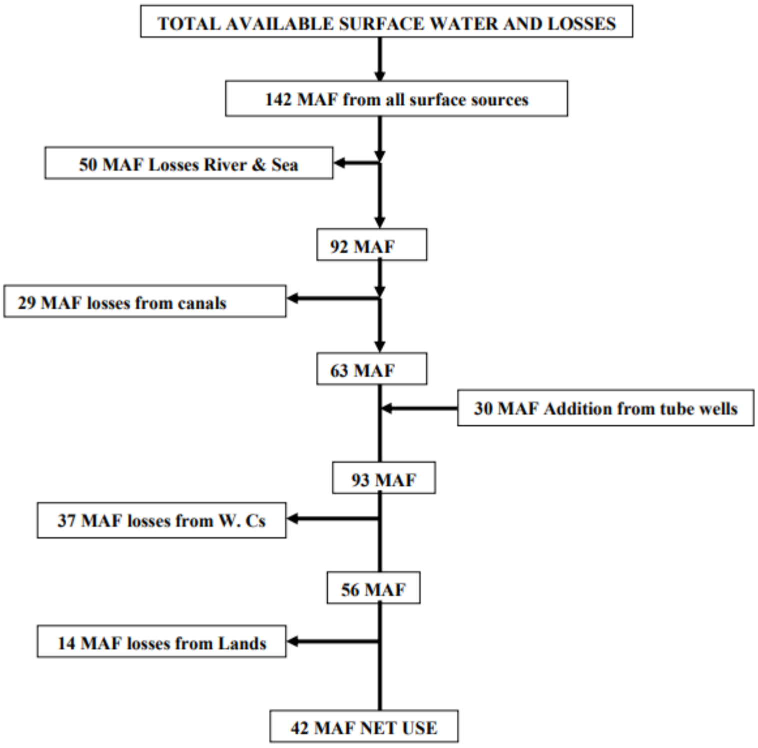


Figure 1. *Flow Chart shows Total Available surface water and It's losses [3].*

1.2. Flood 2010 in Pakistan

Floods have always been natural disasters, which are associated with human and financial losses and have influence on human's life. The risks have also increased due to climate changes and human interference to the river systems. Human has fighting with flood in different ways for a long time but the fact must be accepted that flood is not fully controlled but its losses can be reduced by flood management [4].

Flood 2010 began in late July, resulting from heavy monsoon rains in Khyber Pakhtunkhwa, Punjab, Balochistan and Sindh. Over all Pakistan's one-fifth area was affected by flood. According to Government data, flood directly affected about 20 million people, mostly by destruction of property, livelihood and infrastructure with a death toll of close to 2000. In response to previous data Indus River was also affected by floods in 1973 and 1976 after that Pakistan created Federal Flood Commission (FFC) in 1977. To analyze and forecasting regarding to floods in Sindh and their impacts on hydraulic structures, especially on barrages this research was carried out. As we know that Sukkur barrage was in critical position during the flood 2010. The barrage was built during the British government in 1923 to 1932 and was known by Lloyd Barrage. It is Pakistan's largest single irrigation network of its kind in the world. It irrigates from Sukkur district to almost all parts of the province except few. SukkurBarrage functionally used to control the floods and for irrigation. This barrage economically support the entire country. It is very important to mitigate measurements corresponding to repair of mega structure before repair our research is used to find out figures through HEC RAS software by applying conditions like Flood 2010. HEC RAS is computer based program that model the flow conditions through natural rivers and other channels. The program was developed by US Army Corps of Engineers in order to manage the rivers, harbors and other public works on natural state. In this software satellite images are transferred through Geographic Information System to HEC RAS. GI System is well designed to capture, store, manipulate, analyze and manage. After transferring image, HEC RAS will decide contours of image and will treat image in its real position to solve hydraulic problems. In our research Images of sukkur barrages were taken from satellite and contours were set, exact values of flood 2010 were put in software, reality was imagine and flow was observed. After that, levees of river were set, gated structure was also set in model on reality base, proper gate opening according to flow was given to model and then analyzed.

