9.11 DAM BREAK ANALYSIS AND DISASTER MANAGEMENT PLAN

Kaleshwaram project envisages of various components like Barrages (03 numbers), Water conveyance system (gravity canal and tunnels), Online storages (17 numbers) and Distributory Network System etc.

One of the main components of Kaleshwaram project is Sri Komaravelli Mallana Sagar online Storage having capacity of about 50 TMC. It is reported that Sri Komaravelli Mallanna Sagar online storage will be having capacity of about 25-30 % of overall water demand and has been kept at higher elevation to act as mother online storage and also as carryover storage in case there is a water shortage in the system. The proposed Sri Komaravelli Mallanna Sagar will be having its F.R.L at RL 557.00 m. The length of Bund will be 22.90 km and maximum height of 61.5 m. I&CAD Department of Telangana state has requested Central Water & Power Research Station (CWPRS), Pune to carry out Dam Break Analysis (DBA) for preparation of guidelines for Emergency Action Plan for proposed Sri Komaravelli Mallana Sagar. Dam Break Studies has been carried out at CWPRS using 1-Dimensional (1-D) Dynamic mathematical model for different breach parameters. The flood hydrograph due to breach have been routed through existing natural stream Kurelli Vaagu. The annexure report presents the results of model study carried out for dam break flood discharge, predicted water levels along the stream and likely flood inundation area marked on Survey of India (SOI) toposheets.

Detailed Dam Break Analysis and Disaster Management Plan for Komaravelli Mallana Sagar and three barrages i.e. Medigadda, Annaram and Sunidilla is given in Annexure 9.12.

DAM BREAK ANALYSIS AND DISASTER MANAGEMENT PLAN

1. Need for Dam Break Analysis

The construction of dams in rivers can provide considerable benefits such as the supply of drinking and irrigation water as well as the generation of electric power and flood protection; however, the consequences which would result in the event of their failure could be catastrophic. They vary dramatically depending on the extent of the inundation area, the size of the population at risk, and the amount of warning time available.

Dam break may be summarized as the partial or catastrophic failure of a dam leading to the uncontrolled release of water. Such an event can have impacts on the land and communities downstream of the failed structure. A dam break may result in a flood wave up to tens of meters deep traveling along a valley at quite high speeds. The impact of such a wave on developed areas can be devastating. Such destructive force comes as an inevitable loss of life, if advance warning and evacuation is not planned. Additional features of such extreme flooding include movement of large amounts of sediment.

As far as the dam break analysis of Kaleshwaram Project is concerned, there are three proposed barrages namely Sundilla, Annaram and Medigadda Barrrage in cascade where Sundilla is upstream most and Medigadda is downstream most barrage on river Godavari. Immediately upstream of the Sundilla Barrage there is Yellampally Dam/Barrage, which has been constructed very recently and is functional. Although, Yellampally has been named as barrage but virtually for all technical purposes it is a large dam having a storage of about 87 MCM below its crest level and about 484.36 MCM storage against gates of about 10 m height.The crest level of Yellampally Barrage is 8 – 10m high about natural bed level and stores water of about 87 MCM and therefore, it can be categorized as Large Dam, because, its storage capacity below the crest level is more than 60 MCM and hence it confirms BIS classification norms for large dams. It is in this context, dam break study become necessary for the Kaleshwaram Project. Moreover, in case of failure of Yellampally Dam/Barrage it will have very adverse impact on the proposed three barrage of Kaleshwaram system, because these barrages are also having very high storage capacity although they are confined mostly to the river flood plain zone only. In view of above, dam break study of the Kaleshwaram system has been carried out taking Yellampally acting as a dam and other three barrages as integral component of the system.

2. Dam Break Inundation Analysis

The outflow flood hydrograph from a dam failure is dependent upon many factors such as physical characteristics of the dam, volume of reservoir and the mode of failure. The parameters which control the magnitude of the peak discharge and the shape of outflow hydrograph include: the breach dimensions, the manner and length of time for the breach to develop, the depth and volume of water stored in the reservoir, and the inflow to the reservoir at the time of failure. The shape and size of the breach and the elapsed time of development of the breach are in turn dependent upon the geometry of the dam, construction materials and the causal agent for failure.

3. Objectives of Dam Break Analysis

The objective of dam break modelling or flood routing is to simulate the movement of a dam break flood wave along a valley or indeed any area ‘downstream’ that would flood as a result of dam failure. The key information required at any point of interest within this flood zone is generally:

i. Time of first arrival of flood water
ii. Peak water level – extent of inundation
iii. Time of peak water level
iv. Depth and velocity of flood water (allowing estimation of damage potential)
v. Duration of flooding

The nature, accuracy and format of information produced from a dam break analysis will be influenced by the end application of the data. Further, to reasonably prepare an emergency plan, it will be necessary for the dam break analysis to provide:

i. Inundation maps at a scale sufficient to determine the extent of and duration of flooding in relation to people at risk, properties and access routes
ii. Identification of structures (bridges etc.) likely to be destroyed
iii. Indication of main flow areas (damage potential of flow)
iv. Timing of the arrival and peak of the flood wave
v. Identification of features likely to affect mobility / evacuation during and after the event including impact on infrastructure and the deposition and scour of debris and sediment.

The dam break analysis for Kaleshwaram system of Barrages and Yellampally Dam has been carried out to ascertain the impact of uncontrolled release of water in the downstream in the hypothetical conditions of failure of dam

3.1. Study for the Current Project

TheYellampally Dam/Barrage is 1180.7m long having overall capacity of about 571 MCM out of which 87 MCM storage is below the crest and remaining about 484 MCM against the gates. The maximum height of the crest above the river bed is about 10 m. there are 62 gates having size of 15 m x 10.2 m.

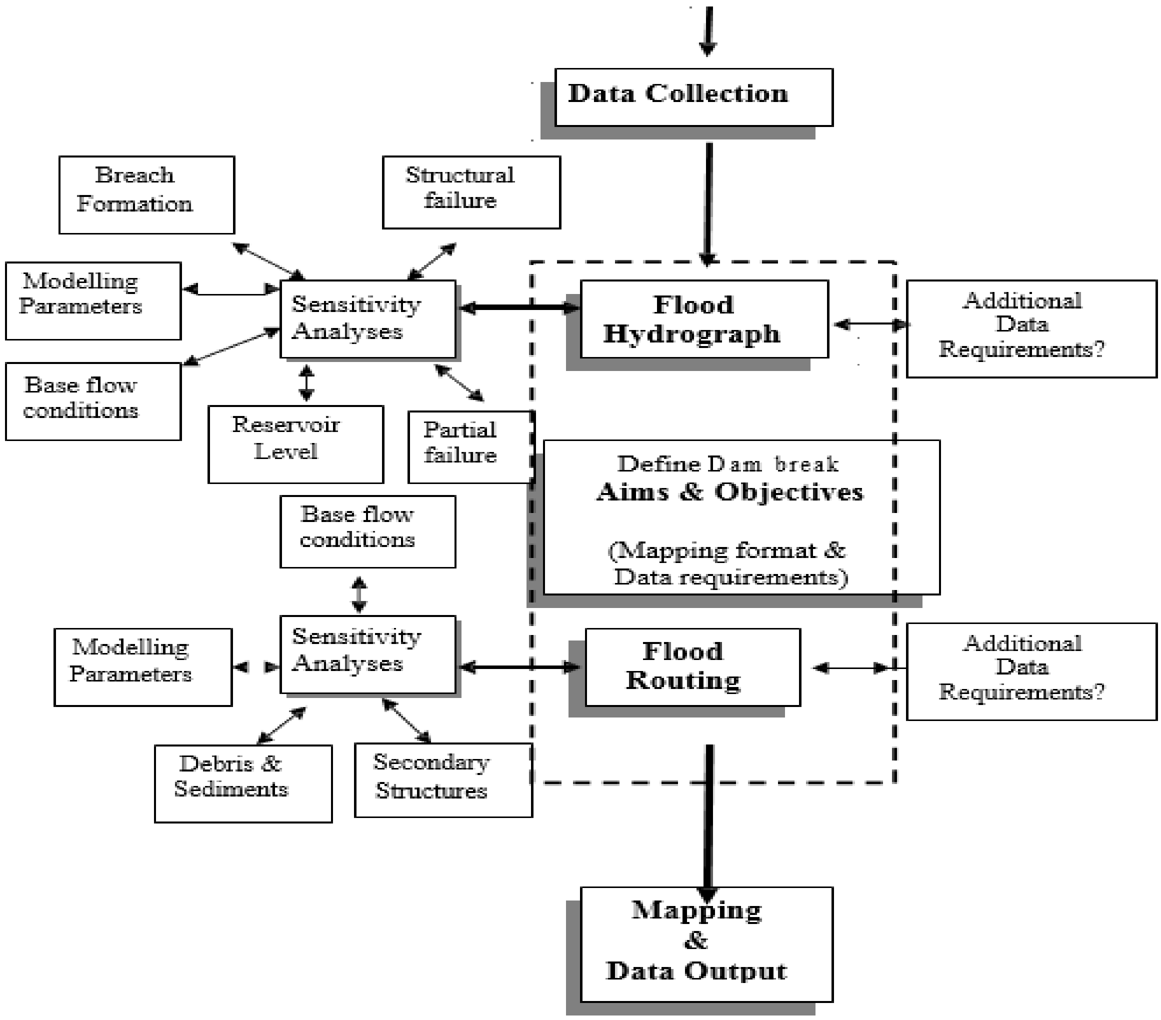
The dam break analysis for Kaleshwaram system including Yellampally Dam has been carried out to ascertain the impact of uncontrolled release of water in the downstream, in the hypothetical condition of failure of dam. The present study comprises of the hydrodynamic simulations due to following occurrences:

- SPF with Dam Break with initial reservoir level at pond level.

As such, the dam break analysis carried out predicts the outflow hydrograph due to dam breach, the maximum water level and discharge along with time of travel at different locations of the river downstream of the dam. These studies will also give assessment of inundation area due to the heaviest flood that may occur in case of failure of dam/barrages being constructed.

4. Dam break modelling process

Generally, dam break modeling can be carried out by either i) scaled physical hydraulic models or ii) mathematical simulation using computer. A modern tool to deal with this problem is the mathematical model, which is most cost effective and approximately solves the governing flow equations of continuity and momentum by computer simulation. A flow chart for mathematical modeling is given below.



FLOW CHART OF DAM BREAK MODELLING PROCESS

Mathematical modeling of dam breach floods can be carried out by either one dimensional analysis or two dimensional analyses. In one dimensional analysis, the information about the magnitude of flood, i.e., discharge and water levels, variation of these with time and velocity of flow through breach can be had in the direction of flow.In the case of two dimensional analysis, the additional information about the inundated area, variation of surface elevation and velocities in two dimensions can also be assessed. One dimensional analysis is generally accepted when valley is long and narrow and the flood wave characteristics over a large distance from the dam are of main interest. On the other hand, when the valley widens considerably downstream of dam and large area is likely to be flooded, two dimensional analysis may be adopted. In the instant case, as the Godavari river is long and the flood wave characteristics over a large distance from the dam are of main interest, one dimensional modeling was adopted.

4.1. Hydrodynamic Modelling

The basic theory for dynamic routing in one dimensional analysis consists of two partial differential equations originally derived by Barre De Saint Venant in 1871. The equations are:

i. Conservation of mass (continuity) equation

$$(\partial Q/\partial X) + \partial (A+A_0)/\partial t - q = 0$$

ii. Conservation of momentum equation

$$(\partial Q/\partial t) + \{\partial(Q^2/A)/\partial X\} + g\,A\,((\partial h/\partial X) + S_f + S_c) = 0$$

Where,
Q = discharge;
A = active flow area;
9.118
A_0= inactive stora
h = water surface elevation;
q= lateral outflow;
X = distance along waterway;
t = time;
S_f = friction slope;
S_c = expansion contraction slope and
g = gravitational acceleration.

4.2. Selection of Model

Selection of an appropriate model to undertake dam break flood routing is essential to ensure the right balance between modeling accuracy and cost (both in terms of software cost and time spent in developing & running the model). In the instant case, ***HEC- RAS*** model released by Hydrologic Engineering Center of U.S. Army Corps of Engineers has been selected. HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The model contains the advanced features for dam break simulation.

5. HEC-RAS Model

The present version of HEC-RAS system contains two one-dimensional hydraulic components for: i) Steady flow surface profile computations; ii) unsteady flowsimulation. The steady/unsteady flow components are capable of modeling subcritical, supercritical, and mixed flow regime water surface profiles. The system can handle a full network of channels, a dendric system, or a single river reach. The basic computational procedure is based on the solution of one- dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. The graphics include X-Y plots of the river system schematic, cross-sections, profiles, rating curves, hydrographs, and many other hydraulic variables. Users can select from pre-defined tables or develop their own customized tables. All graphical and tabular output can be displayed on the screen, sent directly to a printer, or passed through the Windows clipboard to other software, such as word processor or spread sheet. Reports can be customized as to the amount and type of information desired.

5.1. Model Stability during unsteady flow simulation

HEC-RAS uses an implicit finite difference scheme. The common problem of stability in the case of unsteady flow simulation can be overcome by suitable selection of following;

a) Computational time step

b) Theta weighing factor for numerical solution

c) Cross section spacing along the river reach

d) Solution iterations

e) Solution tolerance

f) Weir and spillway stability factors

i. **Computational time step**

Stability and accuracy can be achieved by selecting a computational time step that satisfies the current condition;

$C_r = V_w(\Delta t/\Delta x) \leq 1.0$

Therefore, $\Delta t \leq (\Delta x/V_w)$

Where:

V_w = Flood wave speed

V = Average velocity of flow

Δx = Distance between the cross sections

Δt = Computational time step

For most of the rivers the flood wave speed can be calculated as:

$$V_w = dQ/dA$$

However, an approximate way of calculating flood wave speed is to multiply the average speed by a factor. Factors for various channel shapes are shown in the table below.

Channel shape	**Ratio (Vw/V)**
Wide rectangular	1.67
Wide parabolic	1.44
Triangular	1.33
Natural channel	1.5

ii. **Theta weighing factor for numerical solution**

Theta is a weighing factor applied to the finite difference approximations when solving the unsteady flow equations. Theoretically, theta can vary from 0.5 to 1.0. Theta of 1.0 provides the most stability, while theta of 0.6 provides the most accuracy.

iii. **Cross section spacing**

The river cross sections should be placed at representative locations to describe the change in geometry. Additional cross sections should be added at locations where changes occur in discharge, slope, velocity and roughness. Cross sections must also be added at levees, bridges, culverts, and other structures. Additional cross sections should be added at locations where changes occur in discharge,slope, velocity, and roughness to describe the change in geometry. Bed slope plays an important role in deciding the cross section spacing. Streams having steep slope require cross sections at a closer spacing say 500 m or so. For larger uniform rivers with flat slope the cross section spacing can be kept from 1000m to 3000m.

iv. Solution iterations

At each time step derivatives are estimated and the equations are solved. All the computational nodes are then checked for numerical error. If the error is greater than the allowable tolerances, the program will iterate. The default number of iterations in HEC-RAS is set to 20. Iteration will improve the solution.

v. Solution tolerance

Two solution tolerances can be set or changed by the user: i) water surface calculation ii) storage area elevation. Making the tolerance larger can reduce the stability problem. Making them smaller can cause the program to go to the maximum number of iterations every time.

vi. Weir and spillway factor for numerical solution

Weirs and spillways can often be a source of instability in the solution. During each time step, the flow over a weir/spillway is assumed to be constant. This can cause oscillations by sending too much flow during a time step. One solution is to reduce the time step.

6. Input Data and Model Setup

6.1. Data required for dam break modelling

Understanding a dam break analysis requires following range of data in general:

- Cross sections of the river from upstream to dam site and up to location downstream of the dam to which the study is required.
- Salient features of the all hydraulic structures at the dam site
- Design flood hydrograph

- Stage-Volume relationship for the reservoir
- Manning's roughness coefficient for different reaches of the river under study
- Topographic map of the downstream area for preparation of inundation map after dam break studies.

The reservoir is normally modelled as a storage area to describe the storage characteristics by the use of storage-volume at different levels. This point will often also be the upstream boundary of the model, where inflow hydrograph may be specified. However, in case of very long and wide reservoirs the routing of the inflow floods has to be carried out and hence the reservoir itself will also have to be represented by cross sections at regular intervals. The downstream boundary will be either a stage discharge relation or time series water level as in case of tidal waves etc.

6.2. River Godavari

About 64 km from its source, the Godavari receives the water of Darna river and at a short distance lower down the river, it gets out of the high rainfall zone of the Western Ghats and there is no further significant contribution to the river flow until about 150 km below when it receives the combined waters of the Pravara and Mula rivers. About 483 km lower, Manjra river joins from the south. The river Pranahita conveying the combined waters of the rivers Penganga, Wardha and Wainganga falls into the Godavari about 306 km below the Manjra confluence. About 48 km lower, the Godavari receives the water of the Indrāvati River. Both Pranahita and Indrāvati are major rivers in their own right. Sabari is the last major tributary which falls into the Godavari 100 km above Rajahmundry.

The slope of the river from its source to 100 km distance is 2.7 m per km, 0.3 m per km in the next 700 km and 1.19 m per km in the next 160 km up to the confluence of Godavari with Pranahita. In the next reach, up to the sea, the slope is very mild, about 0.23 m per km.

The river Manjra rises in the Balaghat range in the Bhir district of Maharashtra at an altitude of about 823 m. The river flows in a generally east and southeasterly direction for 515 km. The total length of the river from the source to its confluence with the Godavari, at an altitude of 329 m is about 724 km.

The Pranahita with its three principal branches, the Penganga, the Wardha and the Wainganga is by far the most important tributary of the Godavari. The Penganga rises at an altitude of about 686 m in the Buldana range in Maharashtra and after flowing for a length of 676 km in a generally southeasterly and easterly direction joins river Wardha at an elevation of 174 m. Except in its upper most reach of about 161 km which is mostly barren and hilly, the river passes through dense forests of Yeotmal and Nanded districts and is then joined by several tributaries.

The Wardha rises at an altitude of 777 m in the Betul district of Madhya Pradesh and enters Maharashtra about 32 km from its source. After flowing further for a distance of 483 km in a generally southeasterly direction it joins the Wainganga at an elevation of 145 m. For the last 42 km of its course it forms the boundary between Maharashtra and Andhra Pradesh. Throughout its course, river flows through dense forests.

River Wainganga rises at an altitude of 640 m in Seoni district of Madhya Pradesh and after flowing for a short length, it takes a turn towards east and then, south forming a great loop. After flowing for a total length of 274 km in Madhya Pradesh, it forms the boundary between Madhya Pradesh and Maharashtra for about 32 km. It then continues to flow towards south for another 188 km to join the Wardha.

The combined waters of the Wainganga and the Wardha, now called Pranhita, flow for 113 km along the border between Maharashtra and Andhra Pradesh before falling into the Godavari at an elevation of 107 m.

The Indravati rises at an altitude of 914 m in the Kalahandi district of Orissa on the western slopes of the Eastern Ghats. It flows westward through Koraput and Bastar districts, turns south and about 531 km from its source joins the Godavari at an elevation of about 82 m. The important tributaries of the Indravati are the Narangi, Boardhing, Kotri and Bandia from its right and Nandiraj from its left.

The Sabari also known as the Kolab is one of the important tributaries of the Godavari. The Sabari rises at an altitude of 1,372 m in the Sinkaram hill range of the Eastern Ghats. After flowing for a short distance in northwesterly and westerly direction, it turns south and joins Godavari about 418 km from its source at an altitude of 25 m about 97 km upstream of Rajahmundry.

In the present case, three barrages namely Sundilla, Annaram and Medigadda have been proposed in the Godavari River at RD 30.5 Km, 62.0 Km and 107.6 Km from existing Yellampally Dam respectively.

6.3. Flood Hydrograph

The design flood for the Yellampally Dam/Barrage as adopted in the design and construction of barrage are as per details given in the table placed below.

Table-1: Design Flood Hydrograph

Time (hrs)	Inflow (cumecs)	Time (hrs)	Inflow (cumecs)	Time (hrs)	Inflow (cumecs)	Time (hrs)	Inflow (cumecs)
0	1031	41	57235	82	27115	123	6479
1	1030	42	59687	83	26475	124	6216
2	1029	43	61548	84	25836	125	5969
3	1025	44	62963	85	25202	126	5736
4	1019	45	64061	86	24570	127	5513
5	1018	46	64830	87	23939	128	5299
6	1024	47	65174	88	23309	129	5093
7	1041	48	65097	89	22683	130	4895
8	1059	49	64650	90	22058	131	4703
9	1097	50	63921	91	21434	132	4518
10	1216	51	62935	92	20814	133	4340
11	1455	52	61754	93	20198	134	4156
12	1851	53	60398	94	19587	135	4011
13	2455	54	58874	95	18981	136	3859
14	3251	55	57155	96	18381	137	3704
15	4282	56	55332	97	17788	138	3551
16	5602	57	53496	98	17203	139	3400
17	7285	58	51674	99	16628	140	3322
18	9345	59	49911	100	16062	141	3106
19	11690	60	48236	101	15506	142	2900
20	14060	61	46677	102	14963	143	2777
21	16299	62	45248	103	14430	144	2643
22	18413	63	43923	104	13912	145	2502
23	20448	64	42689	105	13407	146	2359
24	22484	65	41538	106	12916	147	2492
25	24501	66	40412	107	12438		
26	26418	67	39281	108	11974		
27	28218	68	38175	109	11364		
28	29919	69	37130	110	10929		
29	31538	70	36138	111	10507		

30	33082	71	35187	112	10099		
31	34517	72	34281	113	9705		
32	35928	73	33422	114	9324		
33	37439	74	32615	115	8957		
34	39088	75	31836	116	8603		
35	40953	76	31122	117	8262		
36	43118	77	30423	118	7936		
37	45602	78	29740	119	7620		
38	48393	79	29076	120	7316		
39	51392	80	28410	121	7024		
40	54416	81	27759	122	6745		

6.4. Elevation Area Capacity Curves of Dam/Barrages

The Elevation Area Capacity Curves of Dam/Barrages present in the system and used for present Dam Break Modelling Study are placed below.