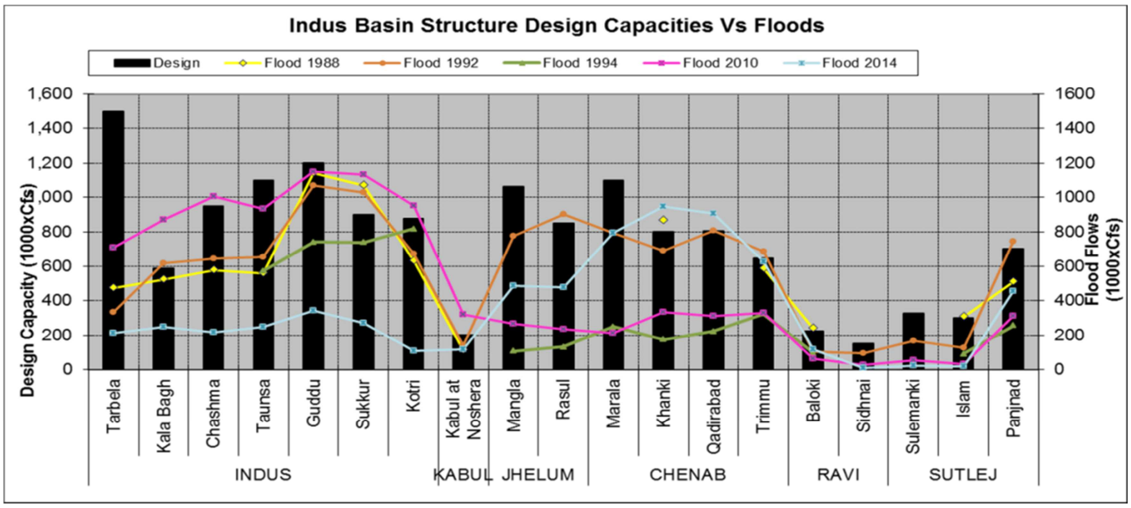


***Figure 2.** Indus Basin Structure Design Capacities Vs Different Floods.*

1.3. Importance of Levees

In flood 2010 pore water pressure was main cause of breach at Thori Bund in August. Recession of water was flowing through different major cities of Sindh includes: Qambar-Shahdadkot and Dadu. Irrigation Department of Sindh claimed that cut was not deliberate in bund but was due to water over toping and pore pressure caused breaches. Over all it is important to know the conditions of Bunds of Sindh regarding to its physical and internal resistance, which mainly depends on properties of soil and height of Bund as compare to Flood Water. Bunds of river Indus are high ranges from 5-15 m and are made up to soil (compacted earth) having sand content mostly were observed Silty-Clay. Loop Bunds have also been constructed to give added protection against flood.

1.4. Manual Analysis for Stability of Bund

Method of Slices is one of the reliable method to find stability of bund [5]:

Wt is the weight of the soil slice but also includes external loads on the slope surface and weight of water if the slope is submerged.

T and E forces on the vertical boundaries of the slice are shear and lateral forces due to adjacent slice.

$$N = \text{Wtcos}\,\alpha\ (\text{ifsubmergence})\ \text{or}$$

$$\text{Wtcos}\,\alpha - U\ (\text{if submerged}) \quad (1)$$

$$\text{Lower length of slice} = b / (\cos\alpha)\ \text{or} = b \sec\alpha \quad (2)$$

Also:

Assume a failure surface for analysis.

Make slices of failure portion of surface.

Material properties at bottom should be same, same material.

Bottom should be formed on curved as chord.

More slices will make more refined solution.

Find Factor of safety of each slice and then sum of all slices.

Find lowest Factor of safety for different failure surfaces.

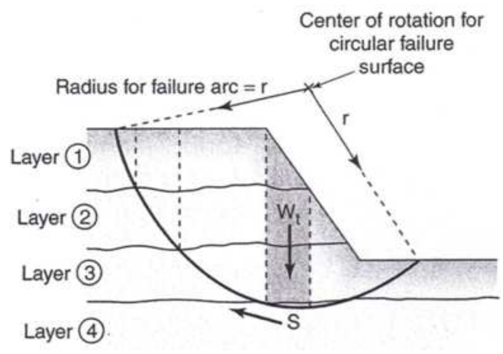


***Figure 3.** Shows selection of slices so base arc passes through only one soil type.*

1.5. Study Area

After Flood 2010, it was important to study the region of sukkur and sukkur barrage to control high flood as it was the high flood in Pakistan with massive destruction. As Shown in Figure Almost one fifth portion of Pakistan was immersed in Flood water. For future planning it is important to measure precautions and avoid destructions.