Table-2: Elevation Area Capacity of Sripada Yellampally Project

Sl No	Reduced Level	Area	Capacity	Total Capacity	Total Capacity
		in M.Sqmt		in M.Cum	in T.M.C.
1	127.000	0.000	0.0000	0.0000	0.0000
2	128.000	0.032	0.0107	0.0107	0.0004
3	129.000	0.035	0.0335	0.0442	0.0016
4	130.000	1.142	0.4590	0.5032	0.0178
5	131.000	2.587	1.8161	2.3193	0.0819
6	132.000	4.032	3.2869	5.6062	0.1980
7	133.000	6.467	5.2018	10.8080	0.3817
8	134.000	11.293	8.7686	19.5766	0.6913
9	135.000	13.176	12.2110	31.7876	1.1226
10	136.000	17.246	15.1657	46.9533	1.6582
11	137.000	19.350	18.2880	65.2413	2.3040
12	138.000	22.909	21.1045	86.3458	3.0493
13	**138.300**	**23.921**	**22.1460**	**93.7190**	**3.3097**
14	139.000	26.283	24.5767	110.9225	3.9172

15	140.000	29.894	28.0692	138.9917	4.9085
16	141.000	36.015	32.9070	171.8987	6.0706
17	142.000	40.516	38.2368	210.1355	7.4209
18	143.000	45.790	43.1305	253.2660	8.9441
19	144.000	52.526	49.1242	302.3902	10.6789
20	145.000	58.629	55.5564	357.9466	12.6409
21	146.000	67.900	63.2078	421.1544	14.8731
22	147.000	75.062	71.4657	492.6201	17.3969
23	**148.000**	**82.351**	**78.6784**	**571.2985**	**20.1754**
24	149.000	89.810	86.0535	657.3520	23.2144
25	150.000	96.356	93.0738	750.4258	26.5013
26	151.000	105.573	100.9294	851.3552	30.0656
27	152.000	144.556	110.0334	961.3886	33.9514

Table-3:Elevation Area Capacity ofMedigadda Barrage

Elevation (m)	Area (Ha)	Capacity (MCM)	Capacity (TMC)
88	55.78	16.43	0.58
89	123.70	16.71	0.59
90	359.25	18.41	0.65
91	1212.58	25.77	0.91
92	2115.75	42.20	1.49
93	2583.08	65.70	2.32
94	3016.03	93.74	3.31
95	3979.71	128.57	4.54
96	4927.40	173.04	6.11
97	5925.70	227.41	8.03
98	7132.24	292.55	10.33
99	8275.03	369.58	13.05
100	9364.79	457.93	16.17
101	10815.55	558.75	19.73

102	12050.90	673.17	23.77
103	13412.78	800.32	28.26
104	15227.76	943.62	33.32
105	17167.31	1105.61	39.04

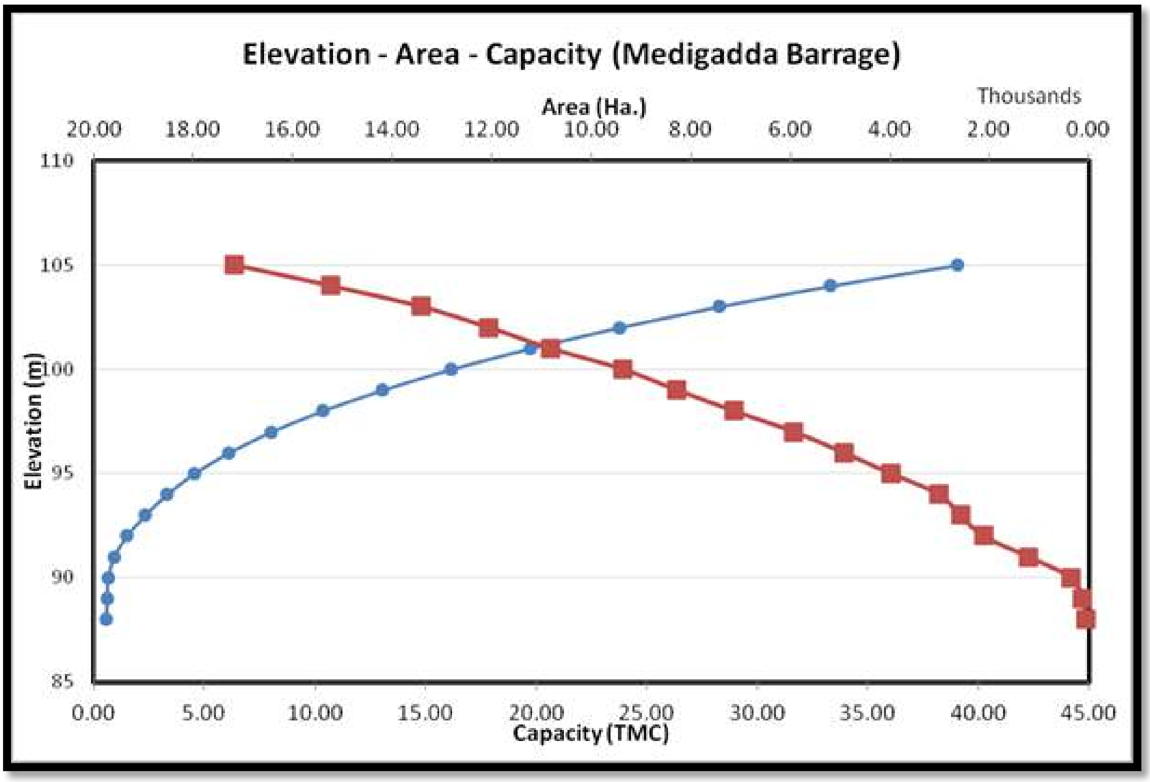


Table-4:Elevation Area Capacity ofAnnaram Barrage			
Elevation (m)	**Area (Sq. Km)**	**Capacity (MCM)**	**Capacity (TMC)**
107	0.67	0.00	0.00
108	1.55	1.13	0.04
109	2.69	3.12	0.11
110	5.37	7.08	0.25
111	10.35	14.73	0.52
112	13.37	26.62	0.94
113	17.76	42.20	1.49
114	22.77	62.30	2.20
115	28.94	88.36	3.12
116	35.28	120.36	4.25
117	42.18	159.16	5.62

118	54.83	207.30	7.32
119	65.08	267.34	9.44
120	74.36	337.01	11.90

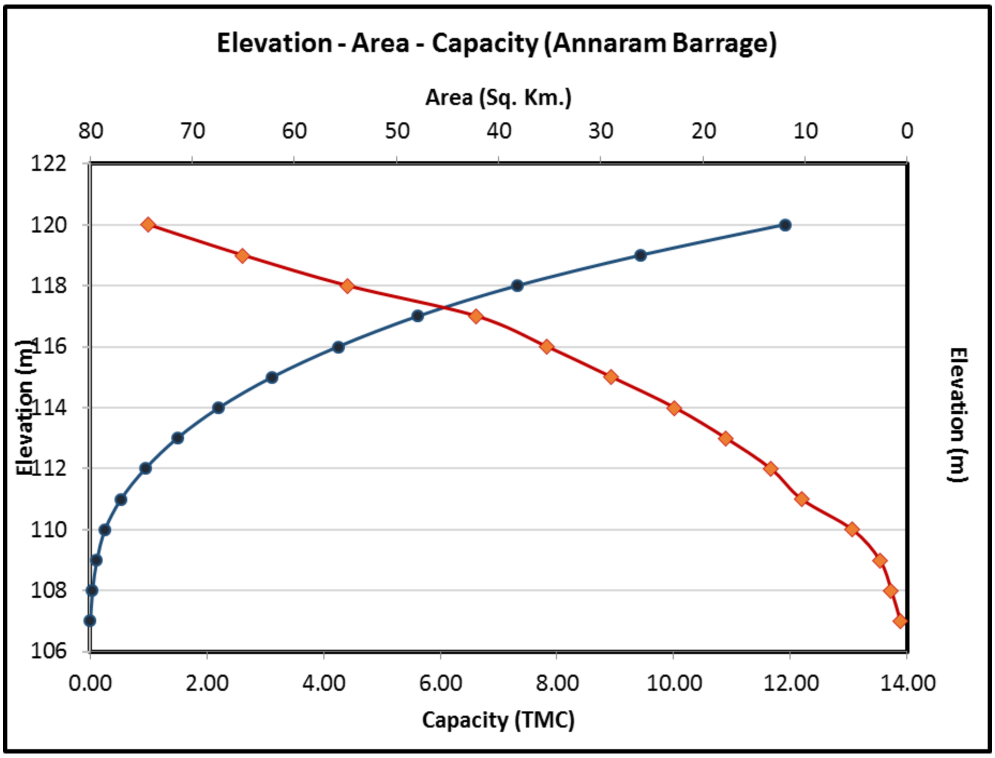
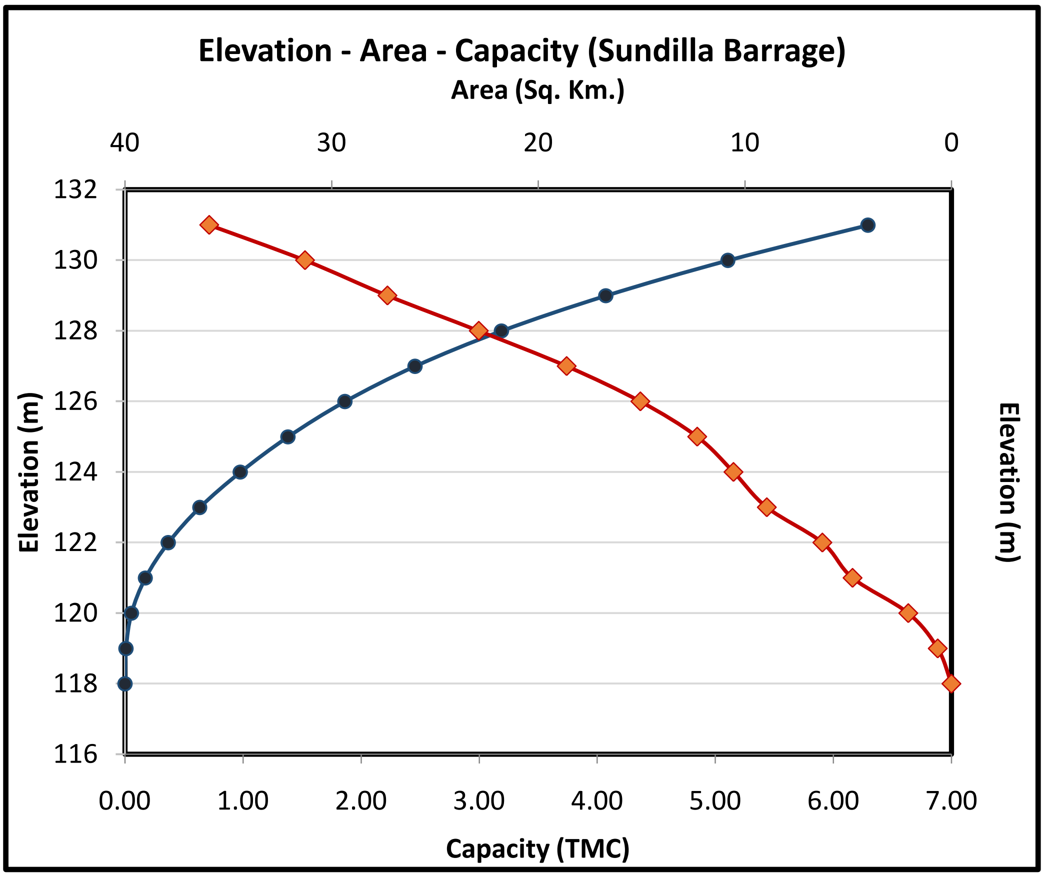


Table-5:Elevation Area Capacity ofSundilla Barrage			
Elevation (m)	**Area (Sq. Km)**	**Capacity (MCM)**	**Capacity (TMC)**
118	0.00	0.00	0.00
119	0.66	0.28	0.01
120	2.09	1.42	0.05
121	4.78	4.81	0.17
122	6.24	10.48	0.37
123	8.93	17.84	0.63
124	10.55	27.75	0.98
125	12.30	39.08	1.38
126	15.05	52.68	1.86
127	18.62	69.67	2.46
128	22.87	90.34	3.19
129	27.29	115.26	4.07
130	31.28	144.72	5.11
131	35.92	178.13	6.29



6.5. Breach Parameters

A rectangular breach at an El 132 m with side slope 1:0 and breach formation time as 1.0 hr. have been considered in the study for dam break analysis of Yellampally Dam/Barrage. After the breach, immediately below the dam, the maximum flow will occur immediately after the start of breach.

6.6. Upstream Boundary

For the dam break model simulation, the design flood has been considered as the upstream boundary. The ordinates of Inflow Design Flood Hydrograph impinged to reservoir are given in **Table-1**.

6.7. Downstream Boundary

The Normal depth has been used as the downstream boundary for the dam break model set up. The downstream boundary has been applied at the cross section of Godavari River123 km d/s of YellampallyDam/Barrage axis. The HEC- RAS Model set up results of the dam break studies is given in **Table-6.**

7. RESULTS OF DAM BREAK.ANALYSIS

The simulation results are given in Table-6 and the plot of water surface profile along the Godavari River is given Fig.1. The water surface elevation profile at selected locations below the proposed dam/barrages are also attached. The result of study shows that there would not be much effect of failure of Yellampally Dam on the system of Barrages of Kaleshwaram Project along with inundation of the adjoining area because the storage below the crest of the Yellampally reservoir is only 87 MCM and for other barrages there are virtually no storage below its crest, since the crest of these barrages have been kept 1 to 2 m above the river bed. As such the failure of these barrage will not have any effect on the downstream once the gates are opened. Only Yellampally Dam/Barrage will have some effect on its failure as there is a storage of about 87 MCM below its crest. As the width of the river is more than a 1 Km at most of the places therefore, even in the case of its failure the effect on water surface level is confined to 1 to 3 m along the entire reach of Kaleshwaram System.As such, as far as Kaleshwaram system of Barrages below Yellmapally Dam is concerned it is safe even in case of failure of Yellampally Dam with marginal inundation along the bank of Godavari river.

Table -6Results of Dam Break Analysis for Kaleshwaram System of Dam & Barrages												
Reach	**River Station**	**Profile**	**Q Total**	**Min Ch El**	**W.S. Elev**	**Crit W.S.**	**E.G. Elev**	**E.G. Slope**	**Vel Chnl**	**Flow Area**	**Top Width**	**Froude # Chl**
	(KM)		**(m3/s)**	**(m)**	**(m)**	**(m)**	**(m)**	**(m/m)**	**(m/s)**	**(m2)**	**(m)**	
YELLAMPALLY TO KALESHWARAM	0.24	Max WS	64927.13	127.50	148.53		149.30	0.00	4.71	21733.22	2806.78	0.35
YELLAMPALLY TO KALESHWARAM	0.24	Max WS	64927.10	127.50	148.51	145.09	149.29	0.00	4.72	21697.30	2806.49	0.35
YELLAMPALLY TO KALESHWARAM	0.24		**Inl Struct (Yallampally Dam/Barrage)**									
YELLAMPALLY TO KALESHWARAM	0.23	Max WS	65549.45	127.50	148.44		149.25	0.00	4.80	21501.47	2804.89	0.36
YELLAMPALLY TO KALESHWARAM	0.23	Max WS	65547.64	127.50	148.44		149.25	0.00	4.81	21486.93	2804.77	0.36
YELLAMPALLY TO KALESHWARAM	0.20	Max WS	65545.83	127.50	148.41		149.28	0.00	5.25	21412.56	2804.17	0.38
YELLAMPALLY TO KALESHWARAM	0.10	Max WS	65528.32	127.50	148.36		149.24	0.00	5.29	21254.48	2802.88	0.38
YELLAMPALLY TO KALESHWARAM	0.00	Max WS	65512.84	127.50	148.30		149.20	0.00	5.33	21093.05	2801.56	0.38
YELLAMPALLY TO KALESHWARAM	-0.20	Max WS	61279.24	127.50	137.45	145.10	154.52	0.02	18.77	3478.05	462.27	2.03
YELLAMPALLY TO KALESHWARAM	-0.50	Max WS	65452.27	128.00	143.21		144.03	0.00	4.34	19601.80	2979.43	0.39
YELLAMPALLY TO KALESHWARAM	-1.00	Max WS	65462.04	128.00	143.29		143.74	0.00	3.22	25330.40	2978.39	0.27
YELLAMPALLY TO KALESHWARAM	-1.50	Max WS	65457.05	127.57	143.17		143.57	0.00	2.96	26389.45	3000.00	0.26
YELLAMPALLY TO KALESHWARAM	-2.00	Max WS	65456.74	128.00	143.15		143.45	0.00	2.57	29639.12	3000.00	0.22
YELLAMPALLY TO KALESHWARAM	-2.50	Max WS	65452.38	127.50	143.05		143.32	0.00	2.40	30569.72	3000.00	0.21
YELLAMPALLY TO KALESHWARAM	-3.00	Max WS	65452.15	127.36	142.90		143.23	0.00	2.73	28936.24	3000.00	0.23
YELLAMPALLY TO KALESHWARAM	-3.50	Max WS	65444.22	127.07	142.60		142.97	0.00	3.02	26830.82	3000.00	0.27
YELLAMPALLY TO KALESHWARAM	-4.00	Max WS	65444.00	126.54	142.48		142.82	0.00	2.83	28006.10	3000.00	0.25
YELLAMPALLY TO KALESHWARAM	-4.50	Max WS	65436.32	127.08	142.22		142.65	0.00	3.30	25967.70	3000.00	0.28
YELLAMPALLY TO KALESHWARAM	-5.00	Max WS	65439.80	127.00	142.22		142.53	0.00	2.71	29289.57	3000.00	0.24
YELLAMPALLY TO KALESHWARAM	-5.50	Max WS	65439.47	126.50	142.10		142.39	0.00	2.66	30192.10	3000.00	0.22
YELLAMPALLY TO KALESHWARAM	-6.00	Max WS	65432.87	126.83	141.88		142.25	0.00	2.99	27196.98	3000.00	0.26
YELLAMPALLY TO KALESHWARAM	-6.50	Max WS	65432.73	126.50	141.72		142.05	0.00	2.80	28631.51	3000.00	0.24
YELLAMPALLY TO KALESHWARAM	-7.00	Max WS	65429.53	125.69	141.61		141.97	0.00	2.84	27637.42	3000.00	0.25

YELLAMPALLY TO KALESHWARAM	-7.50	Max WS	65429.41	125.50	141.53		141.86	0.00	2.71	28363.59	3000.00	0.24
YELLAMPALLY TO KALESHWARAM	-8.00	Max WS	65426.67	125.50	141.39		141.76	0.00	2.83	26715.41	2853.66	0.25
YELLAMPALLY TO KALESHWARAM	-8.50	Max WS	65426.55	125.50	141.29		141.66	0.00	2.90	27507.10	2945.69	0.24
YELLAMPALLY TO KALESHWARAM	-9.00	Max WS	65426.44	124.54	141.20		141.47	0.00	2.50	31449.20	3000.00	0.21
YELLAMPALLY TO KALESHWARAM	-9.50	Max WS	65426.24	125.00	141.11		141.42	0.00	2.63	29397.12	3000.00	0.22
YELLAMPALLY TO KALESHWARAM	-10.00	Max WS	65425.99	125.00	141.05		141.31	0.00	2.42	31355.31	3000.00	0.20
YELLAMPALLY TO KALESHWARAM	-10.50	Max WS	65424.23	124.50	140.94		141.25	0.00	2.59	29407.26	3000.00	0.22
YELLAMPALLY TO KALESHWARAM	-11.00	Max WS	65424.15	124.00	140.83		141.17	0.00	2.80	28947.93	3000.00	0.23
YELLAMPALLY TO KALESHWARAM	-11.50	Max WS	65423.98	123.50	140.61		141.05	0.00	3.00	23444.20	2348.95	0.27
YELLAMPALLY TO KALESHWARAM	-12.00	Max WS	65423.78	123.24	140.38		140.90	0.00	3.31	21727.94	2258.68	0.31
YELLAMPALLY TO KALESHWARAM	-12.50	Max WS	65422.70	123.00	140.05		140.74	0.00	3.94	19739.70	2072.71	0.33
YELLAMPALLY TO KALESHWARAM	-16.50	Max WS	65107.96	120.53	138.33		139.06	0.00	4.01	19340.81	2273.69	0.35
YELLAMPALLY TO KALESHWARAM	-17.00	Max WS	65120.14	121.58	138.47		138.82	0.00	2.88	27888.22	3000.00	0.25
YELLAMPALLY TO KALESHWARAM	-17.50	Max WS	65133.70	121.00	138.28		138.66	0.00	3.00	27551.05	3000.00	0.25
YELLAMPALLY TO KALESHWARAM	-18.00	Max WS	65147.49	120.50	138.04		138.59	0.00	3.52	23036.65	3000.00	0.30
YELLAMPALLY TO KALESHWARAM	-18.50	Max WS	65161.20	120.50	137.76		138.44	0.00	4.02	21281.96	2608.23	0.33
YELLAMPALLY TO KALESHWARAM	-19.00	Max WS	65175.38	120.08	137.83		138.21	0.00	2.99	26316.78	2964.03	0.26
YELLAMPALLY TO KALESHWARAM	-19.50	Max WS	65190.16	120.00	137.60		138.09	0.00	3.49	24067.61	2771.04	0.29
YELLAMPALLY TO KALESHWARAM	-20.00	Max WS	65205.00	120.00	137.47		137.92	0.00	3.19	24341.83	2832.37	0.29
YELLAMPALLY TO KALESHWARAM	-20.50	Max WS	65219.87	124.50	137.03		137.70	0.00	3.71	18896.85	2503.36	0.38
YELLAMPALLY TO KALESHWARAM	-21.00	Max WS	65236.13	119.50	136.96		137.47	0.00	3.47	23945.66	3000.00	0.30
YELLAMPALLY TO KALESHWARAM	-21.50	Max WS	65254.02	119.49	136.87		137.30	0.00	3.35	26207.24	3000.00	0.28
YELLAMPALLY TO KALESHWARAM	-22.00	Max WS	65272.14	119.00	136.68		137.15	0.00	3.50	25617.42	3000.00	0.29
YELLAMPALLY TO KALESHWARAM	-22.50	Max WS	65290.61	119.00	136.62		136.99	0.00	3.21	27851.93	3000.00	0.26
YELLAMPALLY TO KALESHWARAM	-23.00	Max WS	65309.32	119.00	136.53		136.88	0.00	3.09	28601.87	3000.00	0.25
YELLAMPALLY TO KALESHWARAM	-23.50	Max WS	65328.58	118.86	136.22		136.79	0.00	3.79	23682.53	2925.16	0.31
YELLAMPALLY TO KALESHWARAM	-24.00	Max WS	65348.37	118.00	136.07		136.61	0.00	3.65	24280.12	3000.00	0.30
YELLAMPALLY TO KALESHWARAM	-24.50	Max WS	65367.82	117.50	135.90		136.46	0.00	3.71	23519.09	2742.44	0.30
YELLAMPALLY TO KALESHWARAM	-25.00	Max WS	65387.00	118.50	135.83		136.25	0.00	2.88	23454.26	2732.29	0.29

YELLAMPALLY TO KALESHWARAM	-25.50	Max WS	65406.99	118.00	135.56		136.14	0.00	3.74	23471.06	3000.00	0.30
YELLAMPALLY TO KALESHWARAM	-26.00	Max WS	65427.91	118.00	135.52		135.96	0.00	3.31	25921.62	2850.95	0.27
YELLAMPALLY TO KALESHWARAM	-26.50	Max WS	65449.27	118.47	135.50		135.79	0.00	2.72	31095.12	3000.00	0.22
YELLAMPALLY TO KALESHWARAM	-27.00	Max WS	65470.96	118.00	135.37		135.67	0.00	2.65	30970.39	3000.00	0.21
YELLAMPALLY TO KALESHWARAM	-27.50	Max WS	65492.76	117.89	135.37		135.60	0.00	2.29	33957.28	3000.00	0.18
YELLAMPALLY TO KALESHWARAM	-28.00	Max WS	65514.79	117.50	135.33		135.51	0.00	2.07	36976.29	3000.00	0.17
YELLAMPALLY TO KALESHWARAM	-28.50	Max WS	65534.89	117.50	135.19		135.40	0.00	2.22	35333.55	3000.00	0.18
YELLAMPALLY TO KALESHWARAM	-29.00	Max WS	65554.95	116.50	135.20		135.37	0.00	1.92	38512.71	3000.00	0.15
YELLAMPALLY TO KALESHWARAM	-29.50	Max WS	65576.98	116.50	135.14		135.32	0.00	2.03	36674.54	3000.00	0.16
YELLAMPALLY TO KALESHWARAM	-30.00	Max WS	65598.66	116.50	135.08		135.25	0.00	1.93	38881.44	3000.00	0.15
YELLAMPALLY TO KALESHWARAM	-30.40	Max WS	65616.16	116.00	135.05		135.22	0.00	1.98	38354.27	3000.00	0.16
YELLAMPALLY TO KALESHWARAM	-30.50	Max WS	65620.64	116.00	135.04	123.88	135.21	0.00	1.92	38340.53	3000.00	0.16
YELLAMPALLY TO KALESHWARAM	-30.55	**Inl Struct (Sundilla Barrage)**										
YELLAMPALLY TO KALESHWARAM	-30.60	Max WS	65620.64	116.00	134.76		134.94	0.00	1.96	37500.19	3000.00	0.16
YELLAMPALLY TO KALESHWARAM	-30.70	Max WS	65625.05	116.00	134.75		134.92	0.00	1.97	37463.64	3000.00	0.16
YELLAMPALLY TO KALESHWARAM	-30.80	Max WS	65629.48	116.00	134.73		134.91	0.00	2.03	37406.02	3000.00	0.16
YELLAMPALLY TO KALESHWARAM	-31.00	Max WS	65638.25	116.00	134.73		134.89	0.00	1.89	39210.79	3000.00	0.15
YELLAMPALLY TO KALESHWARAM	-31.50	Max WS	65659.95	116.00	134.66		134.82	0.00	1.90	39376.29	3000.00	0.15
YELLAMPALLY TO KALESHWARAM	-32.00	Max WS	65681.66	116.00	134.58		134.79	0.00	2.19	35254.87	3000.00	0.17
YELLAMPALLY TO KALESHWARAM	-32.50	Max WS	65703.38	115.50	134.50		134.70	0.00	2.19	36484.17	3000.00	0.17
YELLAMPALLY TO KALESHWARAM	-33.00	Max WS	65725.19	115.50	134.39		134.61	0.00	2.51	35321.08	3000.00	0.19
YELLAMPALLY TO KALESHWARAM	-33.50	Max WS	65747.07	115.00	134.30		134.54	0.00	2.45	33257.21	3000.00	0.20
YELLAMPALLY TO KALESHWARAM	-34.00	Max WS	65768.42	115.00	134.17		134.40	0.00	2.32	34915.96	3000.00	0.18
YELLAMPALLY TO KALESHWARAM	-34.50	Max WS	65789.72	115.00	134.13		134.38	0.00	2.42	33457.54	3000.00	0.19
YELLAMPALLY TO KALESHWARAM	-35.00	Max WS	65811.70	114.50	134.04		134.32	0.00	2.49	31892.42	3000.00	0.20
YELLAMPALLY TO KALESHWARAM	-35.50	Max WS	65833.44	114.50	133.97		134.25	0.00	2.60	31823.68	3000.00	0.20
YELLAMPALLY TO KALESHWARAM	-36.00	Max WS	65854.59	114.50	133.93		134.14	0.00	2.31	36222.36	3000.00	0.18
YELLAMPALLY TO KALESHWARAM	-36.50	Max WS	65876.00	114.00	133.83		134.06	0.00	2.44	34868.73	3000.00	0.19
YELLAMPALLY TO KALESHWARAM	-37.00	Max WS	65897.63	114.00	133.72		134.02	0.00	2.81	31525.37	3000.00	0.21

YELLAMPALLY TO KALESHWARAM	-37.50	Max WS	65919.35	113.50	133.67		133.91	0.00	2.52	34366.00	3000.00	0.19
YELLAMPALLY TO KALESHWARAM	-38.00	Max WS	65941.55	113.50	133.66		133.87	0.00	2.28	36739.44	3000.00	0.17
YELLAMPALLY TO KALESHWARAM	-38.50	Max WS	65963.98	113.50	133.57		133.82	0.00	2.48	34184.68	3000.00	0.19
YELLAMPALLY TO KALESHWARAM	-39.00	Max WS	65985.98	113.00	133.46		133.75	0.00	2.69	31995.02	3000.00	0.20
YELLAMPALLY TO KALESHWARAM	-39.50	Max WS	66007.27	112.50	133.36		133.63	0.00	2.67	33275.62	3000.00	0.20
YELLAMPALLY TO KALESHWARAM	-40.00	Max WS	66028.88	113.00	133.35		133.57	0.00	2.40	35671.66	3000.00	0.18
YELLAMPALLY TO KALESHWARAM	-40.50	Max WS	66050.91	112.00	133.25		133.52	0.00	2.61	33293.72	3000.00	0.20
YELLAMPALLY TO KALESHWARAM	-41.00	Max WS	66072.91	112.50	133.17		133.41	0.00	2.55	34653.52	3000.00	0.19
YELLAMPALLY TO KALESHWARAM	-41.50	Max WS	66094.41	112.00	133.19		133.35	0.00	2.04	40985.07	3000.00	0.15
YELLAMPALLY TO KALESHWARAM	-42.00	Max WS	66115.81	111.50	133.09		133.30	0.00	2.31	36725.52	3000.00	0.17
YELLAMPALLY TO KALESHWARAM	-42.50	Max WS	66137.56	111.50	133.02		133.26	0.00	2.40	34281.97	3000.00	0.18
YELLAMPALLY TO KALESHWARAM	-43.00	Max WS	66158.74	111.50	133.03		133.20	0.00	1.93	38328.18	2817.41	0.15
YELLAMPALLY TO KALESHWARAM	-43.50	Max WS	66177.72	111.50	132.63		133.23	0.00	3.89	23599.77	2312.09	0.28
YELLAMPALLY TO KALESHWARAM	-44.00	Max WS	66195.64	111.00	132.25		133.14	0.00	4.89	19977.02	2459.24	0.35
YELLAMPALLY TO KALESHWARAM	-44.50	Max WS	66211.70	110.50	131.92		132.80	0.00	4.21	16462.27	1782.20	0.40
YELLAMPALLY TO KALESHWARAM	-45.00	Max WS	66222.34	110.50	130.74		132.36	0.00	5.63	11753.99	1129.27	0.56
YELLAMPALLY TO KALESHWARAM	-45.50	Max WS	66231.72	110.50	130.92		131.85	0.00	4.27	15502.39	1444.88	0.42
YELLAMPALLY TO KALESHWARAM	-46.00	Max WS	66240.16	110.50	128.83		131.30	0.00	6.97	9506.23	882.10	0.68
YELLAMPALLY TO KALESHWARAM	-46.50	Max WS	66244.55	110.50	125.61	125.36	129.88	0.00	9.15	7237.20	793.99	0.97
YELLAMPALLY TO KALESHWARAM	-47.00	Max WS	66250.97	110.50	126.83		128.26	0.00	5.29	12547.94	1702.44	0.61
YELLAMPALLY TO KALESHWARAM	-47.50	Max WS	66265.27	110.50	126.62		127.71	0.00	5.20	17817.14	2705.61	0.44
YELLAMPALLY TO KALESHWARAM	-48.00	Max WS	66284.45	110.50	126.75		127.31	0.00	3.77	23677.28	2985.16	0.32
YELLAMPALLY TO KALESHWARAM	-48.50	Max WS	66304.18	110.50	126.61		127.08	0.00	3.43	25168.29	3000.00	0.29
YELLAMPALLY TO KALESHWARAM	-49.00	Max WS	66323.29	110.00	126.46		126.85	0.00	3.04	27186.91	3000.00	0.26
YELLAMPALLY TO KALESHWARAM	-49.50	Max WS	66342.18	110.00	126.44		126.76	0.00	2.67	29006.25	3000.00	0.23
YELLAMPALLY TO KALESHWARAM	-50.00	Max WS	66361.13	110.25	126.39		126.65	0.00	2.38	30117.80	2880.87	0.22
YELLAMPALLY TO KALESHWARAM	-50.50	Max WS	66374.01	112.00	123.43	122.72	126.82	0.00	8.17	8237.88	1227.15	0.88
YELLAMPALLY TO KALESHWARAM	-51.00	Max WS	66386.87	110.00	124.69		125.14	0.00	3.14	24437.96	2664.75	0.29
YELLAMPALLY TO KALESHWARAM	-51.50	Max WS	66405.58	109.50	124.51		124.98	0.00	3.32	23896.10	2711.39	0.31

YELLAMPALLY TO KALESHWARAM	-52.00	Max WS	66425.29	109.50	124.35		124.80	0.00	3.15	24636.86	3000.00	0.29
YELLAMPALLY TO KALESHWARAM	-52.50	Max WS	66445.09	109.50	124.21		124.64	0.00	3.03	24604.89	2647.15	0.28
YELLAMPALLY TO KALESHWARAM	-53.00	Max WS	66464.42	109.50	124.00		124.49	0.00	3.39	23828.61	2756.25	0.30
YELLAMPALLY TO KALESHWARAM	-53.50	Max WS	66484.67	109.50	123.82		124.32	0.00	3.29	23669.86	2930.37	0.30
YELLAMPALLY TO KALESHWARAM	-54.00	Max WS	66505.17	109.00	123.74		124.15	0.00	2.94	25407.70	2820.84	0.27
YELLAMPALLY TO KALESHWARAM	-54.50	Max WS	66526.04	108.50	123.59		124.02	0.00	3.36	25555.43	3000.00	0.29
YELLAMPALLY TO KALESHWARAM	-55.00	Max WS	66545.75	108.58	123.45		123.77	0.00	3.06	28980.76	3000.00	0.26
YELLAMPALLY TO KALESHWARAM	-55.50	Max WS	66564.52	109.50	123.38		123.61	0.00	2.24	32915.46	3000.00	0.20
YELLAMPALLY TO KALESHWARAM	-56.00	Max WS	66584.38	109.50	123.15		123.47	0.00	2.62	28214.24	3000.00	0.25
YELLAMPALLY TO KALESHWARAM	-56.50	Max WS	66603.52	107.50	122.77		123.19	0.00	3.06	25772.37	3000.00	0.28
YELLAMPALLY TO KALESHWARAM	-57.00	Max WS	66621.87	107.50	122.54		123.01	0.00	3.26	24088.03	3000.00	0.32
YELLAMPALLY TO KALESHWARAM	-57.50	Max WS	66639.62	107.00	122.39		122.76	0.00	2.87	26516.16	3000.00	0.27
YELLAMPALLY TO KALESHWARAM	-58.00	Max WS	66656.64	106.50	122.23		122.63	0.00	2.86	25219.31	3000.00	0.28
YELLAMPALLY TO KALESHWARAM	-58.50	Max WS	66673.38	106.00	122.05		122.46	0.00	2.98	24861.79	3000.00	0.29
YELLAMPALLY TO KALESHWARAM	-59.00	Max WS	66687.39	106.00	121.77		122.26	0.00	3.12	21557.68	2446.69	0.32
YELLAMPALLY TO KALESHWARAM	-59.50	Max WS	66697.98	105.50	121.33		122.00	0.00	3.63	18594.51	2246.17	0.39
YELLAMPALLY TO KALESHWARAM	-60.00	Max WS	66706.81	105.12	121.09		121.69	0.00	3.45	19363.03	2196.66	0.37
YELLAMPALLY TO KALESHWARAM	-60.50	Max WS	66714.91	105.00	120.50		121.34	0.00	4.07	16570.48	2209.20	0.45
YELLAMPALLY TO KALESHWARAM	-61.00	Max WS	66724.15	105.00	120.37		120.98	0.00	3.46	19268.97	2107.92	0.37
YELLAMPALLY TO KALESHWARAM	-61.50	Max WS	66738.67	104.63	119.96		120.66	0.00	3.74	18468.45	2439.68	0.41
YELLAMPALLY TO KALESHWARAM	-62.00	Max WS	66763.56	105.50	119.58	116.25	120.29	0.00	3.92	18664.18	2545.46	0.43
YELLAMPALLY TO KALESHWARAM	-62.02	**Inl Struct (Annarram Barrage)**										
YELLAMPALLY TO KALESHWARAM	-62.20	Max WS	66763.56	105.50	119.40		120.14	0.00	4.02	18198.64	2537.13	0.44
YELLAMPALLY TO KALESHWARAM	-62.50	Max WS	66787.18	105.50	119.04		119.87	0.00	4.22	17304.44	2521.56	0.48
YELLAMPALLY TO KALESHWARAM	-81.00	Max WS	69396.74	86.31	108.60		108.96	0.00	3.34	31835.88	3225.00	0.23
YELLAMPALLY TO KALESHWARAM	-90.00	Max WS	82412.30	86.31	105.23		106.08	0.00	4.39	24461.48	3775.00	0.37
YELLAMPALLY TO KALESHWARAM	-92.00	Max WS	82408.98	88.36	105.00		105.31	0.00	2.52	37139.77	5638.42	0.22
YELLAMPALLY TO KALESHWARAM	-95.00	Max WS	82375.80	88.59	104.66		104.88	0.00	2.16	43145.55	6307.61	0.20
YELLAMPALLY TO KALESHWARAM	-100.00	Max WS	82338.51	89.07	102.80		103.76	0.00	4.39	19602.06	2445.24	0.45

YELLAMPALLY TO KALESHWARAM	-105.00	Max WS	82328.43	88.31	101.08		101.84	0.00	3.86	21415.34	2543.30	0.41
YELLAMPALLY TO KALESHWARAM	-106.00	Max WS	82325.96	88.84	100.42		101.57	0.00	4.76	17292.96	2217.71	0.54
YELLAMPALLY TO KALESHWARAM	-107.00	Max WS	82313.76	86.31	99.13	99.16	102.80	0.00	8.49	9713.29	1369.17	1.01
YELLAMPALLY TO KALESHWARAM	-107.60	**Inl Struct (Kaleshwaram Barrage)**										
YELLAMPALLY TO KALESHWARAM	-108.50	Max WS	81208.49	89.00	96.87	96.56	100.20	0.00	8.09	10038.45	1341.78	0.94
YELLAMPALLY TO KALESHWARAM	-109.00	Max WS	81229.91	89.00	96.85	96.74	100.48	0.00	8.43	9648.36	1309.07	0.98
YELLAMPALLY TO KALESHWARAM	-110.00	Max WS	81299.84	89.00	96.47	97.26	101.26	0.01	9.69	8386.81	1193.86	1.17
YELLAMPALLY TO KALESHWARAM	-111.00	Max WS	81362.34	89.00	96.38	96.73	99.91	0.01	8.33	9874.94	1710.40	1.06
YELLAMPALLY TO KALESHWARAM	-112.00	Max WS	81405.04	89.00	96.27		98.65	0.00	6.84	11908.76	1907.11	0.87
YELLAMPALLY TO KALESHWARAM	-113.00	Max WS	81447.18	88.36	96.26	96.23	98.99	0.00	7.59	11897.07	2224.01	0.89
YELLAMPALLY TO KALESHWARAM	-114.00	Max WS	81501.72	88.00	96.15		97.92	0.00	5.91	13904.01	1942.05	0.69
YELLAMPALLY TO KALESHWARAM	-115.00	Max WS	81599.95	88.00	95.74	96.28	100.02	0.01	9.17	8897.60	1309.79	1.12
YELLAMPALLY TO KALESHWARAM	-116.00	Max WS	81731.05	88.00	95.76		97.91	0.00	6.49	12666.52	1955.54	0.78
YELLAMPALLY TO KALESHWARAM	-117.00	Max WS	81875.52	88.00	95.58		97.68	0.00	6.47	12848.54	1966.23	0.80
YELLAMPALLY TO KALESHWARAM	-118.00	Max WS	82011.96	87.00	95.74		96.69	0.00	4.47	19784.37	2857.76	0.50
YELLAMPALLY TO KALESHWARAM	-119.00	Max WS	82127.63	87.00	95.64		96.61	0.00	4.94	20004.00	3000.00	0.54
YELLAMPALLY TO KALESHWARAM	-120.00	Max WS	82316.79	89.00	94.96		96.24	0.00	5.55	16714.60	3000.00	0.74
YELLAMPALLY TO KALESHWARAM	-121.00	Max WS	82588.01	89.00	94.58		96.06	0.00	5.99	15566.14	3000.00	0.82
YELLAMPALLY TO KALESHWARAM	-122.00	Max WS	83014.38	85.00	95.25		95.73	0.00	3.50	27843.32	3000.00	0.35
YELLAMPALLY TO KALESHWARAM	-123.00	Max WS	83008.06	84.00	85.67	92.76	377.02	3.61	75.62	1097.65	841.66	21.14

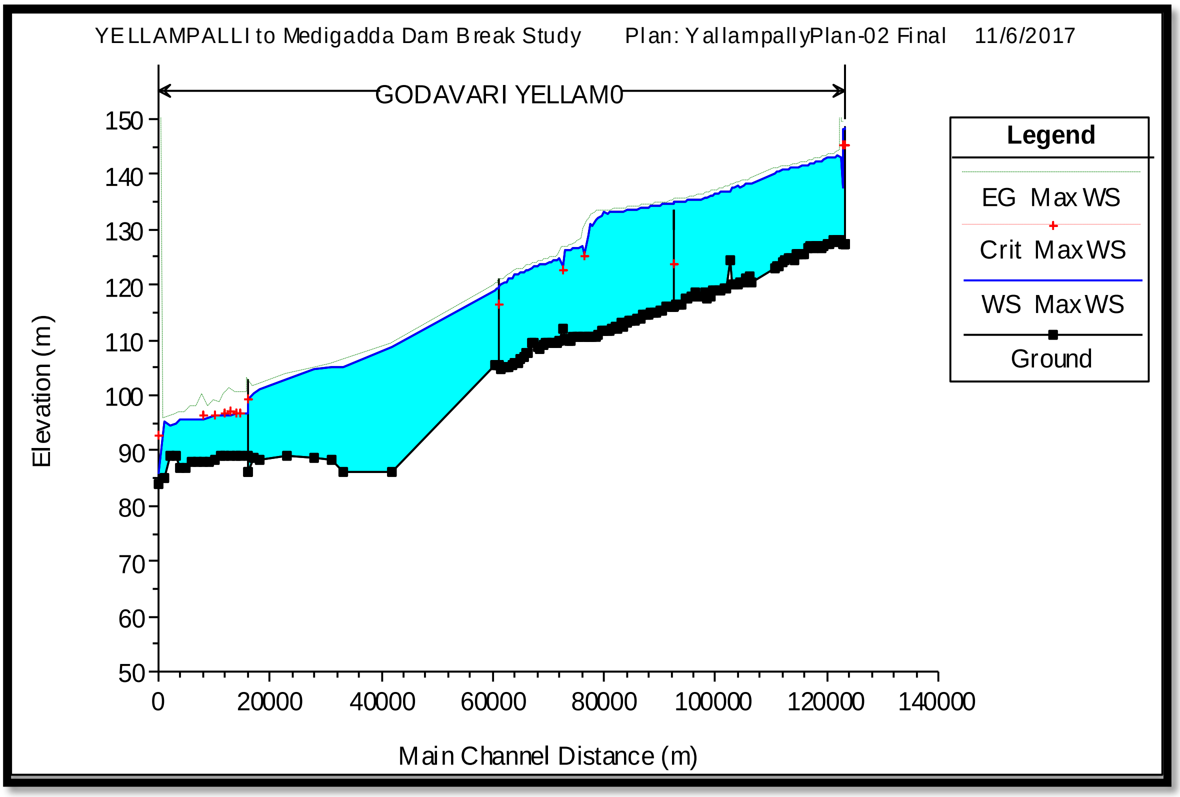


Fig. 1: Water Surface Profile of River Godavari from Yellampally to Medigadda Barrage