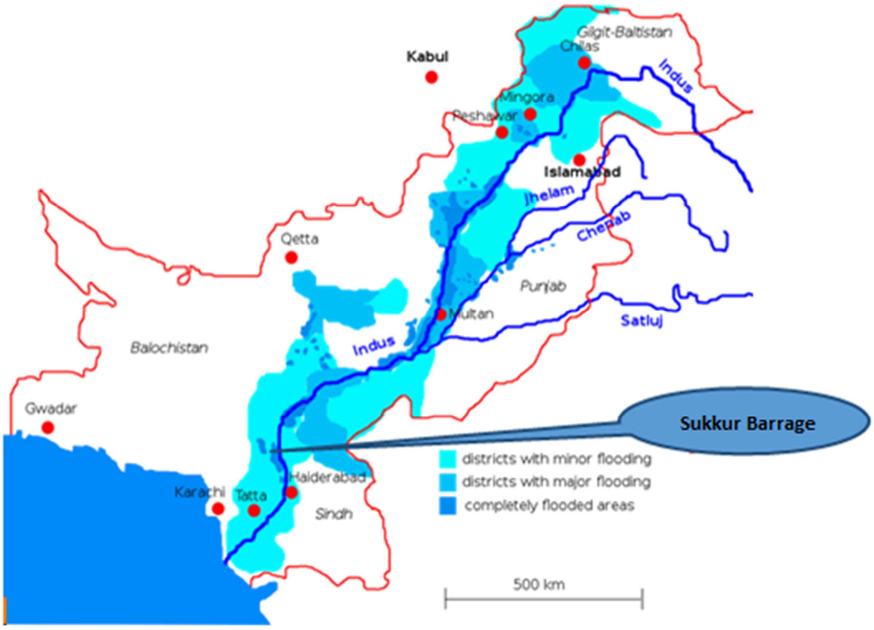


Figure 4. *Shows Flood 2010 Water in different Areas of Pakistan.*

Figure 5. *Shows satellite Image of River Indus.*

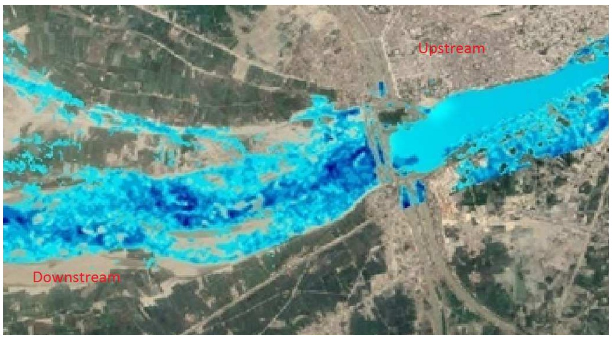


Figure 6. *Shows Flow of water in River Indus at Sukkur Barrage.*

1.6. Sukkur Barrage

Sukkur Barrage has network based on seven canals (9923 km) 6166 miles long, feeding the largest irrigation system in the world, with more than 7.63 million acres of irrigated land which is approximately 25 percent of total canal irrigated area of the country. Structure of barrage is based on 66 spans, each 60 feet and gates weighing 50 tons. Figure shows Sukkur barrage during Flood 2010. Goal of research study is to present a hypothetical flood in Indus River at point of Sukkur barrage with potential changes in geometry of river in premises of Sukkur barrage.

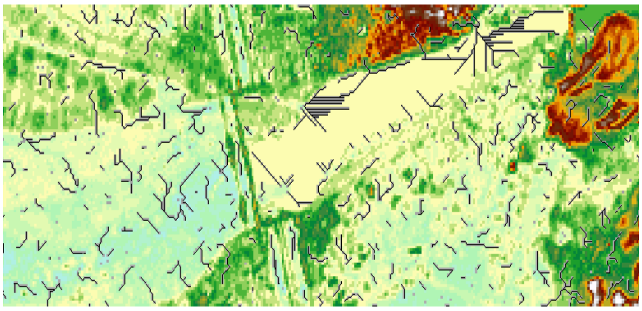


Figure 7. *Shows Drainage Lines in River Indus near Sukkur Barrage.*

Figure 8. *Shows High Flood Level 2010.*

Table 1. *Gates of Head Regulators in normal closed position.*

CANAL	Sill Level	Height of			R L of Top of Bottom Gate in normal closed position	R L of Top of Middle Gate in normal closed position	R L of Top of Top Gate in normal closed position
		Bottom Gate	Middle Gate	Top Gate			
Nara	181.34	4'-6"	8'-9"	8'-9"	185.59	193.84	202.09
K F East	187.28	4'-6"	5'-9"	5'-9"	191.53	196.78	202.03
Rohri	188.11	4'-6"	5'-6"	5'-6"	192.36	197.36	202.36
K F West	185.28	4'-6"	6'-9"	6'-9"	189.53	195.78	202.03
Dadu	184.32	4'-6"	7'-4-1/2"	7'-4-1/2"	188.57	195.45	202.32
Rice	183.13	4'-6"	8'	8'	187.38	194.88	202.38
NW Canal	183.75	4'-6"	7'-9"	7'-9"	188	195.25	202.5

Figure 9. *Shows High Flood Level 2010 Passes from Sukkur Barrage.*

HEC RAS:

US Army engineering team has done some analysis on simulation river problems such as cross structures. Study results are related with the designing and producing river modeling software such as HEC RAS. Model has some advantages as its accessibility and free use, easy applicability in windows and tabulate, graphical representation of the input-output and also easy use of modeling as considered. Our Project model was simulated in HEC RAS software by generating mesh, levees and gated structure in model and then applying flow conditions to observe the hydraulic functions of Barrage. Figure shows mesh generated, boundary conditions and levees in software.