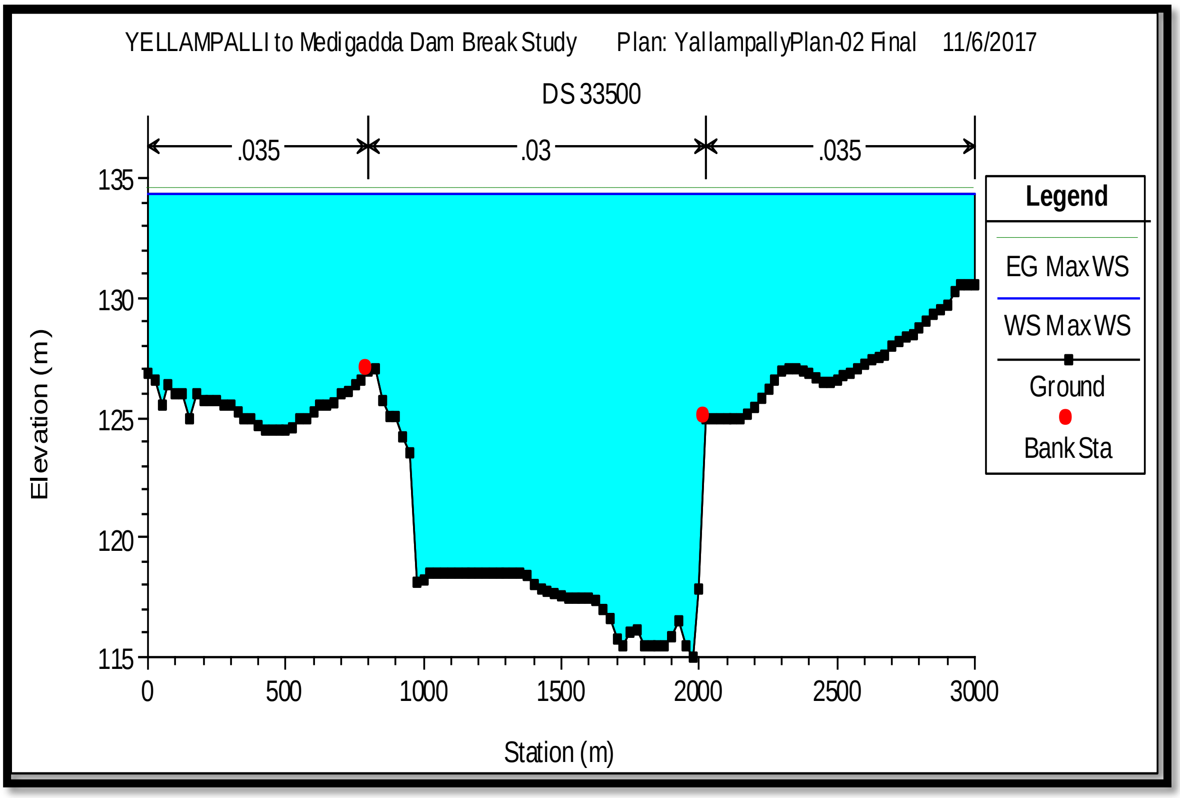


Fig. 2: Downstream of Sundilla Barrage

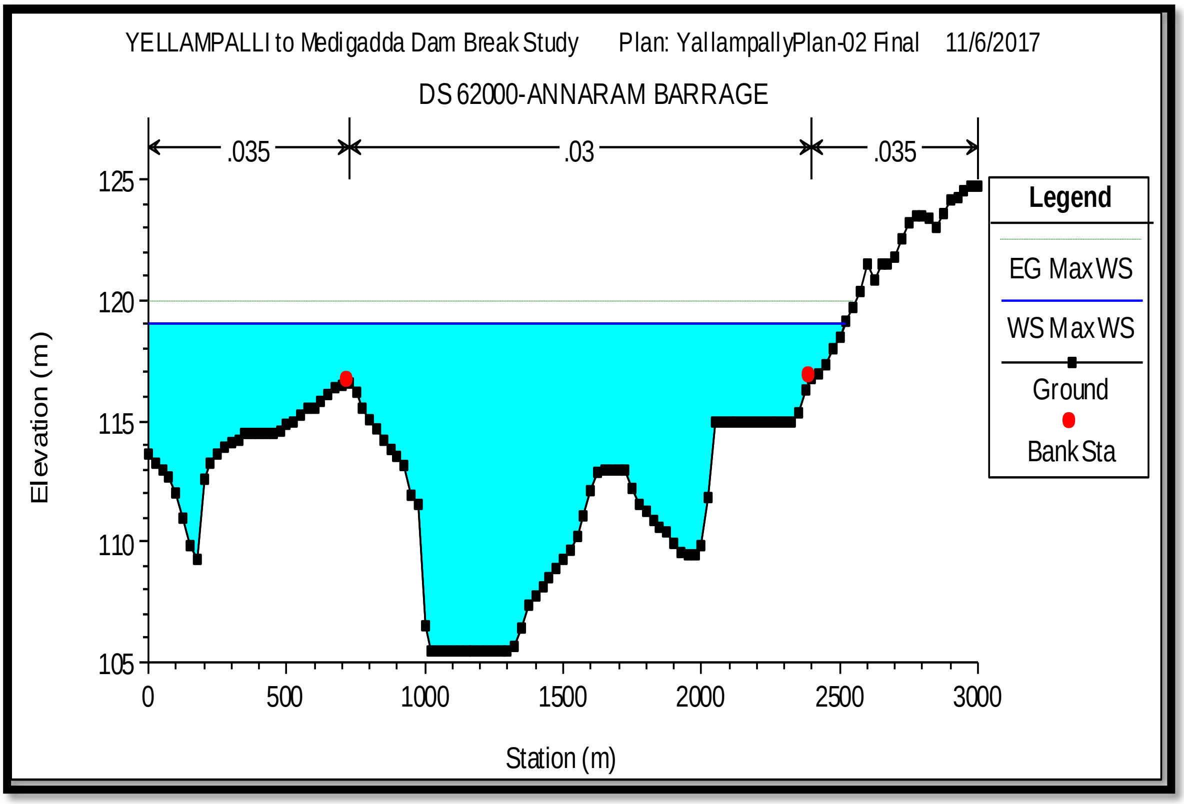


Fig. 3: Downstream of Annaram Barrage

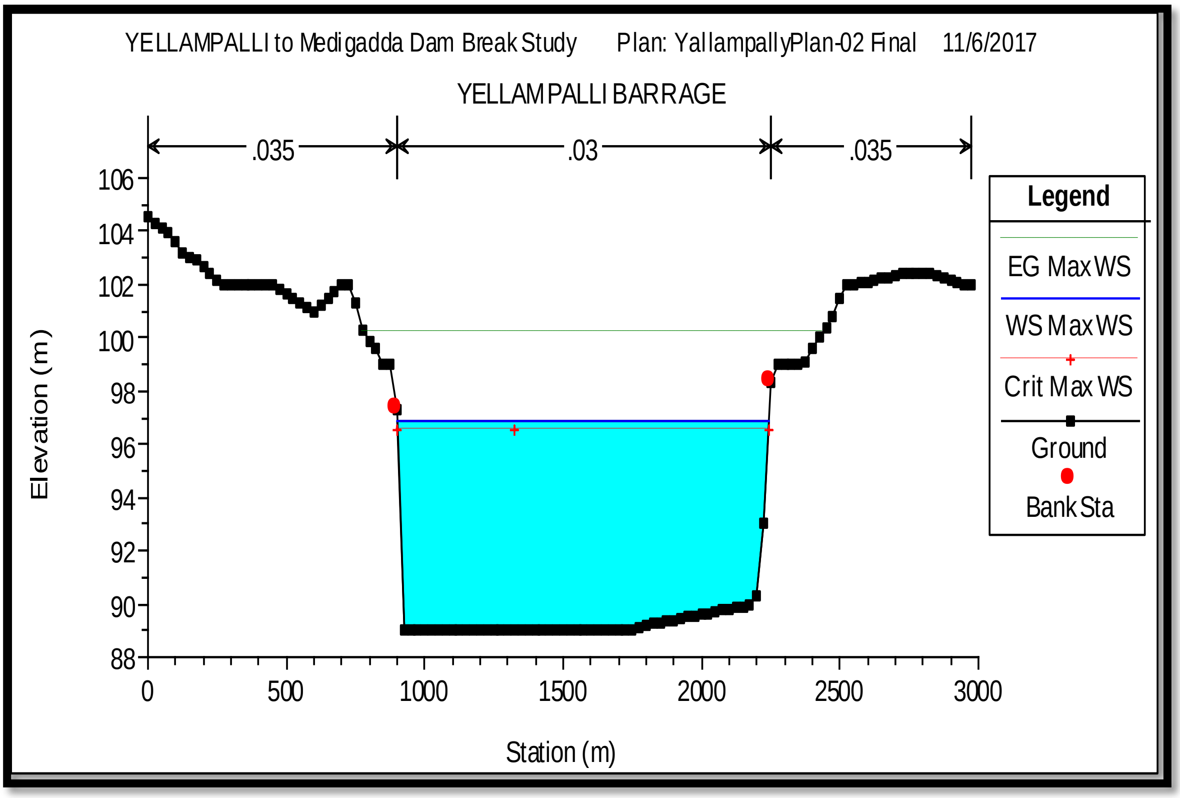


Fig. 4: Downstream of Medigadda Barrage

8. DISASTER MANAGEMENT PLAN

8.1. Status of Emergency

The emergency planning for dam break scenario is devised on the basis of results of dam break analysis mainly the travel time of flood wave to various locations in the downstream stretch of the river. The plan is, therefore, based on such measures, which are purely preventive in nature. The degree of alertness has to enhance during high stage of river manifested with sharp increase in discharge. Though there cannot be very sharp edge demarcation between different levels of emergency yet the following flood conditions have been contemplated and the preventive measures suggested against each as given in **Table-7.**

Table-7: Status of Emergency

S. No.	Status of emergency	Water Level	Preventive measures
1.	Normal Flood	Below FRL i.e. EL 148.5m and flood discharge below 65000 cumecs	Utmost vigil observed in regulation of spillway gates
2.	Level –1 Emergency	Rises above EL 148.5m and flood discharge below 65000 cumecs	(1) All gates fully operational (2) All the official should attend dam site. Local officials informed and warning system be kept on alert.
3.	Level –2 Emergency	Above MWL i.e. EL 148.5 but below top of dam i.e. EL 150 m and the discharge continues rising above 65000cumecs	Communication & public announcement system should be put into operation and flood warning issued to people.
4.	Level –3 Emergency	Top of dam i.e. EL 150 m	(1) All staff from dam site to move to safer places (2) Possibility of dam failure should be flashed to District Administration.
5.	Disaster	Rising above EL 150 m and the breach appears in any form	District Administration and Project authorities be intimated and only life saving measures should be resorted too

8.2. Dam Safety and Maintenance Manual

Based on standard recommended guidelines for the safety inspection of dams a manual should be prepared by the project proponents in respect of dam safety surveillance and monitoring aspects. This should be updated with the availability of instrumentation data and observation data with periodical review. The need for greater vigil has to be emphasized during first reservoir impoundment and first few years of operation. The manual should also delve on the routine maintenance schedule of all hydro-mechanical and electrical instruments. It should be eloquent in respect of quantum of specific construction material needed for emergency repair along with delineation of the suitable locations for its stocking and also identify the much needed machinery and equipment for executing emergency repair work and for accomplishing the evacuation plan.

8.3. Emergency Action Plan

Once the Emergency situation is foreseen, the Emergency Action Plan may be put in operation, which may include;

- Areas likely to be evacuated with priorities to be notified.
- Safe routes to be used for evacuation. Such routes have to be identified, discussed and planned sufficiently in advance for proper implementation of the Plan.
- Means of transportation.
- Traffic Control.
- Shelters for evacuees.
- Procedures for evacuation of people from hospitals, public places, prisons etc.
- Procedures for care and security of property from evacuated areas from anti-social elements.
- Instructions regarding assignment of specific functions and responsibilities of various members of evacuation teams

8.4. Emergency Action Committee

The Emergency Action Committee may comprise of:

- District Magistrates
- Concerned Chief Engineer of the Project
- Concerned Superintending Engineer of the Project
- Representative of P&T Department

- Representative of State Transport Department
- Representative of State Electricity Board
- Representative of Civil Supplies Department
- District Agricultural Officer
- District Health Officer
- District Commandant of Home Guards
- District Publicity Office
- Local MP/MLA
- Special Invitee from Local Social Organization / NGO

8.5. Public Information System

During a crisis following an accident, the affected people, public and media representatives would like to know about the situation from time to time and the response of the emergency authorities to the crisis. It is important to give timely information to the public in order to prevent panic and rumors.

The emergency public information can be carried out in three phases.

(i) Before the crisis

This will include the safety procedure to be followed during an emergency through posters, talks, and mass media in local language. Leaflets containing do’s/ don’ts should be circulated to educate the affected population.

(ii) During the crisis

Dissemination of information about the nature of the incident, actions taken and instructions to the public about protective measures to be taken, evacuation, etc. are the important steps during this phase.

(iii) After the crisis

Attention should be focused on information concerning restoration of essential services, movement / restrictions, etc. Various tasks of the public information system would include;

- Quick dissemination of emergency instructions to the personnel and public

- To receive all calls from public regarding emergency situations and respond meticulously
- Obtain current information from the Central Control Room.
- Prepare news release
- Brief visitors/media
- Maintain contact with hospitals and get information about the casualties

8.6. Efficient Communication System

An efficient communication system is absolutely essential to achieve a successful Emergency Preparedness Plan and this has to be finalized in consultation with local authorities and administrative setup. More often the entire communication facility gets disrupted in a disaster situation. The wireless facility which is comparatively free from general encumbrances of the communication system shall be invariably a part of emergency preparedness plan. The respective department of police, who generally has this facility, must have standing instructions to convey disaster messages effectively in time. In addition, telephone facility shall be available at dam site, vulnerable points and population centers. Vehicles equipped with sirens and public address system may also be kept ready for densely populated areas. Warning sirens may also be installed in the likely affected population to save warning time.

8.7. Spare Equipment/Material/Labour

The spare equipment/material, labor etc. should be available at pre-decided locations. The quantities of such equipment & places/locations should be reasonable & decided by Flood Control Authorities considering overall district requirement.

8.8. Responsibilities of Various Authorities

Superintending Engineer in-charge of the project shall be responsible to operate the facilities in accordance with approved reservoir operation procedures to be made for the purpose before barrage is completed, regularly observe and report flood conditions to the concerned Chief Engineer and take preventive actions at the dam site in emergency or potential emergency condition.

It is expected that during high flood event, the Superintending Engineer in charge of the dam shall also be present at the dam site to guide the others. It is also expected that the Chief Engineer Project Manager is being kept informed of the situation and in emergency.

District Collector, who is the Civil Administrator for the district, shall be responsible for ordering, coordinating and controlling evacuation and relief measures. Consequently, MPs, MLAs, Panchayat representatives in the disaster prone areas and all responsible persons of the locality shall be invited/ associated in the Emergency Action Plan.

The services of voluntary organizations like Red Cross and other Agencies, who may be active in the area shall be utilized. To chalk out the plan of Action and fixing responsibilities, a meeting shall be held by the District Collector before onset of the flood season every year to define the respective duties in the event of disaster flood occurrence. An awareness drill/ programme shall also be arranged. A mock exercise to test the level of preparedness without creating panic in the public should be encouraged to understand strength/weaknesses and take corrective steps.

8.9. Actions Following Discovery of Problems

A close vigilance of the dam by Executive Engineer a competent person is the basic requirement for the Emergency Action Plan. When some distress in the dam is noticed, the nature and potentialities of the problems are required to be identified immediately by the Executive Engineer in charge of dam. Immediately, initiative for remedial measures and further activities for involving the operation of Emergency Action Plan be taken.

The information of any unusual development on the dam should be immediately flashed/ conveyed by the Executive Engineer in charge of the dam to the higher officials in the Department by means of the fastest available communication facilities such as wireless message/ telephone or telegram. In the event of likely failure of dam, the man with highest designation present at the dam site shall initiate the actions as described in notification procedure and possible construction repairs depending on the seriousness of the development. Therefore, it is necessary that the staff posted on the vigilance and maintenance of the dam be adequately trained/ experienced to handle various emergent situations.

8.10. Notification Procedures

Notification procedures are an integral part of any emergency action plan. Separate procedures should be established for slowly and rapidly developing situations and failure. Notifications would include communication of either an alert situation or an alert situation followed by a warning situation. An alert situation would indicate that although failure or flooding is not imminent, a more serious situation could occur unless conditions improve. A warning situation would indicate that flooding is imminent as a result of an impending failure of the dam. It would normally include an order for evacuation of delineated inundation areas.

Copies of the EAP shall be displayed at prominent locations, in the rooms and locations of the personnel named in the notification chart. For a regular watch on the flood level situation, it is necessary that the flood cells be manned by two or more people so that an alternative person is always available for notification round the clock. For speedy and unhindered communication, a wireless system is a preferable mode of communication. Telephones may be kept for back up, wherever available. It is also preferred that the entire flood cells, if more than one, are tuned in the same wireless channel. It will ensure communication from the dam site to the control rooms. The communication can be established by messenger service in the absence of such modes of communication.

- Using multiple warning channels (police, radio, television, telephone, sirens, loudspeakers, mobiles etc.)
- Using official sources for warning (city civil officials, police, fire fighting etc.)
- Repeat warnings
- Ensuring that warnings are consistent and accurate
- Giving specific instructions about what actions should and should not be taken by people of the area to protect themselves.
- Conveying to the affected persons, possible extent of duration of flood/danger and urgency. However, this should not be overplayed to cause panic.

All departments, which are charged with the emergency preparedness, shall be identified and nodal officer in each department shall be identified from each department in advance. Such officers shall be provided residential telephone/cell phone in addition to their office telephones during the flood season. It is evident that the emergency preparedness plan is an integrated matter requiring technical expertise, specific administrative skill and spontaneous public participation (if is required) to be practical, pragmatic and successful.

8.11. Management after receding of Flood Water

The officer-in-charge of relief camp shall assist in the process of timely evacuation and rehabilitation of the persons likely to be affected, cattle and property. He shall also maintain record of persons/families in the camp and make arrangements for essential items of daily use and ensure reasonable health, sanitation, water supply and street lighting facilities. A daily situation report shall be sent to the control room. Some of the measures which need to be implemented are listed as below:

- Provision of various food items and shelter to the evacuees.
- Provision of fuel for various evacuees.
- Provision of adequate fodder supply.
- Arrangements for potable water supply.
- Commissioning of low cost sewage treatment and sanitation facilities, and disposal of treatment sewage.
- Expeditious disposal of dead bodies human and livestock.
- Immunization programmes for prevention of outbreak of epidemics of various water related diseases.
- Adequate stocks of medicines of various diseases, especially water-related diseases.

Government of India
Ministry of Water Resources,
River Development and
Ganga Rejuvenation

भारत सरकार
जल संसाधन, नदी विकास
और गंगा संरक्षण मंत्रालय

केन्द्रीय जल और विद्युत अनुसंधान शाला

CENTRAL WATER AND POWER RESEARCH STATION

तकनीकी रिपोर्ट संख्या : 5537

अक्तूबर, 2017

TECHNICAL REPORT NO. 5537
OCTOBER, 2017

श्री कॉमरावेली मल्लन्ना सागर, सिद्दीपेट, तेलंगाना के लिए बांध भंग अध्ययन और आपातकालीन क्रिया योजना

DAM BREAK ANALYSIS AND EMERGENCY ACTION PLAN FOR SRI KOMARAVELLI MALLANNA SAGAR, SIDDIPET, TELANGANA.

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भारत सरकार
Government of India

केन्द्रीय जल और विद्युत अनुसंधान शाला
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Ministry of Water Resources,
River Development & Ganga Rejuvenation
खडकवासला, पुणे / Khadakwasla, Pune – 411 024

संख्या. : पृ.ज.द.इ/ Kaleshwaram/2017/ दि:

श्री के एन आनंद
अधिशाषी अभियंता
कालेश्वरम प्रोजेक्ट सीडी 1
आईबी बिल्डिंग की पहली मंजिल, भरत नगर
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Shri K. N. Anand
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Siddipet - 502103

विषय : Final report on 'Dam Break Analysis and Emergency Action Plan for Sri Komaravelli Mallanna Sagar, Siddipet, Telangana'

महोदय,

Please find enclosed the Final Technical Report No. 5537 on 'Dam Break Analysis and Emergency Action Plan for Sri Komaravelli Mallanna Sagar, Siddipet, Telangana' in duplicate for your kind perusal.

Kindly acknowledge the receipt of report along with the feedback in the prescribed format.

Thanking you,

भवदीय,

31-10-2017
(रा. सु. जगताप)
संयुक्त निदेशक

संलग्न: यथा उपरोक्त

भारत सरकार

केंद्रीय जल तथा विद्युत अनुसंधान शाला

पुणे- 411024

GOVERNMENT OF INDIA
CENTRAL WATER AND POWER RESEARCH STATION
PUNE – 411 024

नदी तथा जलाशय प्रणाली प्रतिमानन
RIVER AND RESERVOIR SYSTEM MODELLING

तकनीकी रिपोर्ट संख्या 5537

अक्तूबर, 2017

TECHNICAL REPORT NO. 5537

OCTOBER, 2017

श्री कॉमरावेली मल्लन्ना सागर, सिद्दीपेट, तेलंगाना के लिए बांध सेंध अध्ययन और आपातकालीन क्रिया योजना

DAM BREAK ANALYSIS AND EMERGENCY ACTION PLAN FOR SRI KOMARAVELLI MALLANNA SAGAR, SIDDIPET, TELANGANA

REPORT DOCUMENT SHEET

Technical Report No.: 5537 Month and Year: October, 2017

TITLE: DAM BREAK ANALYSIS AND EMERGENCY ACTION PLAN FOR SRI KOMARAVELLI MALLANNA SAGAR, SIDDIPET, TELANGANA

Officers responsible for conducting the studies:

S/Shri P. Vijayagopal, Scientist 'C', S. Naveed Ali, Scientist 'B', K. Narasayya & A. G. Golandaj, Assistant Research Officers and Dheeraj Tamrakar, Research Assistant under the supervision of Shri R.S.Jagtap, Joint Director

Name and address of organization conducting the studies:

Surface Water Hydraulics Division,
River and Reservoir System Modelling Group,
Central Water & Power Research Station, Pune 411024

Name and address of authority sponsoring the studies:

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Synopsis

Irrigation and Command Area Development (I&CAD) Department of Government of Telangana State has taken up the execution of a prestigious lift irrigation project to meet various irrigation requirements of backward and drought prone areas covering uplands. The project is named as Kaleshwaram Project. One of the main components of Kaleshwaram project is Sri Komaravelli Mallana Sagar online Storage having capacity of about 50 TMC. The study is carried out to estimate the effect of flooding in the downstream of the proposed project in the case of eventuality of failure of the dam. A generalized flood routing model (unsteady flow simulation), HEC-RAS has been used to simulate the problem. Dam breach of Sri Komaravelli Mallana Sagar dam and further routing of flood through Kurelli Vaagu River for a length of about 47 km downstream is simulated in the mathematical model. It was assumed that the dam breaks when the level of water reaches top of the dam and start over topping so as to cover vulnerable senarios. Three different dam break simulations with different breach timings (18 min, 30 min and 60 min) have been carried out. Dam breach flood hydrographs and likely maximum flood water surface elevations are computed. The results estimated using 1-D mathematical model in HEC-RAS were further imported in ARC-GIS and Q-GIS for the preparation of inundation map for likely worst scenario. The villages affected nearby the right bank and left bank of study reach coming under inundation zone were marked on Toposheet using Q-GIS, which can be utilized as a key input for preparation of Emergency Action Planning

Key words: Dam Break, HEC-RAS, Cross-section of channel, 1-D mathematical model, Flood routing, Inundation map, Toposheet.

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Dam Break Analysis and Emergency Action Plan for Sri Komaravelli Mallanna Sagar, Siddipet, Telangana

1.0 INTRODUCTION

Irrigation and Command Area Development (I&CAD) Department of Government of Telangana State has taken up the execution of a prestigious lift irrigation project to meet various irrigation requirements of backward and drought prone areas covering uplands (Figure 1). The project is named as Kaleshwaram Project. Out of the total 225 TMC of water requirement, 180 TMC of water is proposed to be lifted for this scheme at Medigadda village, below the point of confluence of Pranhitha and Godavari River, 20 km downstream of Kaleshwaram village. Kaleshwaram project envisages of various components like Barrages (03 numbers), Water conveyance system (gravity canal and tunnels), Online storages (17 numbers) and Distributory Network System etc.

One of the main components of Kaleshwaram project is Sri Komaravelli Mallana Sagar online Storage having capacity of about 50 TMC. It is reported that Sri Komaravelli Mallanna Sagar online storage will be having capacity of about 25-30 % of overall water demand and has been kept at higher elevation to act as mother online storage and also as carryover storage in case there is a water shortage in the system. The proposed Sri Komaravelli Mallanna Sagar will be having its F.R.L at RL 557.00 m. The length of Bund will be 22.90 km and maximum height of 61.5 m. I&CAD Department of Telangana state has requested Central Water & Power Research Station (CWPRS), Pune to carry out Dam Break Analysis (DBA) for preparation of guidelines for Emergency Action Plan for proposed Sri Komaravelli Mallana Sagar. Dam Break Studies has been carried out at CWPRS using 1-Dimensional (1-D) Dynamic mathematical model for different breach parameters. The flood hydrograph due to breach have been routed through existing natural stream Kurelli Vaagu. This report presents the results of model study carried out for dam break flood discharge, predicted water levels along the stream and likely flood inundation area marked on Survey of India (SOI) toposheets.

Sri Komaravelli Mallanna Sagar reservoir has been proposed to act as balancing type of reservoir and kept at higher elevation, therefore the storage will be through lifting of water from Godavari River. In the downstream of proposed Mallanna reservoir, there exist a natural stream Kurelli Vaagu flowing parallel to bund of proposed Sri Komaravelli Mallanna reservoir. Figure 2 shows the location and alignment of the proposed bund and stream Kurelli Vaagu on the Google image. In the eventuality of dam break, the most likely path of flooding will be along this stream because of its lower elevation.

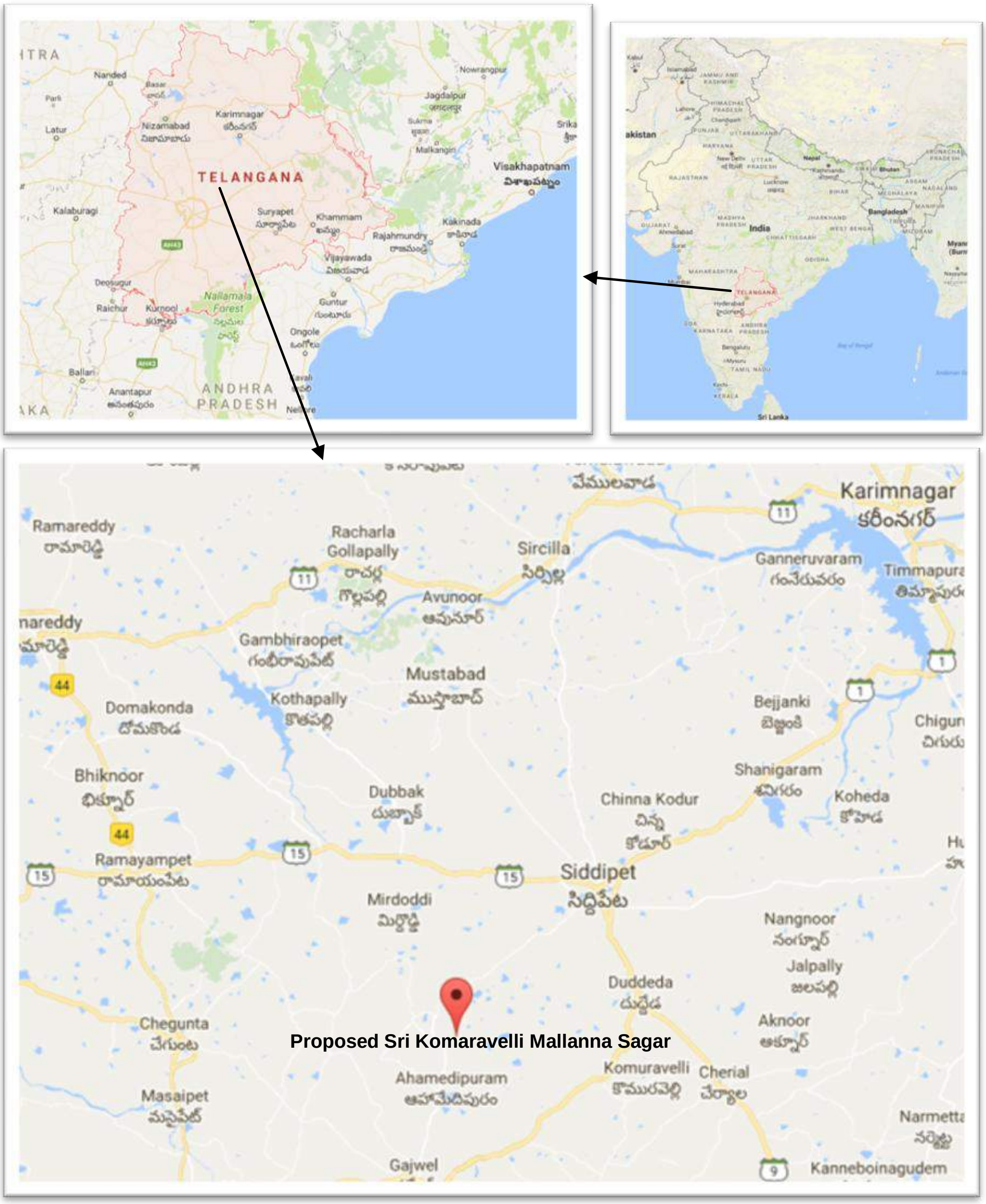

Figure 1: VICINITY MAP OF STUDY AREA

Figure 2: Imagery showing the location and alignment of the proposed bund with existing Kurelli Vaagu stream

2.0 SCOPE OF STUDY

Based on the data made available by project authorities and other relevant data which CWPRS could collect, the scope of work for this study are as below:

1) Estimation of Dam Breach flood hydrographs due to breach of proposed dam under different scenarios of breaking
2) Computation of flood level in the downstream channels by routing dam breach flood hydrographs, independently for different conditions of breaking.
3) To demarcate the area of inundation at important locations and installation for disaster management and Emergency Action Planning.
4) Providing inputs for the Development of Emergency Action Plan in case Dam break.

3.0 METHODOLOGY

For prediction of the reservoir outflow hydrograph due to Dam Break and routing it through the downstream valley, 1-D mathematical model capable of handling unsteady state flow condition has been used. Predicting the outflow hydrograph can be further subdivided into predicting the breach characteristics (e.g., shape, depth, width, rate of breach formation) and routing the reservoir storage through the breach and downstream. Various steps involved in the analysis are described below:

1. Review of salient features of the proposed Sri Komaravelli Mallanna Sagar for identification of most likely vulnerable location of breach.
2. Estimation of breach parameters using appropriate methods.
3. Extract topographic data from RASTER image (ASTER DEM) using ARC-GIS.
4. Development of 1-D mathematical model using appropriate software
5. Simulate the Kurelli Vaagu stream reach from Sri Komaravelli Mallanna Sagar upto Upper Maniar reservoir considering appropriate roughness factor for Dam Break flood condition.
6. Prediction of Inundation levels and demarcation on toposheets for the locations downstream of proposed dam for worst scenarios of breaching.

4.0 DATA USED FOR THE STUDY

Following data have been utilized for carrying out the studies

1. Toposheets from Survey of India (SOI) covering the study area (Scale 1:50,000)
2. Salient features of the Sri Komaravelli Mallanna Sagar and Upper Maniar reservoir.
3. Elevation – Area - Capacity curve / table of the Sri Komaravelli Mallanna Sagar.
4. ASTER DEM downloaded from USGS website.
5. Google Earth Pro imageries

5.0 SITE VISIT

A joint site visit and meeting were conducted by I&CAD Department, Telangana and CWPRS officials at the proposed location of Sri Komaravelli Mallanna sagar and some locations along the stream reach downstream upto Upper Maniar reservoir. During the visit, various locations along the alignment of proposed bund for Sri Komaravelli Mallanna Sagar reservoir were inspected. Sri Komaravelli Mallanna Sagar reservoir is proposed to be a balancing type of reservoir, where the storage will be through lifting of water from Godavari River. Natural flow in catchment may be minimal due to typical and isolated topographic site of the bund. In the downstream of proposed Mallanna reservoir, there exist a natural stream Kurelli Vaagu flowing parallel to bund of proposed Sri Komaravelli Mallanna reservoir. In the eventuality of dam break, the most likely path and possibility of flooding will be along this stream. Some of the locations along this stream were also visited and it was observed that the downstream reach is having rocky bed. It was also noticed that the river bed near Upper Maniar reservoir the reach is of mainly alluvial type. Some of the photos for taken during the site visit are given in Photos 1 to 5. During the discussion it was opined and agreed upon by the project authorities that the simulation of the break in the model will be made at the most likely vulnerable section of the structure at the deepest portion of the dam body i:e at the location where bund is having maximum height.

Photo 1: Location of the submergence area of the proposed dam

Photo 2: Rocky reach of Kurelli Vaagu stream downstream of proposed dam

Photo 3: Existing bridge on Kurelli Vaagu stream.

Photo 4: View of Kurelli Vaagu at upstream reach of Upper Maner reservoir

Photo 5: View of existing dam of Upper Maner reservoir

6.0 THE STUDY APPROACH

Dam breach of Sri Komaravelli Mallana Sagar and further routing of flood through Kurelli Vaagu stream for a length of about 47 km downstream upto Upper Maniar reservoir has been simulated in the study using mathematical model, Hydraulic Engineering Center River Analysis System (HEC RAS) model. Storage (level-pool) routing is used within the reservoir with the tail water elevations computed via the Saint-Venant equations, by dynamic routing through the 47 km routing reach downstream of the proposed reservoir. 109 cross sections of the Kurelli Vaagu Stream and 3 sections close to the proposed bund of dam on the upstream were provided in the model. The task of estimation of maximum water level at selected locations in river Kurelli Vaagu Stream has been carried out by routing the dam break flood hydrograph generated due to the breach of Sri Komaravelli Mallana Sagar. The breach is the opening formed in the structure as it fails. User-specified breach parameters and a description of the reservoir enable HEC- RAS to compute the outflow hydrograph. The breach is assumed to develop over a finite interval of time and will have a final size determined by a terminal bottom width parameter and shape parameter. Such a parametric representation of the breach is utilized in HEC-RAS for reasons of simplicity, generality, wide applicability, and the uncertainty in the actual failure mechanism.

The time for breach formation is in the range of a few minutes to hours depending upon the composition of dam, height, width, the cause of breach etc. The breach up to the bottom of the dam which will cause maximum damage resulting in highest flood is assumed. In general, the dam can fail either by over toping or by piping. In the present studies Sri Komaravelli Mallana Sagar failure is assumed to be due to over toping. It is assumed that reservoir is filled up to top of dam when failure commences. The breaching scenario considered for the study is that Dam breaks at Level Pool Condition (FRL) to simulate the worst scenario.

7.0 HEC-RAS MODEL FOR DAM BREAK ANALYSIS

Dam break modelling can be carried out by either i) scaled physical hydraulic models or ii) mathematical simulation using a computer. A modern tool to deal with this problem is the mathematical model, which is most cost effective and approximately solves the governing flow equations of continuity and momentum by computer simulation. Mathematical modelling of Dam Breach floods can be carried out by either one dimensional analysis or two dimensional analysis. In one dimensional analysis, the information about the magnitude of flood, i.e., discharge and water levels, variation of these with time and velocity of flow through breach can be obtained in the direction of flow. HEC-RAS software is assimilated system of Graphical User Interface (GUI), Separate analysis components, Data storage and Management capabilities and Graphics and Reporting capabilities.

Analysis components for the river system comprise:

1) Unsteady flow simulations: This component of modelling is based on law of conservation of mass and law of conservation of momentum. These laws are expressed in the form of partial differential equation known as continuity equation and momentum equation.

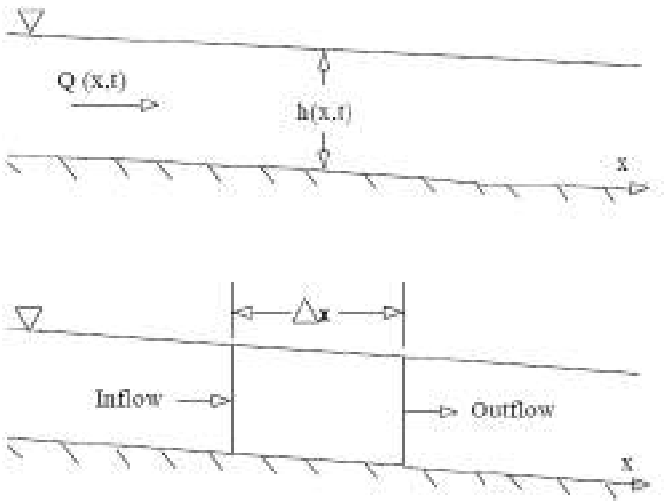

Figure3: ELEMETARY CONTROL VOLUME FOR MOMENTUM EQUATION

The special features like dam break analysis, levee breaching, overtopping etc. are also included in this component of modelling.

2) Graphics and Reporting: Graphics part includes X-Y plotting, cross-section profile, hydrographs, rating curves, etc. Reporting part involved the printed output and input data.

The governing equations of the model are the complete one-dimensional Saint-Venant equations of unsteady flow which are coupled with internal boundary equations representing the rapidly varied (broad-crested weir) flow through structures such as dams and bridge/embankments which can develop a user specified time-dependent breach. Also, appropriate external boundary equations at the upstream and downstream ends of the routing reach are utilized. The basic theory for dynamic routing in one dimensional analysis consists of two partial differential equations originally derived by Barre De Saint Venant in 1871. The equations are:

Conservation of mass (continuity) equation

(∂Q/∂X) + ∂(A + A0) / ∂t - q = 0

Conservation of momentum equation

(∂Q/∂t) + { ∂(Q2/A)/∂X } + g A ((∂h/∂X) + Sf + Sc) = 0

where

Q = discharge;
A = active flow area;
A0 = inactive storage area;
h = water surface elevation;
q= lateral outflow;
x = distance along waterway;
t = time;
Sf = friction slope;
Sc = expansion contraction slope and
g = gravitational acceleration.

Breach outflow is computed as broad-crested weir flow equation:

$$Qb = c_v k_s [3.1 b_i (h - h_b)^{1.5} + 2.45 z (h - h_b)]^{2.5}$$

In which

b_i = computed instantaneous breach bottom width

$= b.t_b / \tau \qquad if\ t_b < \tau$

where

b = terminal width of the bottom of the breach

τ = time interval until the terminal width is attained

t_b = time since beginning of breach formation

h = reservoir water surface elevation

h_b = computed elevation of breach bottom

$= h_d - \frac{(h_d - h_{bm})t_b}{\tau}$ if $0 < t_b < \tau$

$= h_{bm}$ if $t_b > \tau$

where

h_{bm} = final elevation of breach bottom

h_d = height of the dam

z = user specified side-slope of the breach

k_s = computed submergence correction due to downstream tailwater

elevation (h_t)

$= 1.0 - 27.8[\frac{h_t - h_b}{h - h_b} - 0.67]^3 \qquad if\ (h_t - h_b) / (h - h_b) > 0.67$

= 1.0 otherwise

c_v = small computed correction for velocity of approach

$$c_v = 1.0 + 0.023(Q_b{}^2/[B_d{}^2(h - h_{bm})^2(h - h_b)]$$

where

B_d = width of reservoir at the dam

User is required to enter boundary conditions at all external boundaries of the system, as well as at any desired internal locations, and set the initial flow and storage area conditions at the beginning of simulation. The upstream boundary conditions for unsteady flow state can be given as the lateral inflow hydrograph for a reservoir (storage area), or gate openings in case of presence of gates as controlled structure in the system. Downstream boundary conditions for unsteady flow state can be given as the stage/flow hydrographs, rating curves or friction slope of the channel. In addition to the boundary conditions, the user must establish the initial conditions of the system at the beginning of the unsteady flow simulation. Initial conditions consist of flow and stage information at each of the cross sections, as well as elevations for any storage areas defined in the system.

7.1 Breach Parameters

The physical description of the breach will consist of the bottom elevation, bottom width, and side slopes in H:V (side slopes are expressed in units of distance horizontal to every one unit in the vertical). These values represent the breach size as shown in figure 4 below. In addition to this, it is mandatory to specify breach weir coefficient and the breach formation time and the breach trigger condition- whether on a particular elevation or at a particular time interval along with the mode of failure. HEC RAS can be used for overtopping as well as piping as mode of failure for the different dams. The resulting flood wave is routed through the downstream river channel using the unsteady flow simulations.

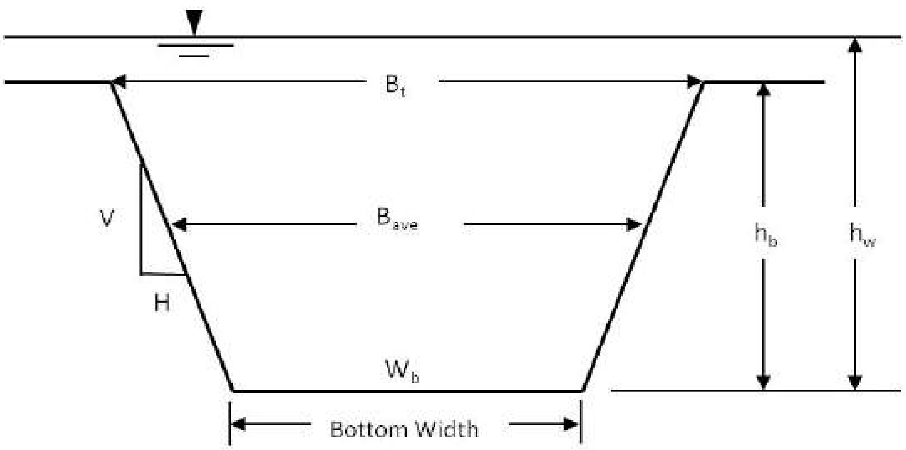

Figure 4: BREACH GEOMETRY

8.0 DAM BREAK ANALYSIS FOR SRI KOMARAVELLI MALLANNA SAGAR

The failure of an embankment dam can be viewed as a two-stage process. First, the actual breach of the dam that must be analyzed, and second, the outflow from the breach to be routed through the downstream valley to determine the resulting flood at population centers. Predicting the outflow hydrograph can be subdivided into predicting the breach characteristics (e.g., shape, depth, width, rate of breach formation) and routing the reservoir storage due to the outflow through the breach. The models do not directly simulate the breach; rather the user determines the breach characteristics independently and provides that information as input to the routing model.

One dimensional mathematical model (HEC-RAS) under unsteady flow condition is used for Dam break analysis of the present study. Dam break flood hydrographs have been simulated under different conditions of breaking when the reservoir is full. Unsteady flow component of this model has been used for routing the generated flood hydrograph due to dam break. The Unsteady flow component is based on law of conservation of mass and law of conservation of momentum.

The dam break studies for Sri Komaravelli Mallanna Sagar have been carried out considering rectangular breach with maximum width of 300m. This optimum size of breach has been derived as per the standard guidelines with reference to the nature of bund and height of the dam. The most vulnerable point of breach could be the location where bund is having maximum height. This location was identified with the help of toposheet (SOI) and satellite imageries. The failure of this section of bund was considered due to overtopping.

For this study CWPRS used the data provided by the project authority like salient features of bund, Area Elevation Capacity curve of reservoir. As mentioned above, the 1-D model required topographical data as well as the boundary condition for running the model. In the absence of actual topographical survey data of the stream downstream of proposed Shri K. Mallanna Sagar, a Digital Elevation Model (DEM) of 30 m resolution available at USGS website (figure 5) was downloaded and processed using ARC-GIS software for topographical data of the stream on the downstream of the proposed Sri Komaravelli Mallanna Sagar. The geometric data required for development of 1-D mathematical model were extracted from ASTER DEM using ARC-GIS and MS-Excel software. The cross sections extracted were compared with few cross sections provided by project authority for validation purpose, and were found to be matching fairly. About 47 km of channel reach from proposed Sri Komaravelli Mallanna Sagar upto Upper Maniar reservoir was considered in the study. 109 cross sections of the Kurelli Vaagu Stream and 3 sections close to the proposed bund of dam on the upstream were provided in the model. The schematic geometry in the HEC-RAS model showing the reservoir and cross sections upto 47 kms as given in model are shown in figure 6. The cross sections were appropriately extended beyond both the banks of the stream varying from 2 to 8 km in length, to know the maximum extent of inundation. Storage (level pool) routing was carried out within the reservoir with F.R.L of Upper Maniar reservoir as downstream boundary. Dynamic routing was carried out in downstream reach and water surface elevations were computed in HEC-RAS using Saint Venant equations by numerical simulations. For the worst possible case, the shape of break was considered as rectangular. Three simulations with the breaching time as 18 minutes, 30 minutes and 1 hour (as per the standard methods for the failure of earthen dams) with the level at F.R.L of the Dam have been considered. Since, this is a pumped storage type of reservoir, catchment flow addition to the reservoir will be negligible. Therefore, the worst breaching scenario may be dam breaching at F.R.L and having minimum breaching time.

Boundary conditions for controlling the simulations were assigned to the model as upstream boundary condition (FRL of proposed bund), downstream boundary condition (FRL of existing reservoir 47 km downstream). With above conditions unsteady simulations under mix flow regime were carried out. The flood levels computed with breach generated flood hydrograph routed through the stream have been analyzed at every cross section.

8.1 Schematization of Kurelli Vaagu stream Reach under Study

The Kurelli Vaagu stream reach of 47 km from proposed Sri Komaravelli Mallanna Sagar upto Upper Maniar reservoir had been simulated in the mathematical model study. Figure 6 shows schematization of this reach. The model grid points indicate the location of river cross sections used for the study. The topography of river was reproduced using the extracted river cross-section data. As mentioned above all these cross sections were appropriately extended on either side of the bank beyond highest natural bank level in order to estimate the flooding effect resulting from dam break flood. These cross sections were provided at about 500m interval in the model.

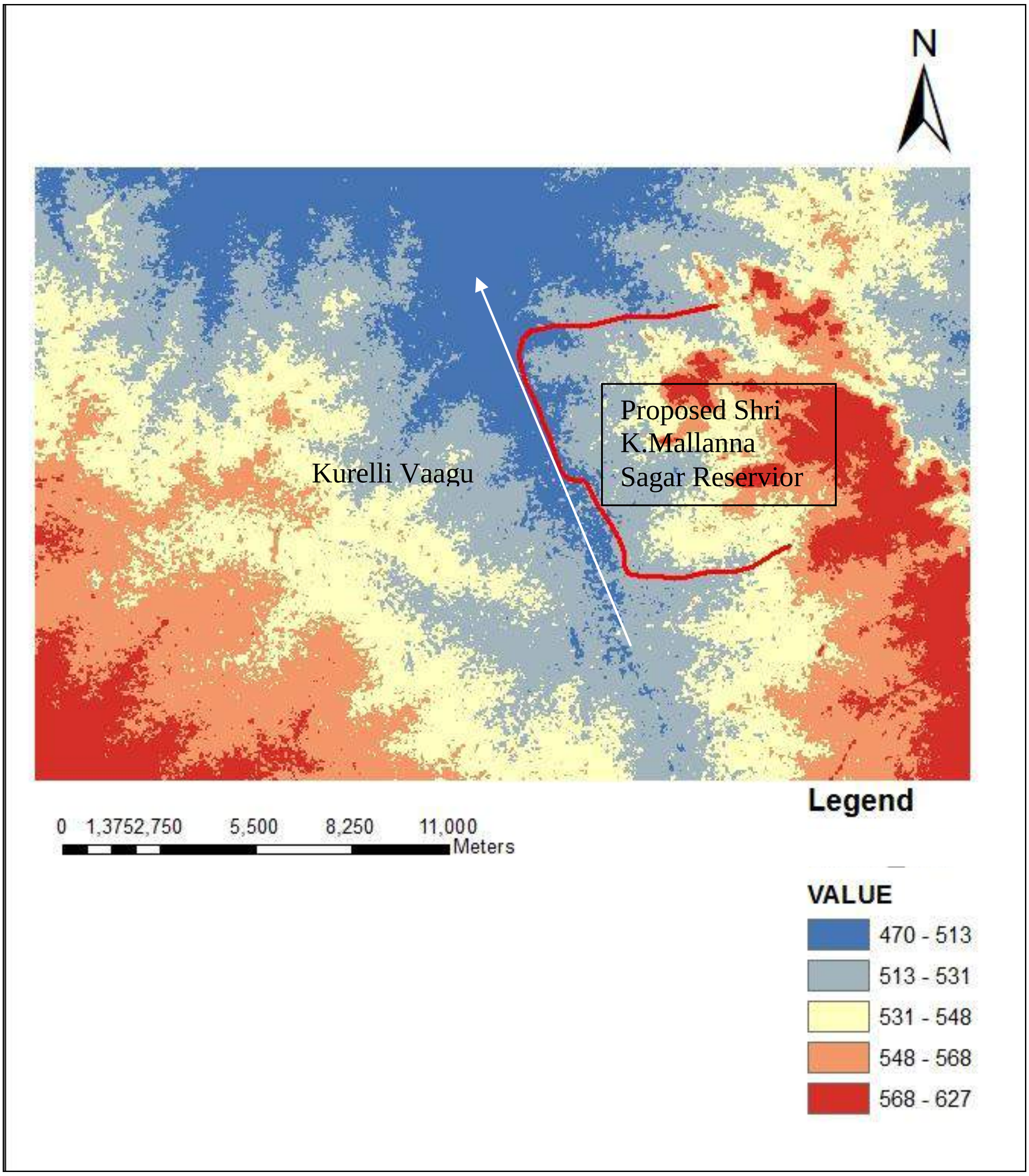

Figure 5: Digital Elevation Model (DEM) used for extraction of cross sections of stream near proposed Sri Komaravelli Mallanna Sagar Reservior