Table 2. *Shows Data, required to analyze model in HEC RAS.*

Data Type	Specification	Source
Digital Surface Model (DSM)	"ALOS World 3D - 30m"	JAXA
MODIS Data	Daily MODIS terra data (june-Dec2010) for extraction of daily flood extents	NASA
Discharge data	Daily discharge datasince 1998 – 2018 for Sukkur barrage	Sukkur Barrage Control Room
High Flood level	Recorded Peak 2010 levels for Sukkur Barrage and u/s & d/s levees	Sukkur Barrage Control Room
Levees alignment	Vector data	Sindh Irrigation Pakistan
Architectural Models	Structure Design & Drawings of Sukkur barrage	Sukkur Barrage Office
Gate Operation Data	Time-series Gate Operation for the year 2010 and all flood years	Sukkur Barrage Control Room

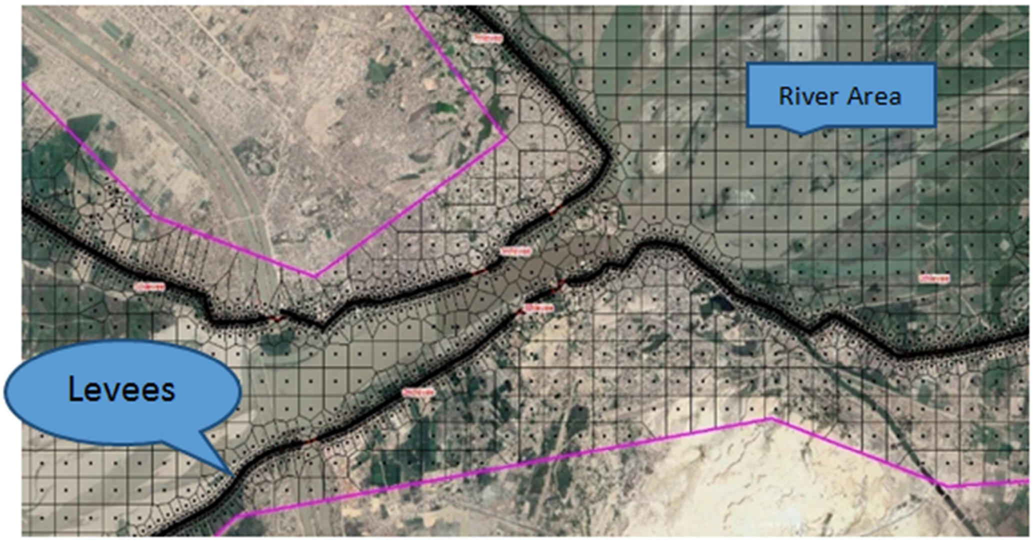


Figure 10. *Shows mesh generated over River Indus includes Levees.*

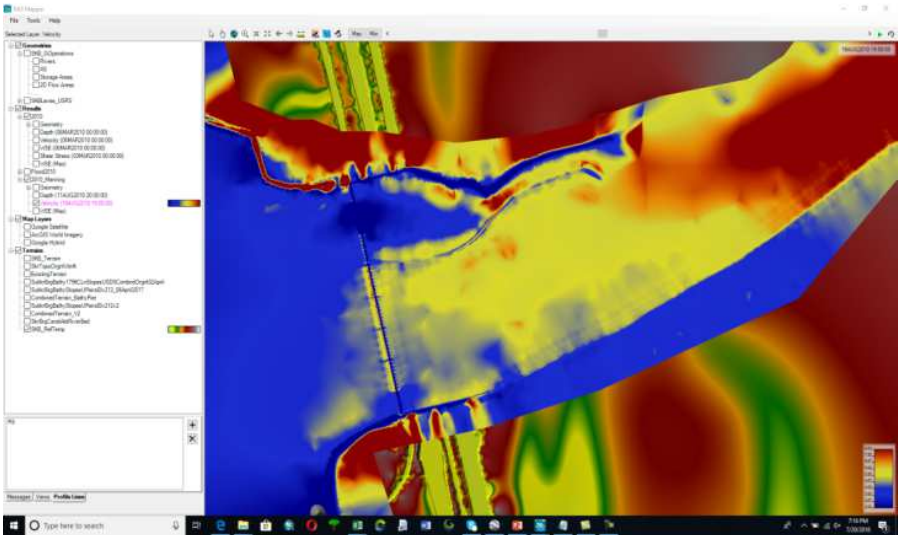


Figure 11. *Shows generated pressure on gates of Sukkur barrage due to velocity of Flood Water.*