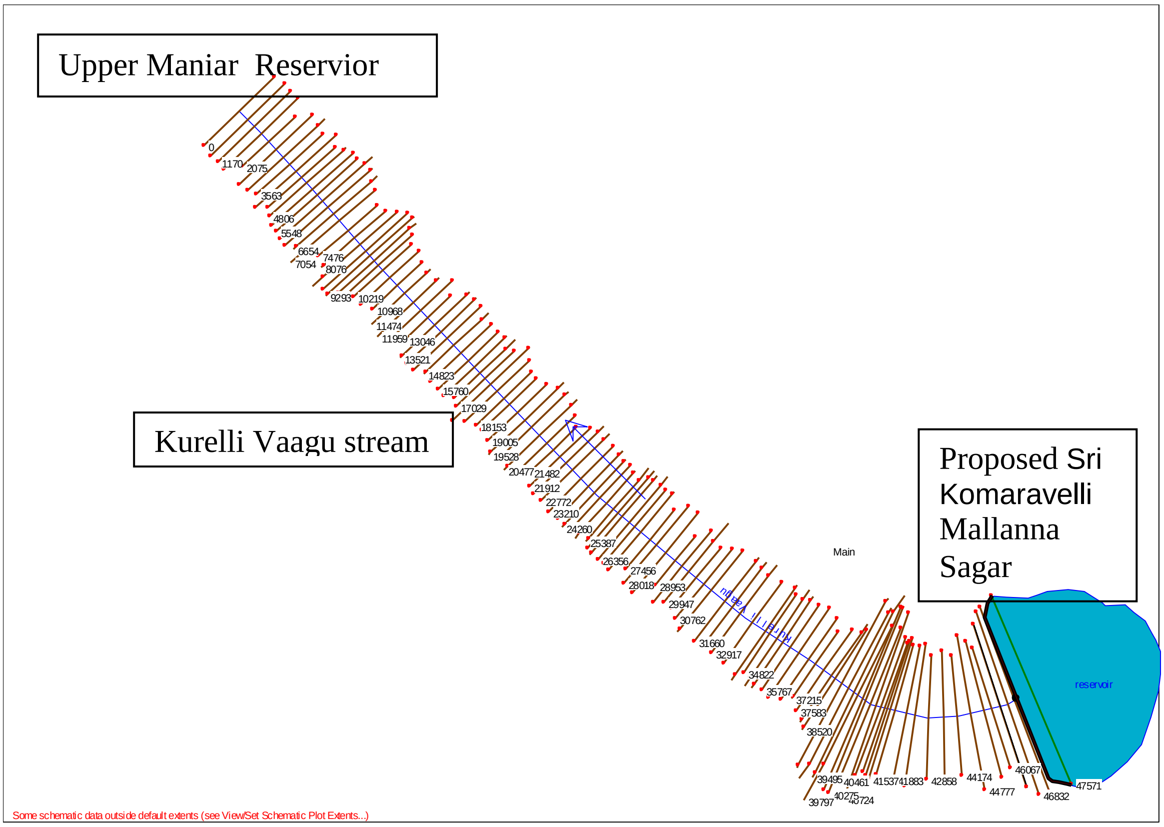

Figure 6 : Schematic Geometry used in HEC-RAS model for proposed Sri Komaravelli Mallanna Sagar with Kurelli Vaagu stream

9.0 MATHEMATICAL MODEL SIMULATION AND RESULTS

The details of the extracted cross sections with reference to chainage (from Upper Maner reservoir) are given in Table 1.These cross sections were used as geometric data for the development of 1-D mathematical model in HEC-RAS. In addition to this, the details of in-line structure i.e. geometric details of the dam and storage area were also provided to the HEC- RAS. The Dam break simulations were carried out for the time to breach of 18 min, 30 min and 60 min. The mode of failure was taken as overtopping for this study.

It was considered that the breaching of dam was initiated when the reservoir is at FRL. Consequently, FRL was used as upstream boundary condition under level pool scenario. FRL of Upper Maniar reservoir was used as a downstream boundary condition for dam break model runs using HEC- RAS model. The initial condition for all cross sections of the study reach was considered as 100 cum/s as per approximately observed lean period flow data noticed during the site inspection. The initial elevation of reservoir was taken as FRL for the unsteady flow simulations using HEC-RAS.

The dam break flood hydrograph and maximum water level profile were estimated and used for plotting inundation map for the study reach of river Kurelli Vaagu.

TABLE 1: Cross section details (w.r.t zero chainage at Upper Maner Reservoir)

Chainage 0 from existing Upper Maner reservoir (m)	***Cross Section No.***	**Chainage 0 from existing Upper Maner reservoir (m)**	***Cross Section No.***	**Chainage 0 from existing Upper Maner reservoir (m)**	***Cross Section No.***
47571	C/S 1	31218	C/S 42	13521	C/S 83
47196	C/S 2	30762	C/S 43	13046	C/S 84
46832	C/S 3	30341	C/S 44	12545	C/S 85
46436	C/S 4	29947	C/S 45	11959	C/S 86
46432	C/S 5	29540	C/S 46	11474	C/S 87
46067	C/S 6	28953	C/S 47	10968	C/S 88
45437	C/S 7	28389	C/S 48	10501	C/S 89
44777	C/S 8	28018	C/S 49	10219	C/S 90
44174	C/S 9	27456	C/S 50	9898	C/S 91
43494	C/S 10	27085	C/S 51	9623	C/S 92
42858	C/S 11	26771	C/S 52	9293	C/S 93
42431	C/S 12	26356	C/S 53	8908	C/S 94
41883	C/S 13	26096	C/S 54	8531	C/S 95
41663	C/S 14	25826	C/S 55	8076	C/S 96
41537	C/S 15	25387	C/S 56	7476	C/S 97
41407	C/S 16	25012	C/S 57	7054	C/S 98
41207	C/S 17	24672	C/S 58	6654	C/S 99
40984	C/S 18	24260	C/S 59	6270	C/S 100
40724	C/S 19	23771	C/S 60	5872	C/S 101
40461	C/S 20	23210	C/S 61	5548	C/S 102
40275	C/S 21	22772	C/S 62	5148	C/S 103
40003	C/S 22	22372	C/S 63	4806	C/S 104
39797	C/S 23	21912	C/S 64	4424	C/S 105
39495	C/S 24	21482	C/S 65	3990	C/S 106
39119	C/S 25	21007	C/S 66	3563	C/S 107
38719	C/S 26	20477	C/S 67	3078	C/S 108
38520	C/S 27	20012	C/S 68	2564	C/S 109
38080	C/S 28	19528	C/S 69	2075	C/S 110
37583	C/S 29	19005	C/S 70	1594	C/S 111
37215	C/S 30	18639	C/S 71	1170	C/S 112
36697	C/S 31	18153	C/S 72	615	C/S 113
36217	C/S 32	17747	C/S 73	0	C/S 114
35767	C/S 33	17374	C/S 74		
35455	C/S 34	17029	C/S 75		
35075	C/S 35	16640	C/S 76		
34822	C/S 36	16235	C/S 77		
34126	C/S 37	15760	C/S 78		
33407	C/S 38	15269	C/S 79		
32917	C/S 39	14823	C/S 80		
32480	C/S 40	14390	C/S 81		
31660	C/S 41	13981	C/S 82		

9.1 Dam Break Simulation under Level Pool Scenario:

In all the 3 cases, a Rectangular Breach shape of width 300 m and bottom elevation at R.L. 512.73 m as feasible at the most vulnerable location of the proposed bund was taken for Dam Break Simulations. Breach weir coefficient was considered as 1.44 for all the cases as suggested in the manual of HEC-RAS software. The unsteady flow simulations were carried out for the simulation time of 24 hours and the maximum water level profile of the study reach was estimated. In addition to this, discharges and velocities corresponding to maximum water level were estimated for all cases.

Also, the dam break flood hydrograph and stage hydrograph for cross section just immediate downstream of proposed Mallanna Sagar Reservior was estimated. The details are shown in Figure 7, Figure 8 for 18 minute breach time, Figure 9, Figure 10 for 30 minute breach time and Figure 11, Figure 12 for 60 minute breach time.

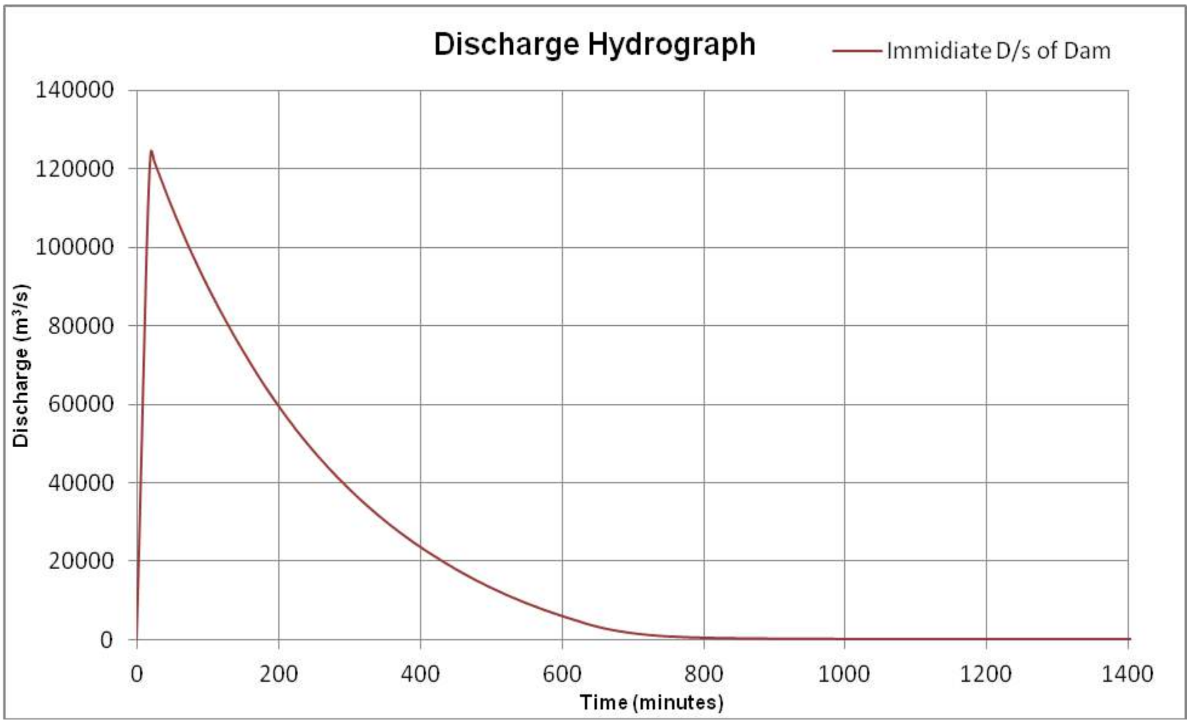

Figure 7: DAM BREAK HYDROGRAPH IMMEDIATE DOWNSTREM OF DAM FOR 18 MINUTES BREACH TIME

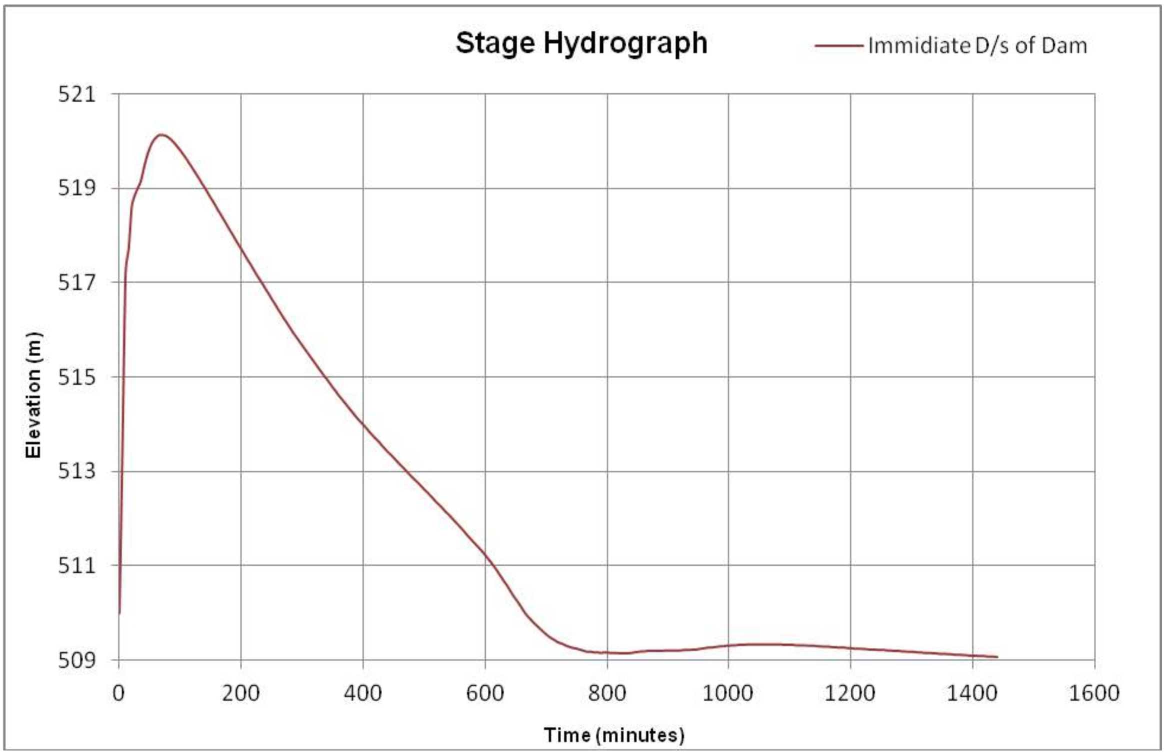

Figure 8: STAGE HYDROGRAPH IMMEDIATE DOWNSTREM OF DAM FOR 18 MINUTES BREACH TIME

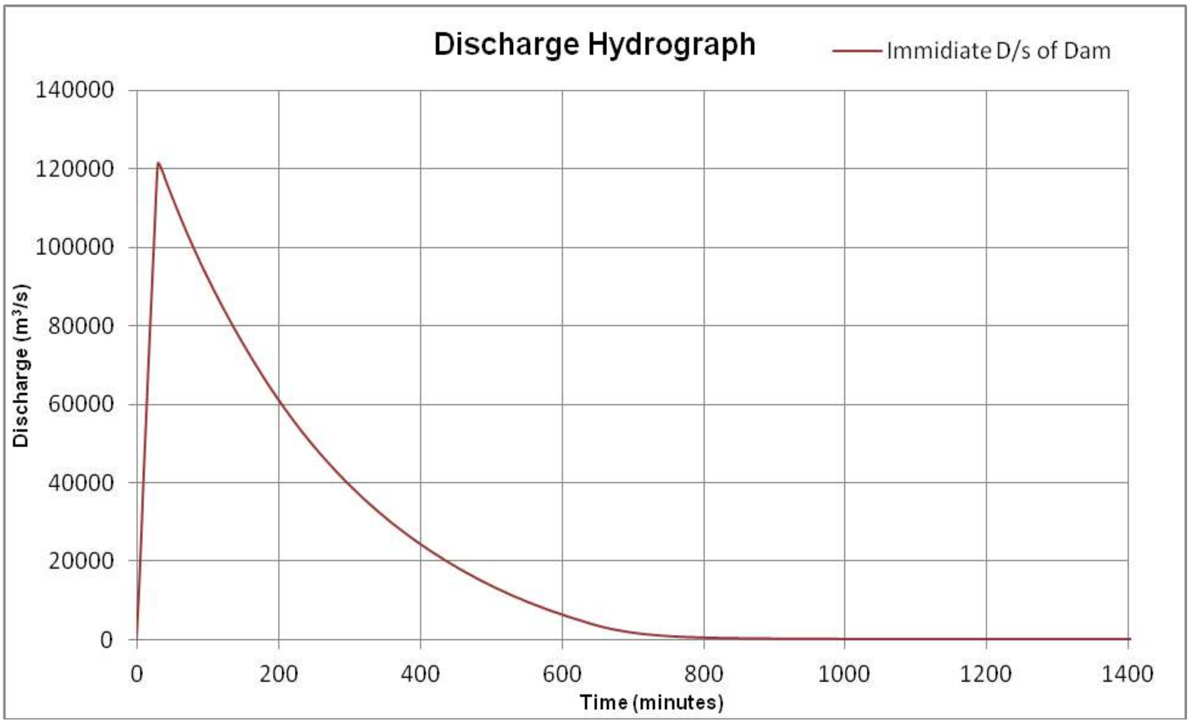

Figure 9: DAM BREAK HYDROGRAPH IMMEDIATE DOWNSTREM OF DAM FOR 30 MINUTES BREACH TIME

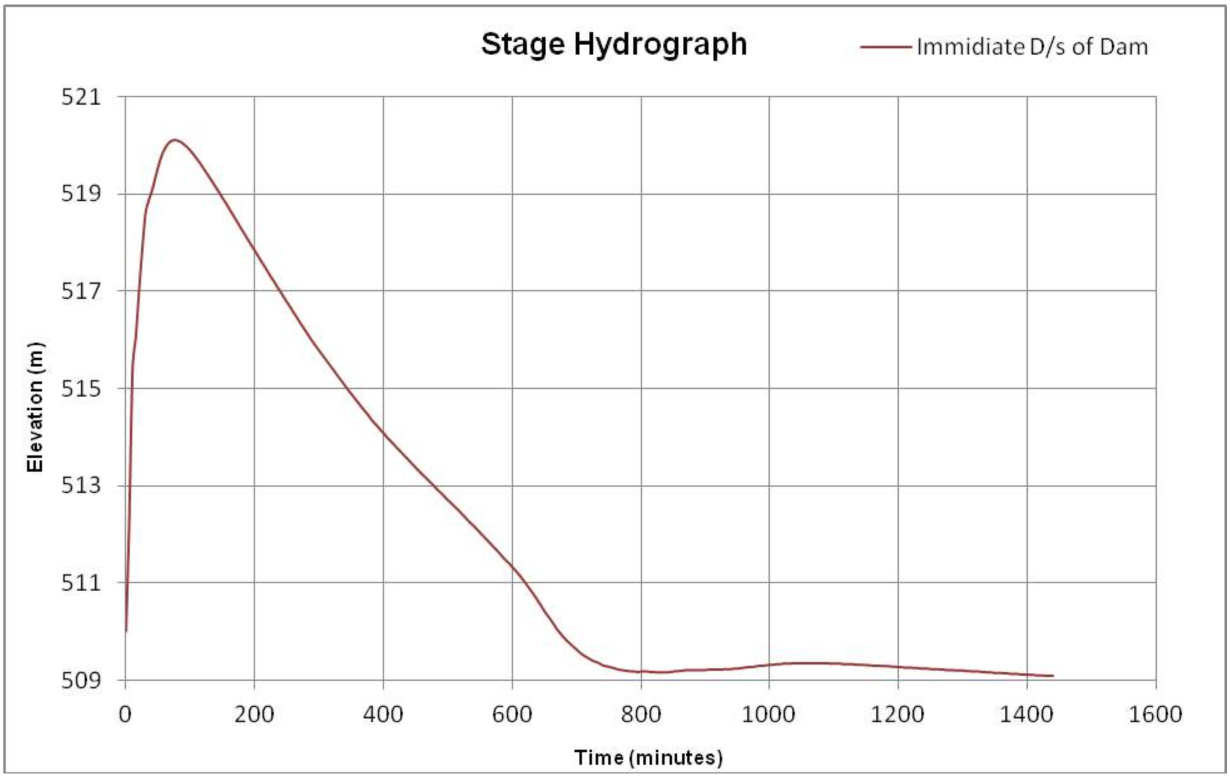

Figure 10: STAGE HYDROGRAPH IMMEDIATE DOWNSTREM OF DAM FOR 30 MINUTES BREACH TIME

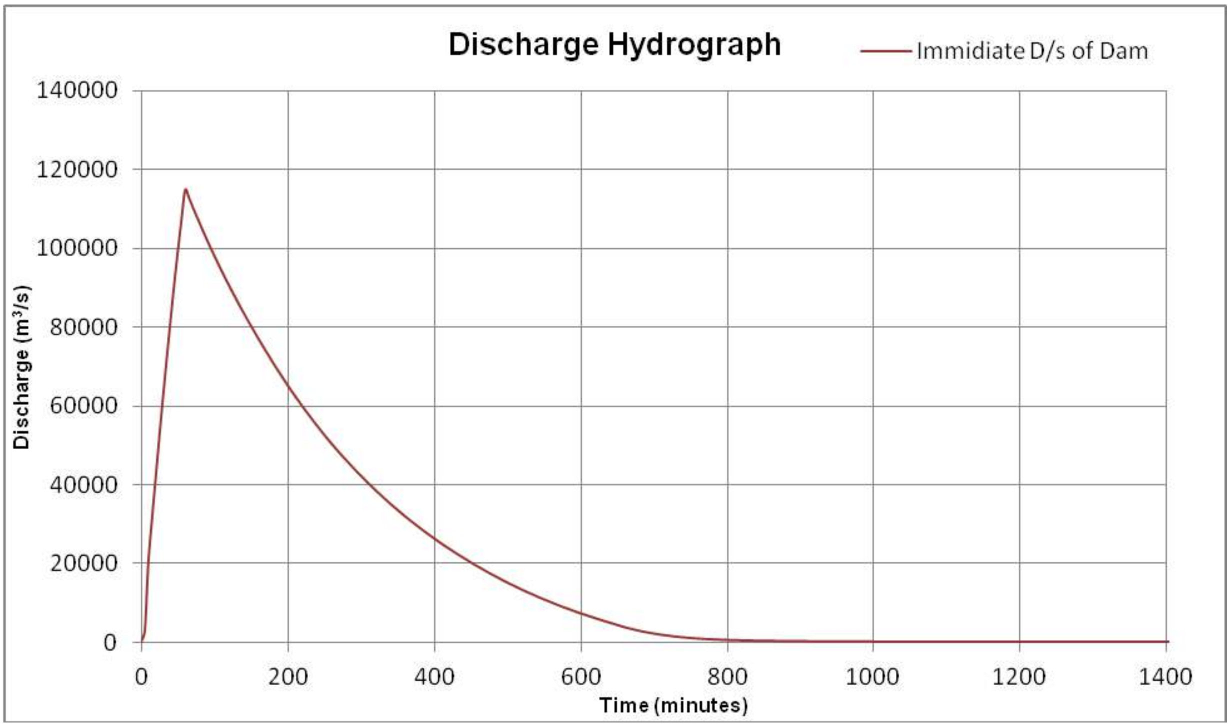

Figure 11: DOWNSTREM OF DAM BREAK HYDROGRAPH IMMEDIATE DAM FOR 60 MINUTES BREACH TIME

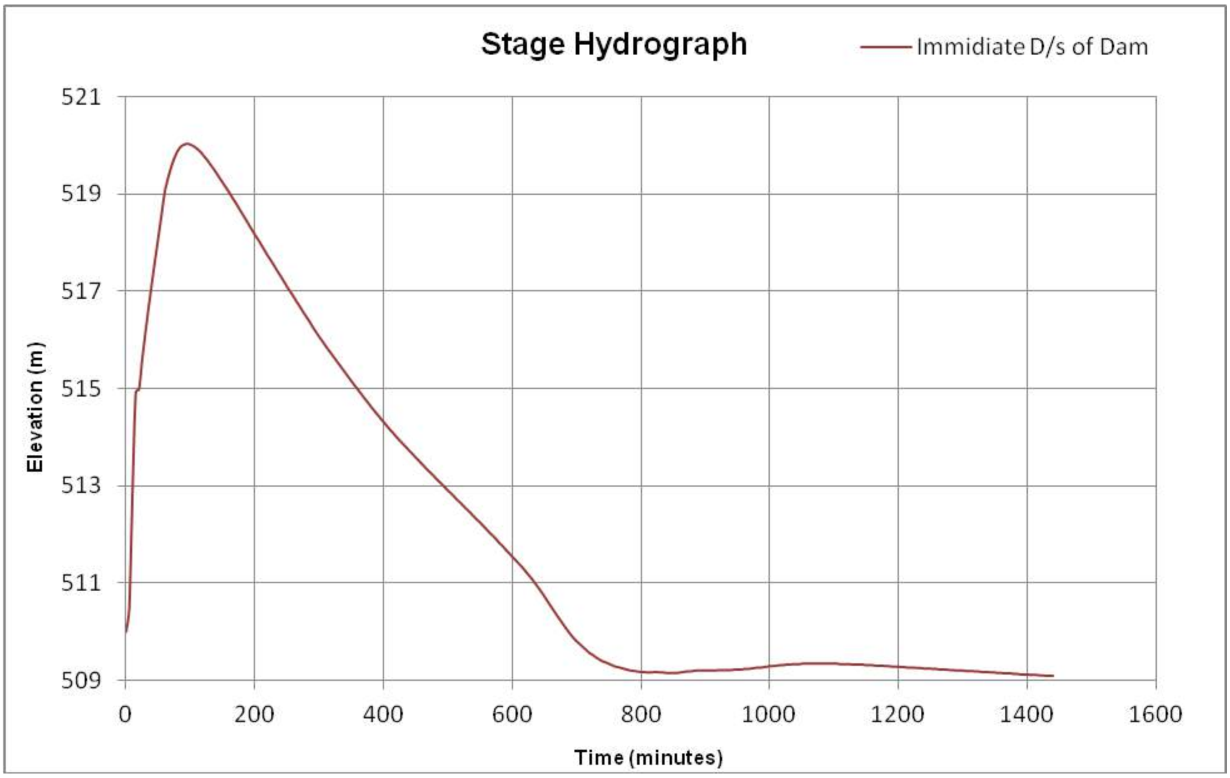

Figure 12: STAGE HYDROGRAPH IMMEDIATE DOWNSTREM OF DAM FOR 60 MINUTES BREACH TIME

The details of the Maximum Water Surface Elevation with corresponding discharge and velocities at each cross section for all the 3 cases are given in the Table 2, Table 3 and Table 4 for breaching time of 18minutes,30 minutes and 60 minutes respectively.