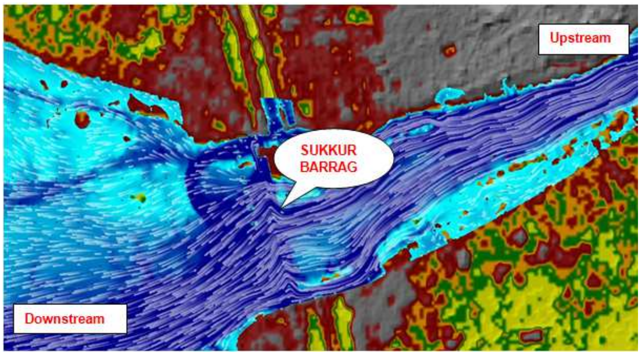


Figure 12. *Shows impact of Flood 2010 water particle tracing from gates of barrage.*

Steps for Model Generation in Computer based program:

1. River geometry through DEM.
2. Exploring RAS geometry to HEC RAS.
3. Check for corrections in HEC RAS.
4. Mesh Generation.
5. Levees formation.
6. Imbedding Barrage model.
7. Installing Gates in Barrage.
8. Applying Flow area boundary conditions.
9. Run Program.
10. Results.

Table 3. *Shows Values for 2D Mash Generation.*

S No		Values
01	Manning's	0.06
02	Cell Volume	0.01
03	Face Profile	0.01
04	Face Area Elevation	0.01
05	Face Conveyance Ratio	0.02
Computation Point Spacing		
06	Spacing DX	1000
07	Spacing DY	1000
08	Normal Depth	0.0025
Break Line Cell Spacing		
09	Minimum (Mesh Spacing)	100
10	Maximum (Mesh Spacing)	500

Table 4. *Weir Data.*

TABLE: STATEMENT SHOWING THE GATE OPENNING OF MAIN BARRAGE, POND LEVEL & DISCHARGE AT SUKKUR AUGUST 2010

Date	Time	Abutment		Pier No 23		Cut Off	Right Pocket	Left Pocket	River Sluices				Left Pocket	Discharge	
		R/B	L/B	U/S	D/S		1--5	15--22	24--32	33--41	42--50	51--59	60--66	U/S	D/S
1	600	198.5	199.2	199.6	195.3	4.3	0.2	3	7	7	6.5	6	0.2	205500	163250
2	600	198	198.8	199.2	196.2	3	1	5	8	8	8	8	1.2	208952	176402
3	600	198.8	199.2	199.6	196.5	3.1	1.5	5	8	8	8	8	2	215660	183810
4	600	198.4	199.4	199.6	196.9	2.7	3.8	6	10	10	9	9	4	252232	224132
5	600	198	198.7	199.2	198	1.2	7	10	16	16	15	14.8	7	311400	283550
6	600	199	198.6	199	198.7	0.3	20	22	F.O	F.O	F.O	F.O	20	600710	577910
7	600	200.9	200.6	200.9	200.7	0.2	F.O	F.O	F.O	F.O	F.O	F.O	F.O	871682	850682
8	600	201.9	201.8	201.9	201.7	0.2	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1049285	1040070
9	600	203	202.9	203	202.9	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1130220	1124720
10	600	203	202.9	203	202.9	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1130995	1108795
11	600	202.8	202.7	202.8	202.7	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1130995	1108795
12	600	202.75	202.7	202.75	202.7	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1113210	1089510
13	600	201.65	201.45	201.75	201.6	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1083660	1053820
14	600	201.55	201.4	201.5	201.4	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1010327	975087
15	600	201.5	201.4	201.5	201.4	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1008377	975087
16	600	201.6	201.5	201.6	201.5	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1021220	987890