Table 2: Predicted maximum Water Levels with corresponding Discharge and Velocity at each cross section for breach time 18 minutes

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
0	47571	562.04	100	0	Within proposed reservior
375	47196	562.04	100	0	
739	46832	562.04	100	0	
1135	46436	562.04	100	0	
1139	46432				At Dam
1504	46067	520.14	102086.5	3.05	D/s of Dam
2134	45437	520	101785.0	2.31	
2794	44777	519.75	101508.8	1.97	
3397	44174	519.31	101103.5	2.55	
4077	43494	519.15	100991.0	2.14	
4713	42858	518.69	100871.1	2.73	
5140	42431	518.28	100809.6	2.83	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
5688	41883	517.7	100763.2	3.51	
5908	41663	515.84	100714.4	6.01	
6034	41537	515.35	100660.4	5.33	
6164	41407	514.99	100644.5	5.39	
6364	41207	514.41	100655.5	6.4	
6587	40984	513.35	100586.5	7.04	
6847	40724	512.41	100501.6	5.05	
7110	40461	511.34	100445.5	6.03	
7296	40275	510.97	100140.9	3.89	
7568	40003	510.72	100085.1	3.49	
7774	39797	510.27	99951.47	3.63	
8076	39495	509.6	99827.1	4.53	
8452	39119	508.82	99427.38	4.53	
8852	38719	508.03	98834.77	4.07	
9051	38520	507.1	98303.41	4.44	
9491	38080	506.51	97970.63	4.8	
9988	37583	505.61	97177.27	4.54	
10356	37215	503.87	96052.55	5.89	
10874	36697	503.53	94591.63	3.4	
11354	36217	503.3	94373.09	2.46	
11804	35767	503.04	94181.13	2.56	
12116	35455	502.48	93783.78	3.35	
12496	35075	502.15	93571.6	3.4	
12749	34822	501.87	93410.68	3.21	
13445	34126	501.9	93445.05	2.55	
14164	33407	501.44	93312.36	2.76	
14654	32917	500.63	93129.41	3.43	
15091	32480	500.28	93061.95	3.07	
15911	31660	499.99	93041.14	3.02	
16353	31218	498	92873.68	4.7	
16809	30762	497.22	92789.06	3.83	
17230	30341	496.53	92735.89	3.92	
17624	29947	495.15	92674.02	5.28	
18031	29540	493.66	92498.93	5.57	
18618	28953	492.78	92171.73	4.44	
19182	28389	492.39	92029.78	2.99	
19553	28018	491.16	91655.71	4.12	
20115	27456	490.68	91507.53	3.53	
20486	27085	490.24	91390.13	3.04	
20800	26771	489.36	91218.98	4.21	
21215	26356	488.51	90898.49	4.74	
21475	26096	487.66	90495.43	4.61	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
21745	25826	487.44	90312.42	3.88	
22184	25387	486.74	89932.97	4.56	
22559	25012	485.97	89305.1	4.42	
22899	24672	485.41	88903.26	4.19	
23311	24260	485.02	88570.14	3.89	
23800	23771	484.47	88200.97	3.74	
24361	23210	483.98	87952.13	3.4	
24799	22772	483.56	87755.27	3.13	
25199	22372	483.34	87695.55	2.85	
25659	21912	482.12	87229.82	4.08	
26089	21482	481.63	86892.31	3.94	
26564	21007	481.63	86890.78	2.81	
27094	20477	481.31	86778.02	2.81	
27559	20012	480.2	86355.16	4.35	
28043	19528	479.75	86100.74	3.71	
28566	19005	479.18	85790.36	3.62	
28932	18639	477.45	85298.27	5.7	
29418	18153	477.35	84580.44	2.87	
29824	17747	477.27	84513.95	2.16	
30197	17374	477.1	84454.06	2.2	
30542	17029	476.34	84096.39	3.68	
30931	16640	475.97	83931.5	3.46	
31336	16235	476.04	83953.41	2.24	
31811	15760	475.84	83905.51	2.48	
32302	15269	475.32	83759.88	3.25	
32748	14823	474.37	83522.75	4.28	
33181	14390	473.71	83310.71	4.19	
33590	13981	473.05	83091.26	4.03	
34050	13521	472.59	82938.85	3.64	
34525	13046	471.8	82750.13	3.51	
35026	12545	470.92	82377.45	4.27	
35612	11959	470.59	82259.93	2.88	
36097	11474	469.74	82075.92	3.12	
36603	10968	469.68	82071.17	2.5	
37070	10501	469.52	82035.12	2.35	
37352	10219	468.93	81965.41	3.43	
37673	9898	467.9	81867.8	5.26	
37948	9623	467.62	81791.45	4.24	
38278	9293	467.73	81803.12	2.82	
38663	8908	467.79	81799.47	1.82	
39040	8531	467.45	81776.9	2.57	
39495	8076	466.55	81753.63	4.2	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
40095	7476	465.9	81731.84	4	
40517	7054	464.73	81701.8	4.44	
40917	6654	463.88	81668.08	4.39	
41301	6270	462.62	81644.01	4.8	
41699	5872	461.11	81599.92	5.29	
42023	5548	459.99	81539.91	4.67	
42423	5148	458.74	81507.35	5.54	
42765	4806	458.23	81456.52	3.71	
43147	4424	457.75	81433.36	3.77	
43581	3990	457.02	81431.77	4.11	
44008	3563	455.86	81423.39	4.75	
44493	3078	455.26	81422.17	4.06	
45007	2564	454.49	81420.65	4.11	
45496	2075	452.68	81411.24	5.92	
45977	1594	452.28	81294.16	3.91	
46401	1170	452.05	81051.45	2.71	
46956	615	452.04	81309.22	1.84	
47571	0	451.85			D/s W.S El

Table 3 : Predicted maximum Water Levels with corresponding Discharge and Velocity at each cross section for breach time 30 minutes (case 2)

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
0	47571	562.04	100	0	Within proposed reservior
375	47196	562.04	100	0	
739	46832	562.04	100	0	
1135	46436	562.04	100	0	
1139	46432				At Dam
1504	46067	520.12	101805.5	3.05	D/s of Dam
2134	45437	519.98	101503.7	2.31	
2794	44777	519.73	101226.4	1.97	
3397	44174	519.29	100762.6	2.55	
4077	43494	519.14	100704.2	2.13	
4713	42858	518.67	100581.1	2.73	
5140	42431	518.26	100496.4	2.83	
5688	41883	517.68	100454.8	3.5	
5908	41663	515.82	100409.7	6.01	
6034	41537	515.33	100367.5	5.32	
6164	41407	514.98	100323.7	5.38	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
6364	41207	514.39	100363.1	6.39	
6587	40984	513.34	100296	7.04	
6847	40724	512.39	100212.5	5.05	
7110	40461	511.33	100137.7	6.02	
7296	40275	510.96	99854.55	3.88	
7568	40003	510.71	99747.08	3.48	
7774	39797	510.25	99641.32	3.63	
8076	39495	509.59	99540.57	4.53	
8452	39119	508.81	99150.39	4.52	
8852	38719	508.01	98566.52	4.06	
9051	38520	507.09	98044.22	4.43	
9491	38080	506.5	97758.19	4.79	
9988	37583	505.6	97025.35	4.54	
10356	37215	503.86	95870.08	5.88	
10874	36697	503.52	94530.66	3.4	
11354	36217	503.3	94257.8	2.46	
11804	35767	503.03	94066.61	2.56	
12116	35455	502.48	93673.94	3.35	
12496	35075	502.14	93463.06	3.4	
12749	34822	501.86	93302.11	3.21	
13445	34126	501.9	93336.86	2.55	
14164	33407	501.44	93176.78	2.76	
14654	32917	500.62	93021.66	3.43	
15091	32480	500.27	92955.2	3.07	
15911	31660	499.98	92934.1	3.02	
16353	31218	497.99	92768.59	4.7	
16809	30762	497.21	92672.06	3.83	
17230	30341	496.52	92632.36	3.92	
17624	29947	495.14	92559.3	5.28	
18031	29540	493.66	92398.21	5.57	
18618	28953	492.78	92074.13	4.44	
19182	28389	492.39	91933.39	2.99	
19553	28018	491.15	91561.62	4.12	
20115	27456	490.67	91414.63	3.52	
20486	27085	490.23	91319.28	3.04	
20800	26771	489.35	91128.59	4.21	
21215	26356	488.5	90836.79	4.74	
21475	26096	487.65	90380.38	4.61	
21745	25826	487.44	90258.93	3.88	
22184	25387	486.74	89884.7	4.56	
22559	25012	485.97	89227.91	4.42	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
23311	24260	485.02	88534.27	3.89	
23800	23771	484.47	88132.08	3.74	
24361	23210	483.98	87887.25	3.4	
24799	22772	483.56	87724.97	3.13	
25199	22372	483.34	87638.06	2.85	
25659	21912	482.12	87172.81	4.08	
26089	21482	481.63	86867.42	3.94	
26564	21007	481.63	86865.3	2.81	
27094	20477	481.31	86727.02	2.81	
27559	20012	480.2	86333.05	4.35	
28043	19528	479.75	86080.52	3.71	
28566	19005	479.18	85771.76	3.62	
28932	18639	477.45	85252.37	5.69	
29418	18153	477.35	84568.91	2.87	
29824	17747	477.27	84532.47	2.16	
30197	17374	477.1	84441.88	2.2	
30542	17029	476.34	84086.23	3.68	
30931	16640	475.97	83922.38	3.46	
31336	16235	476.04	83943.91	2.24	
31811	15760	475.84	83875.32	2.48	
32302	15269	475.32	83751.49	3.25	
32748	14823	474.37	83535.95	4.28	
33181	14390	473.71	83326.2	4.19	
33590	13981	473.05	83086.38	4.03	
34050	13521	472.59	82935.17	3.64	
34525	13046	471.8	82725.97	3.51	
35026	12545	470.92	82400.44	4.27	
35612	11959	470.59	82260.1	2.88	
36097	11474	469.75	82077.23	3.12	
36603	10968	469.68	82073.13	2.5	
37070	10501	469.52	82051.46	2.35	
37352	10219	468.93	81968.52	3.43	
37673	9898	467.9	81871.14	5.26	
37948	9623	467.63	81795.25	4.24	
38278	9293	467.73	81807.12	2.82	
38663	8908	467.79	81803.74	1.82	
39040	8531	467.45	81782.14	2.57	
39495	8076	466.55	81759.29	4.2	
40095	7476	465.9	81737.71	4	
40517	7054	464.73	81702.96	4.44	
40917	6654	463.88	81684.59	4.39	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
41301	6270	462.62	81650.3	4.8	
41699	5872	461.11	81599.55	5.29	
42023	5548	459.99	81546.01	4.67	
42423	5148	458.74	81521.51	5.54	
42765	4806	458.23	81463.38	3.71	
43147	4424	457.75	81453.41	3.77	
43581	3990	457.03	81439.53	4.11	
44008	3563	455.86	81431.38	4.75	
44493	3078	455.26	81430.5	4.06	
45007	2564	454.49	81428.41	4.11	
45496	2075	452.68	81411.98	5.92	
45977	1594	452.28	81305.63	3.91	
46401	1170	452.05	81087.75	2.71	
46956	615	452.04	81308.4	1.84	
47571	0	451.85			D/s W.S El

Table 4 : Predicted maximum Water Levels with corresponding Discharge and Velocity at each cross section for breach time 60 minutes (case 3)

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
0	47571	562.04	100	0	Within proposed reservior
375	47196	562.04	100	0	
739	46832	562.04	100	0	
1135	46436	562.04	100	0	
1139	46432				At Dam
1504	46067	520.03	100252.7	3.04	D/s of Dam
2134	45437	519.89	99955.84	2.3	
2794	44777	519.63	99611.33	1.97	
3397	44174	519.19	99233.07	2.53	
4077	43494	519.04	99173.52	2.12	
4713	42858	518.58	99048.73	2.71	
5140	42431	518.16	98962.23	2.81	
5688	41883	517.59	98920.74	3.49	
5908	41663	515.73	98877.53	5.98	
6034	41537	515.25	98825.54	5.29	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
6164	41407	514.9	98811.3	5.35	
6364	41207	514.31	98833.63	6.37	
6587	40984	513.25	98755.28	7.01	
6847	40724	512.31	98689.81	5.02	
7110	40461	511.25	98618.74	5.99	
7296	40275	510.88	98347.91	3.88	
7568	40003	510.63	98270.02	3.47	
7774	39797	510.18	98143.87	3.61	
8076	39495	509.53	98041.05	4.5	
8452	39119	508.74	97816.04	4.51	
8852	38719	507.94	97272.47	4.05	
9051	38520	507.02	96793.89	4.42	
9491	38080	506.43	96569.65	4.78	
9988	37583	505.54	95938.18	4.52	
10356	37215	503.8	94952.39	5.87	
10874	36697	503.47	93605.47	3.39	
11354	36217	503.24	93350.05	2.45	
11804	35767	502.98	93214.33	2.55	
12116	35455	502.42	92803.88	3.34	
12496	35075	502.09	92604.92	3.39	
12749	34822	501.81	92453.91	3.2	
13445	34126	501.84	92522.15	2.54	
14164	33407	501.38	92367.17	2.75	
14654	32917	500.57	92201.63	3.42	
15091	32480	500.22	92159.38	3.06	
15911	31660	499.93	92124.47	3	
16353	31218	497.95	91982.72	4.69	
16809	30762	497.17	91904.13	3.82	
17230	30341	496.48	91854.75	3.91	
17624	29947	495.1	91796.79	5.27	
18031	29540	493.62	91646.94	5.55	
18618	28953	492.74	91316.45	4.42	
19182	28389	492.35	91201.94	2.98	
19553	28018	491.11	90845.63	4.12	
20115	27456	490.63	90704.27	3.52	
20486	27085	490.19	90612.91	3.03	
20800	26771	489.31	90429.96	4.2	
21215	26356	488.46	90178.28	4.73	
21475	26096	487.62	89771.4	4.6	
21745	25826	487.4	89625.96	3.87	
22184	25387	486.7	89302.64	4.55	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
22559	25012	485.93	88711.98	4.41	
22899	24672	485.37	88330.02	4.18	
23311	24260	484.98	87977.72	3.88	
23800	23771	484.43	87662.19	3.74	
24361	23210	483.95	87394.23	3.4	
24799	22772	483.52	87210.67	3.13	
25199	22372	483.3	87181.77	2.84	
25659	21912	482.09	86735.72	4.07	
26089	21482	481.6	86470.25	3.93	
26564	21007	481.6	86466.11	2.81	
27094	20477	481.28	86306.97	2.81	
27559	20012	480.18	85925.32	4.35	
28043	19528	479.73	85681.42	3.71	
28566	19005	479.15	85436.8	3.62	
28932	18639	477.42	84908.46	5.69	
29418	18153	477.33	84243.63	2.86	
29824	17747	477.25	84208.87	2.16	
30197	17374	477.08	84120.94	2.2	
30542	17029	476.32	83775.25	3.68	
30931	16640	475.94	83615.88	3.46	
31336	16235	476.02	83660.48	2.24	
31811	15760	475.82	83591.53	2.48	
32302	15269	475.29	83470.62	3.25	
32748	14823	474.35	83241.56	4.27	
33181	14390	473.69	83037.63	4.19	
33590	13981	473.04	82826.32	4.03	
34050	13521	472.57	82699.6	3.64	
34525	13046	471.79	82476.02	3.5	
35026	12545	470.91	82134.43	4.27	
35612	11959	470.57	82021.33	2.88	
36097	11474	469.73	81842.26	3.12	
36603	10968	469.66	81839.28	2.5	
37070	10501	469.51	81804.88	2.35	
37352	10219	468.91	81750.09	3.42	
37673	9898	467.88	81655.2	5.25	
37948	9623	467.61	81566.16	4.24	
38278	9293	467.72	81578.57	2.82	
38663	8908	467.77	81586.41	1.81	
39040	8531	467.44	81563.27	2.57	
39495	8076	466.53	81533.66	4.19	

Chainage / Distance (m)		Water level (m)	Discharge (m^3/s)	Velocity (m/s)	Remark
From proposed Dam	From Upper Maniar Dam				
40095	7476	465.89	81512.98	3.99	
40517	7054	464.72	81483.96	4.44	
40917	6654	463.87	81461.05	4.38	
41301	6270	462.6	81421.86	4.8	
41699	5872	461.09	81390.01	5.29	
42023	5548	459.97	81332.3	4.67	
42423	5148	458.73	81300.78	5.54	
42765	4806	458.22	81251.37	3.71	
43147	4424	457.73	81234.41	3.77	
43581	3990	457.01	81221.55	4.11	
44008	3563	455.84	81218.27	4.74	
44493	3078	455.25	81213.99	4.05	
45007	2564	454.48	81212.57	4.11	
45496	2075	452.68	81197.73	5.91	
45977	1594	452.28	81083.93	3.9	
46401	1170	452.04	80844.17	2.7	
46956	615	452.04	81085.83	1.83	
47571	0	451.85			D/s W.S El

Reviewing the results, it was noticed that among the 3 cases, the maximum discharge of 102086.5 m^3/s was attained on the immediate downstream of proposed Mallanna Sagar reservoir for Case 1. Further, discharge decreased towards the downstream cross sections of the study reach of river Kurelli Vaagu and the water level varied between 520.14m at first cross section downstream of proposed reservior to 451.85m at Upper Maniar Reservior. As more emphasis in the analysis is given for estimation of maximum water surface elevation for preparation on 'Inundation map', Maximum water surface elevation and corresponding discharge and velocity are only extracted. However, the maximum discharge and maximum velocity need not be occurring simultaneously at the time of maximum level.

9.2. Water Surface Profiles

The maximum water surface profile for each scenarios has been estimated and shown in Figures 13, 14 & 15. Reviewing all the estimated water surface profiles, it was noticed that the dam break model runs for 18 min breaching time with rectangular shape of breach 300 m wide under level pool scenario generated maximum inundation.

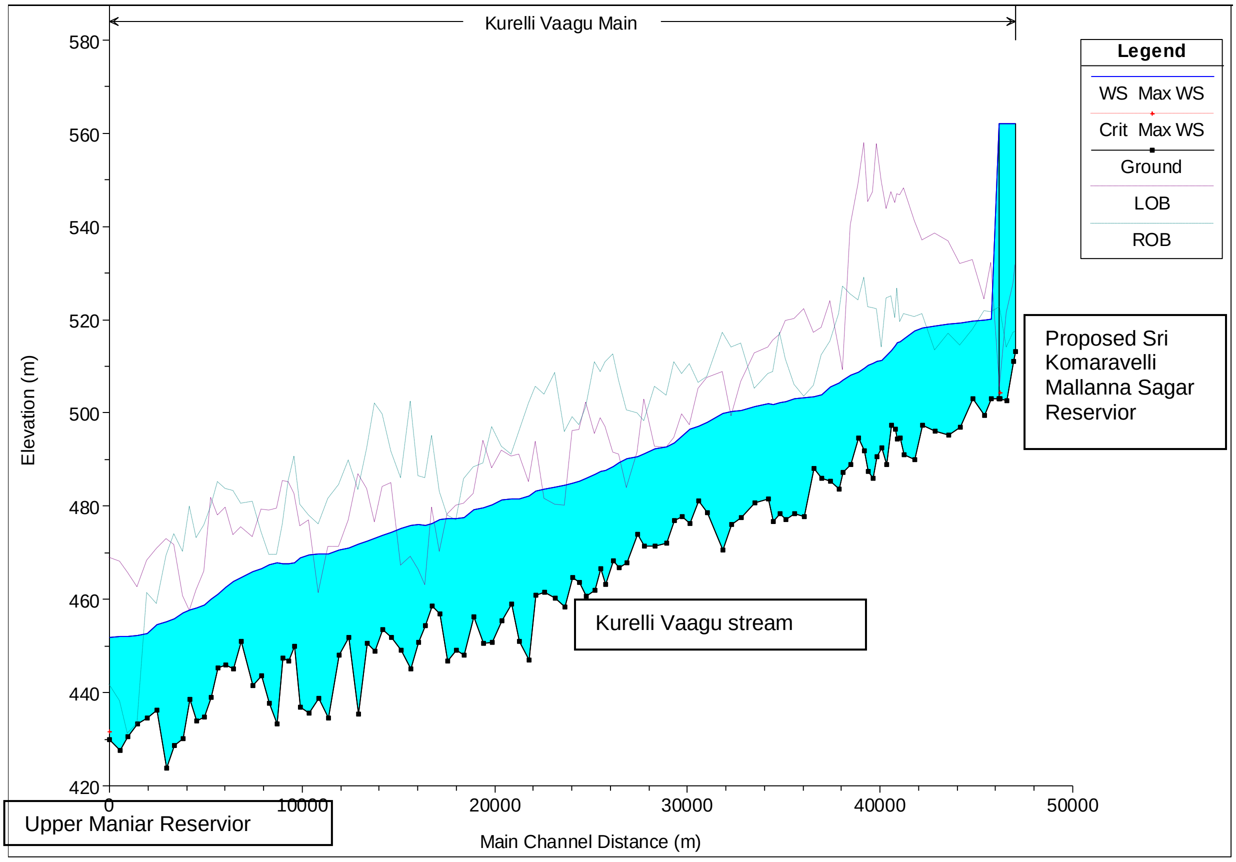

Figure 13 : Longitudinal water surface profile alongwith bed and banks for downstream channel of proposed Sri Komaravelli Mallanna Sagar for 18 minutes breach time.