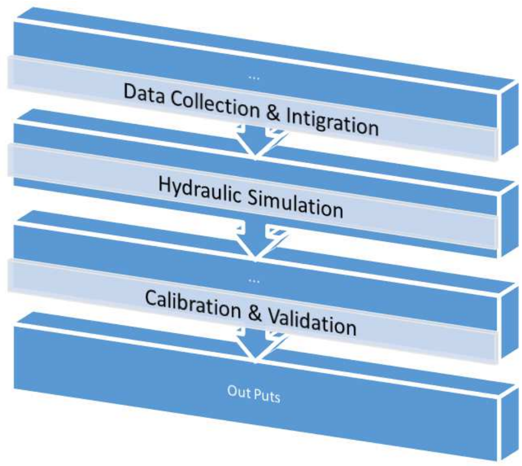
TABLE: STATEMENT SHOWING THE GATE OPENNING OF MAIN BARRAGE, POND LEVEL & DISCHARGE AT SUKKUR AUGUST 2010

Date	Time	Abutment		Pier No 23		Cut Off	Right Pocket	Left Pocket	River Sluices				Left Pocket	Discharge	
		R/B	L/B	U/S	D/S		1--5	15--22	24--32	33--41	42--50	51--59	60--66	U/S	D/S
17	600	201.65	201.55	201.7	201.6	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1025630	993880
18	600	201.65	201.55	201.7	201.6	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1025455	993880
19	600	201.5	201.4	201.5	201.4	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	1001710	965100
20	600	201.45	201.33	201.4	201.3	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	990535	954550
21	600	201.4	201.3	201.4	201.3	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	974453	945758
22	600	201.2	201.1	201.2	201.1	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	892245	854600
23	600	201.5	200.95	201.1	201	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	827350	783580
24	600	201	200.9	201	200.9	0.1	F.O	F.O	F.O	F.O	F.O	F.O	F.O	794852	750602
25	600	201	200.95	201	200.8	0.2	F.O	F.O	F.O	F.O	F.O	F.O	F.O	735748	691978
26	600	201	200.9	200.9	200.7	0.2	F.O	F.O	F.O	22.5	28.5	28	F.O	697335	656795
27	600	201.2	200.8	200.8	200.6	0.2	F.O	F.O	F.O	27	27	26.5	F.O	653551	616351
28	600	201.1	200.7	200.7	200.5	0.2	F.O	F.O	F.O	27	27	26	F.O	603012	562082
29	600	201	200.6	200.6	200.4	0.2	F.O	26	26.5	27	27	26	F.O	557744	515974
30	600	200.8	200.6	200.6	200.4	0.3	F.O	F.O	F.O	F.O	F.O	F.O	F.O	598554	507114
31	600	200.5	200.3	200.5	200.2	0.3	F.O	F.O	F.O	F.O	F.O	F.O	F.O	541660	496830

2. Method

Goal of research study is to present a hypothetical Flood in Indus River at point of Sukkur barrage with potential changes in geometry of river in premises of Sukkur barrage. Model is given as a deterministic data assimilation, in which internal boundary conditions and model parameters are estimated based on downstream real time observed discharge. Considering a situation where the flow of tributaries for a specific river reach is unknown model calculations are corrected by applying the global search algorithm to estimate the optional lateral inflow, so that model underestimation in output flows can be addressed. Furthermore, the manning coefficient is simultaneously adjusted by the optimization algorithm, which is justified by uncertainty in upstream flows, errors in geometry of cross section [6]. Once the geometry is complete, the hydrology can be entered into the model. HEC-RAS requires flows to be entered at all upstream boundaries. In addition, flow changes can be specified along any of the streams [7]. Here, we took satellite image and then generate mesh in area of interest with boundary conditions also set contours and barrage model in selected image with sill level and gates opening as same as flood 2010. After simulation we run model, results are very same to satellite image of flood 2010 in moth of August. Further we calculate velocity pressure on barrage also particle tracing& static velocity Arrows helps to understand the nature of Flood.

2.1. Methodology



2.2. Research Objectives

1. To Model with mesh generated and boundary Conditions in HEC RAS.
2. To set levees /Bunds in reach of River Indus near Sukkur Barrage.
3. To set Gate opening of Sukkur Barrage with Flow Conditions.
4. To check applicability of Model to simulate flood events.

Table 5. *Classification of Flood regarding to Flood Protection Bund [08].*

S No	Classification	Details
01	Low Flood	When the river is flowing within the actual channel with chances to spread over river island.
02	Medium Flood	In medium flood, river flows is partly inundating river but below half of its maximum flood level.
03	High Flood	When the level of river is almost fully submerging and flowing up to high banks but without encroaching on the free board.
04	Very High Flood	When the water level of river flows is between high banks.
05	Exceptionally High Flood	When there is imminent danger of overtopping/breaching or a breach has actually occurred or high bank areas become inundated.

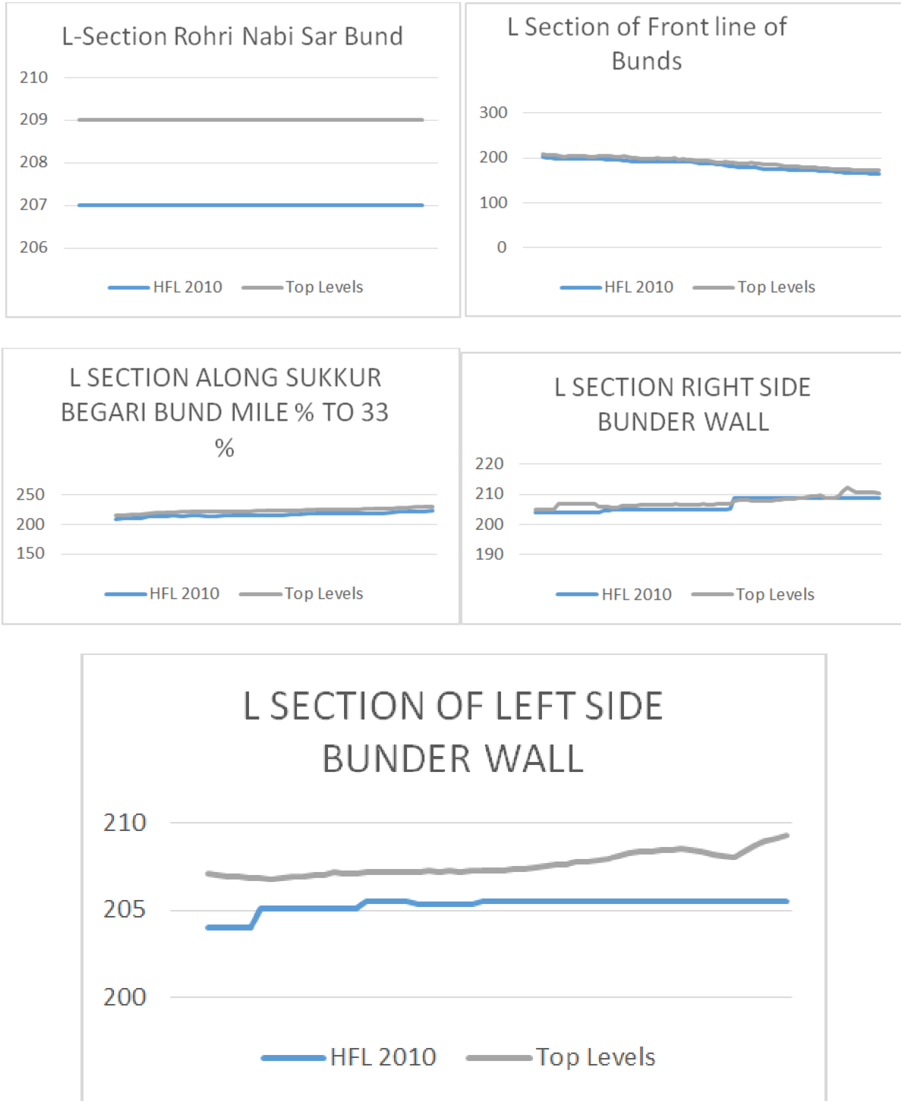


Figure 13. *Shows compression between bunds and flood water level.*

3. Results

Model shows equality between satellite image and model generated scene with same values of flood 2010 with same date and time.

Figure 14. *Shows satellite image during flood 2010.*

I. L-Section of bunds were observed near to over flow during peak discharge.
II. Excessive silt entry in right bank canals.
III. Sand dunes formed in front of head regulators inside right pocket.
IV. Right Bank canalscan nottake the design discharge being in reverse direction of natural slope.
V. Models studies carried out in Puna in from 1935 to 1942 to rectify the problem.
VI. During 2010 the flood management and forecasting for Sindh province becomes indistinguishable and imprecise.
VII. This has intensified further the flood situation in Sindh at Guddu Barrage and further downstream.
VIII. Out of 66 Sluice Gates 56 are operational of Sukkur Barrage.

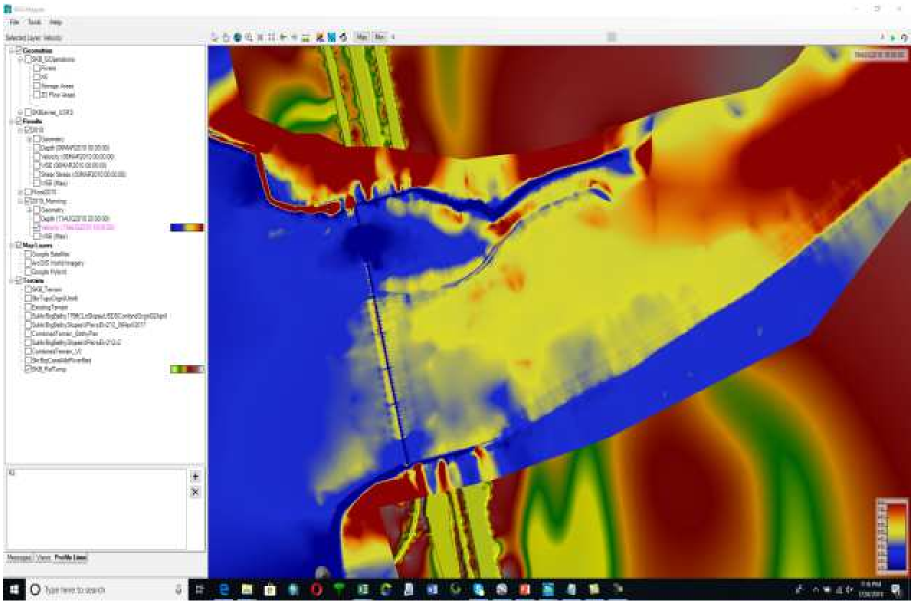


Figure 15. *Shows similarities between model and satellite image during flood 2010.*

4. Suggestions

1. Flood storage volumes and timely effective operation of the Barrages can help to mitigate peak flows along the main stream and tributaries of the Indus.
2. Human intervention and climate change have been the major causes of water availability and sediment deposition in lower Indus basin system. Thus it is suggested that any future interventions should be linked with water availability and climate change effects.
3. Effective flood risk reduction operations would require improvements in real-time operations and monitoring, improvements in forecasting and coordination between the different dams, such that pre-flood releases are made on a timely basis and operators offset flood peak synchronization.
4. Irrigation Department should maintain escape route at R.N Bund 8 Km U/S of sukkur barrage, which follows the natural gradient on the left side of river.
5. The upstream front basin must be cleaned from grass, sand deposited dunes, due to that flow impact right side of barrage canals.
6. When upstream front will be cleaned it will act as basin full of water and that will dilute one side impactt and mean time sediment settling on upstream will be ejected through silt excluders to main river.
7. The front basin acts as lake hence pure water will be supplied to each canal, also this front lake may serve the folloing purposes: it will absorb lateral thrust of coming water, acts basin for aqua life and avoid silt entry in canals.

5. Conclusion

Sukkur Barrage is located in the Indus River, will be studied to enhance its performance through better operating plan through better regulation/operating procedures. This is intended to be done by using HecRAS and HecResim. Standard operating procedures for effective sediment sluicing could be determined though this will requires consistent guidance from Supervisors. From the data collected, a sediment transport model of Lower Indus Basin can be prepared for making better informed decisions to enhance the effectiveness and the life of the Barrages in Sindh. Also, identify the required volumes of sediments required for the existing of Indus Delta.

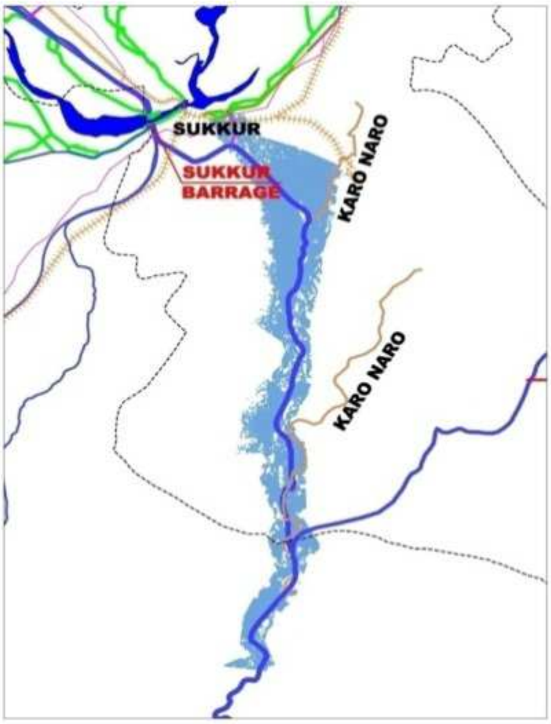


Figure 16. *Shows Flood escape route at R.N Bund 8 Km U/S of sukkur barrage.*

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