***(Note : LOB and ROB shown in the figure are extended bank levels as given in the mathematical model)**

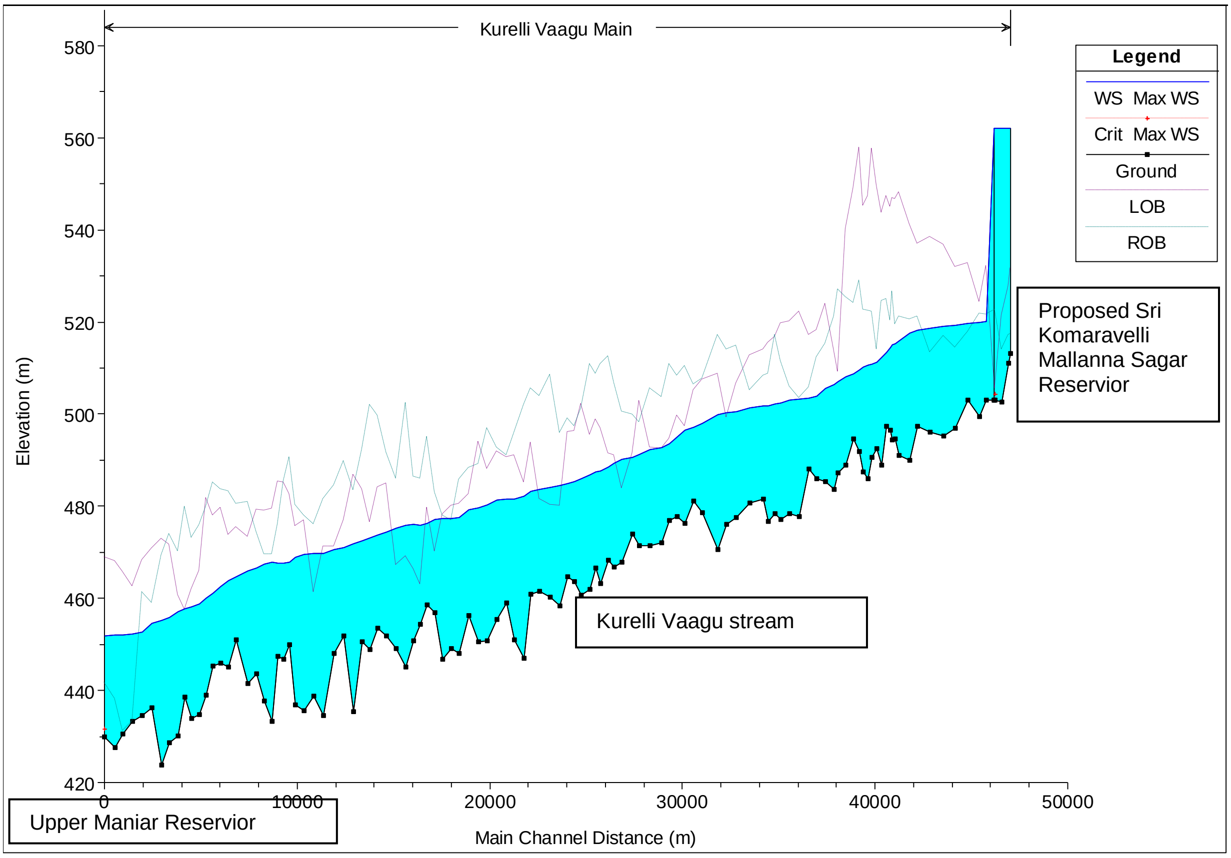

Figure 14 : Longitudinal water surface profile alongwith bed and banks for downstream channel of proposed Sri Komaravelli Mallanna Sagar for 30 minutes breach time.

***(Note : LOB and ROB shown in the figure are extended bank levels as given in the mathematical model)**

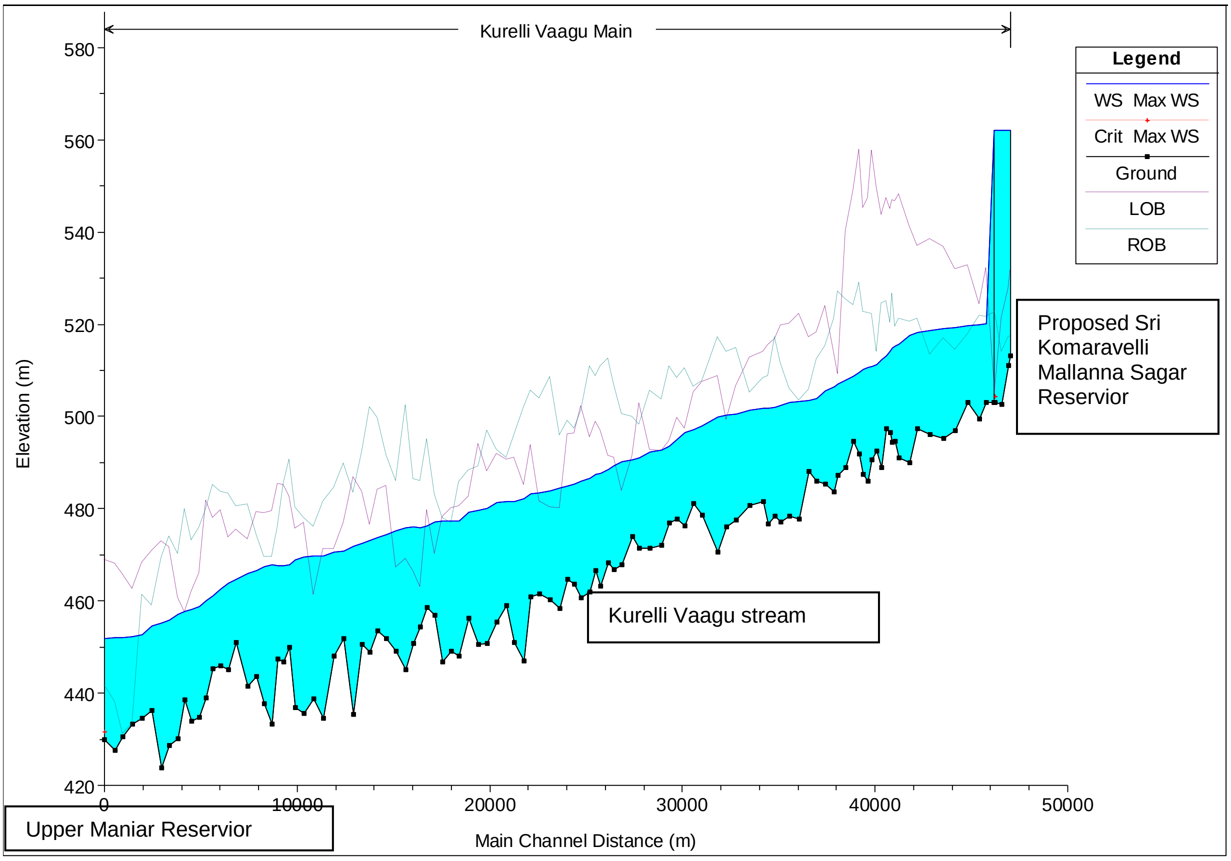

Figure 15 : Longitudinal water surface profile alongwith bed and banks for downstream channel of proposed Sri Komaravelli Mallanna Sagar for 60 minutes breach time.

***(Note : LOB and ROB shown in the figure are extended bank levels as given in the mathematical model)**

Some typical cross sections of Kurelli Vaagu stream at selected locations on the downstream showing maximum water levels (flood inundation levels) are given in figure 16 to figure 21. These figures show the extent of maximum water level and inundation on both the sides of the stream under worst scenario of breach of Shri K. Mallanna sagar.

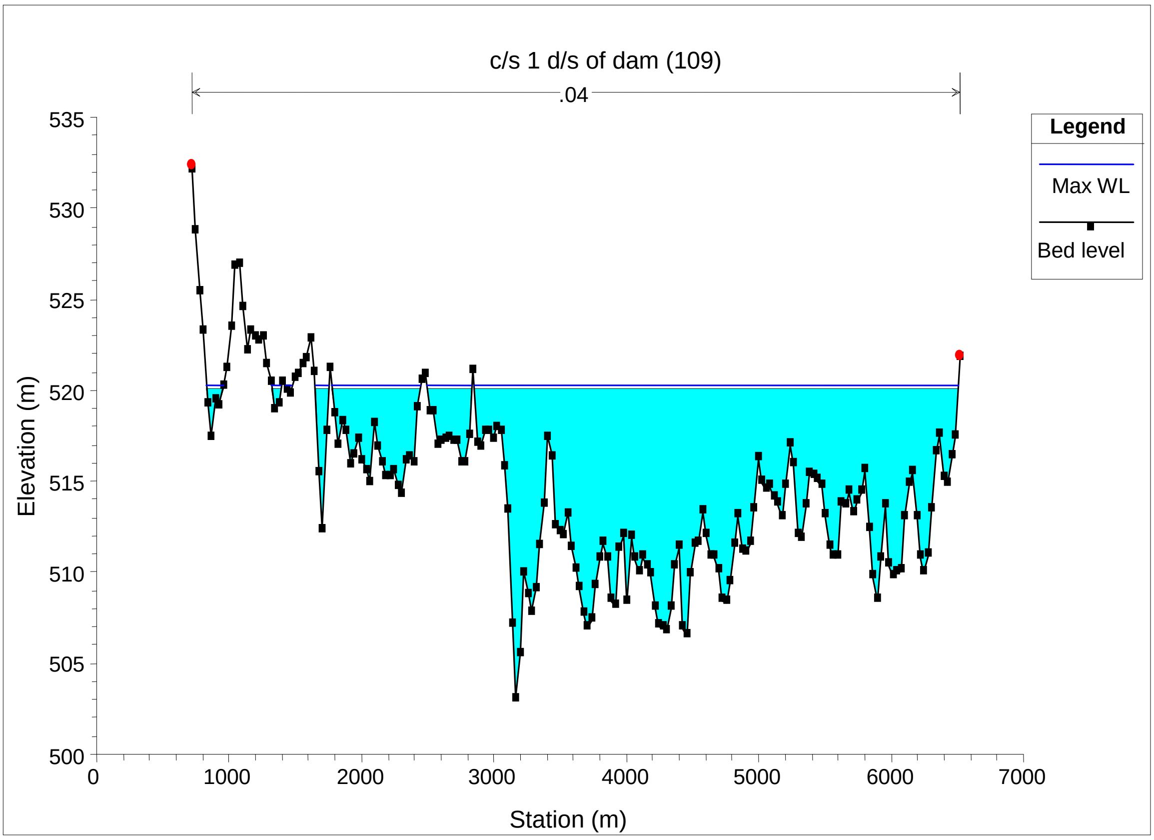

Figure 16: Cross Section of Kurelli Vaagu at 369 m downstream of proposed dam showing maximum water level

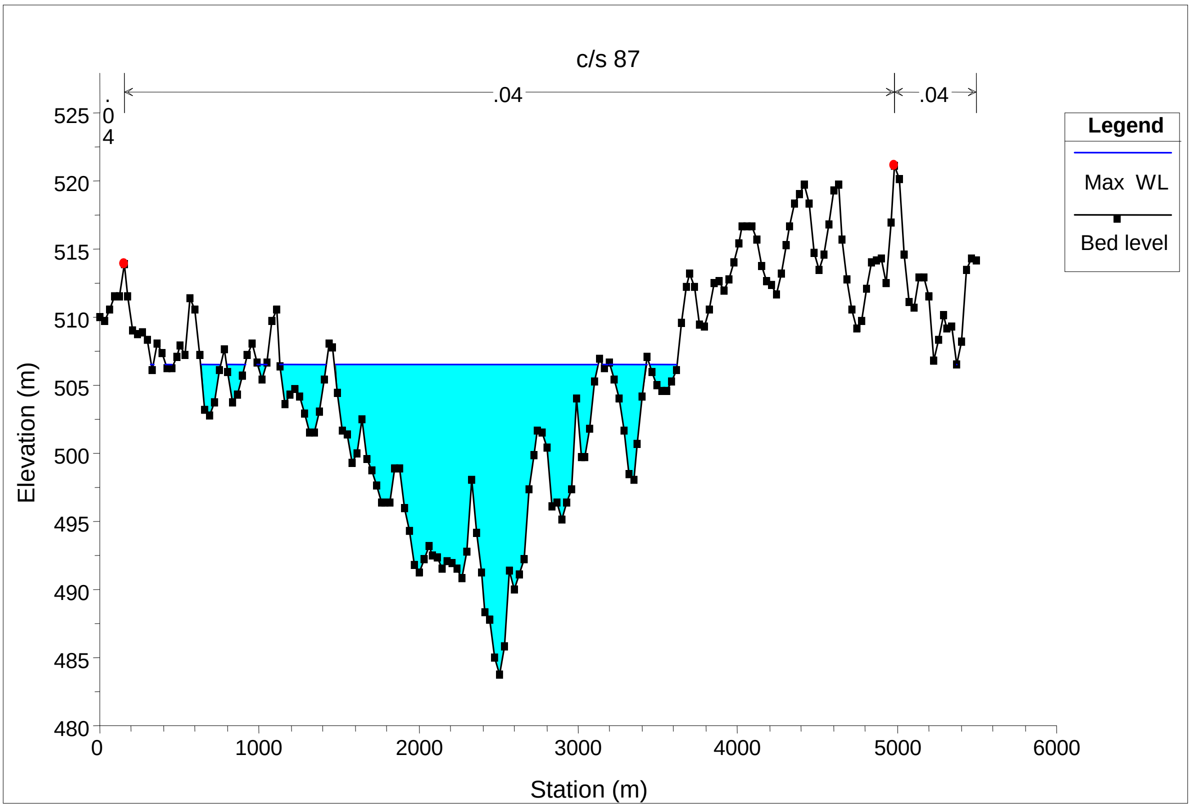

Figure 17: Cross Section of Kurelli Vaagu at 8356 m downstream of proposed dam showing maximum water level

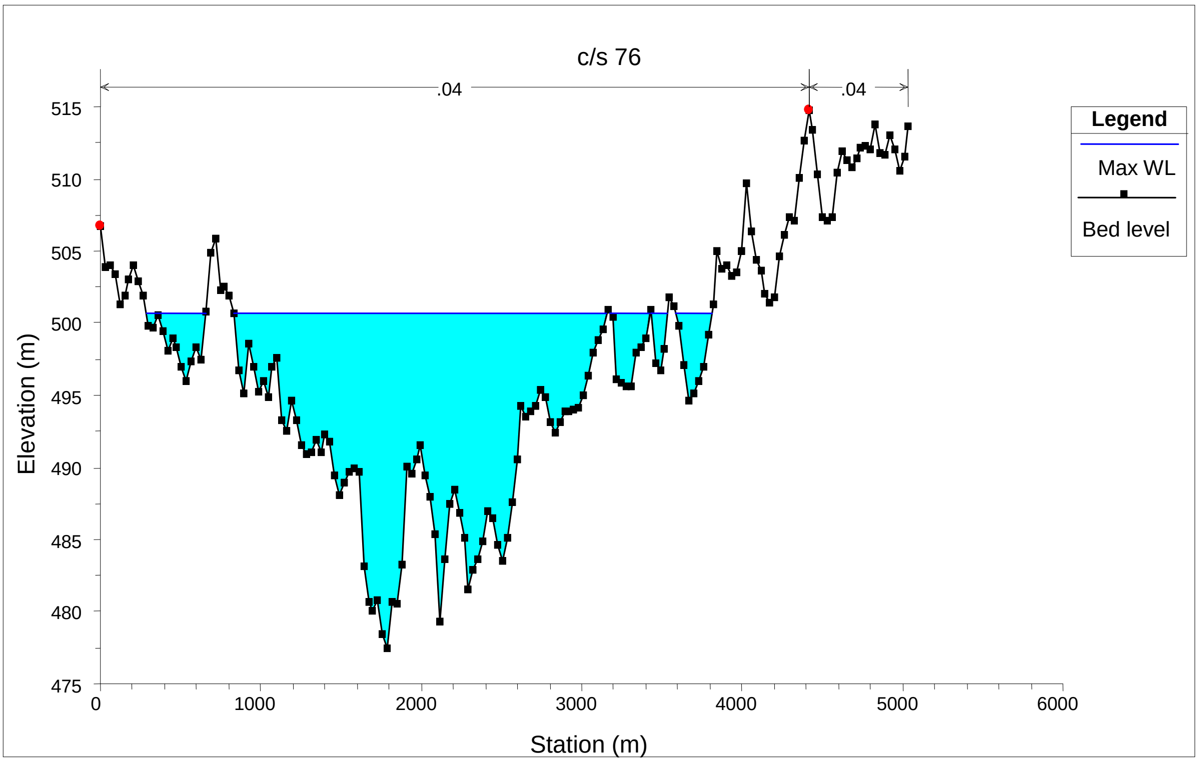

Figure 18: Cross Section of Kurelli Vaagu at 13519 m downstream of proposed dam showing maximum water level

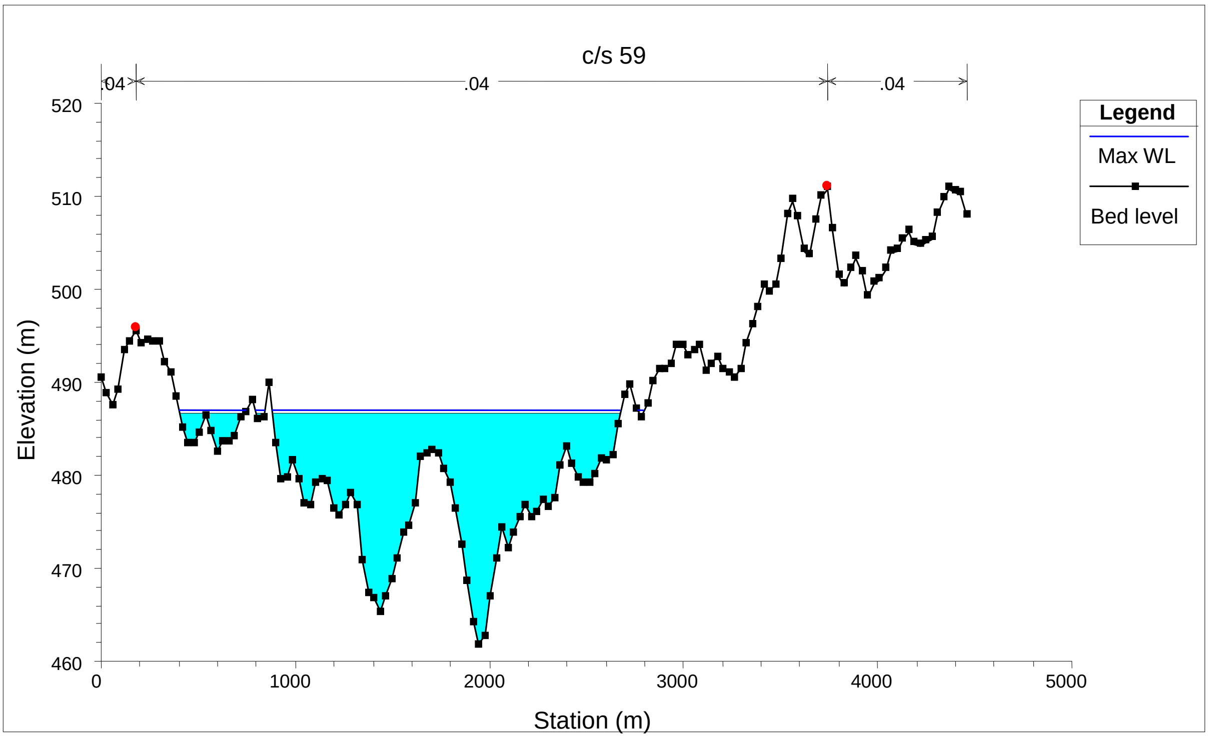

Figure 19: Cross Section of Kurelli Vaagu at 21049 m downstream of proposed dam showing maximum water level

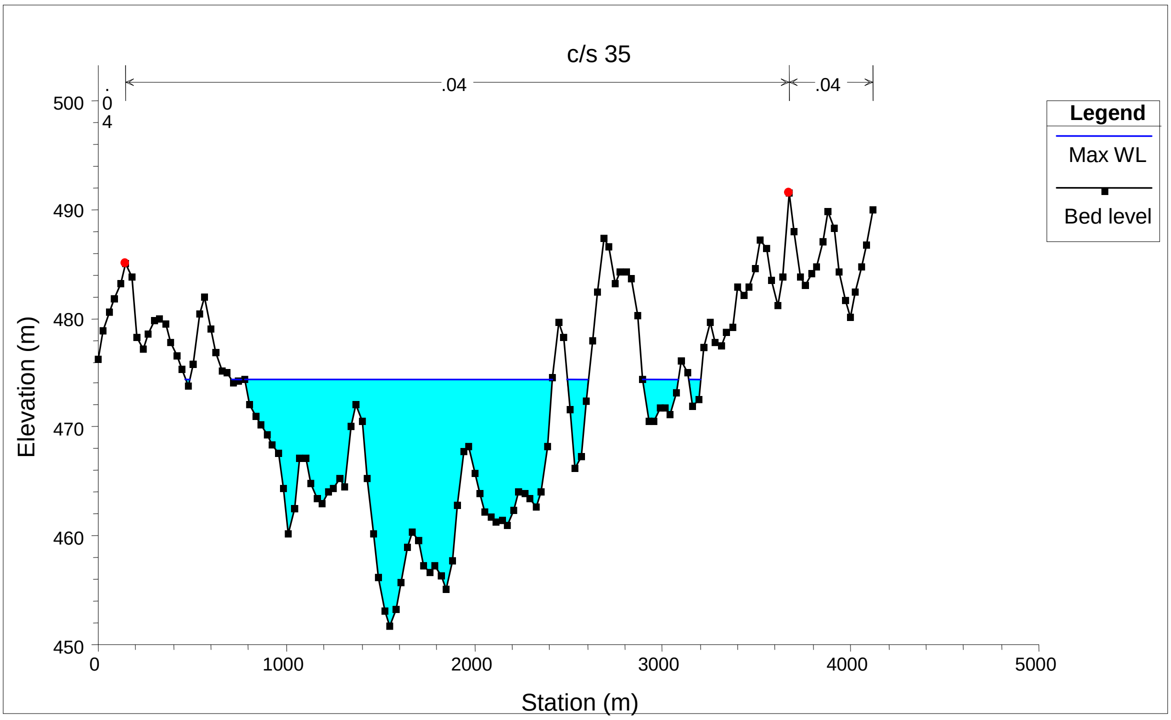

Figure 20: Cross Section of Kurelli Vaagu at 31613 m downstream of proposed dam showing maximum water level

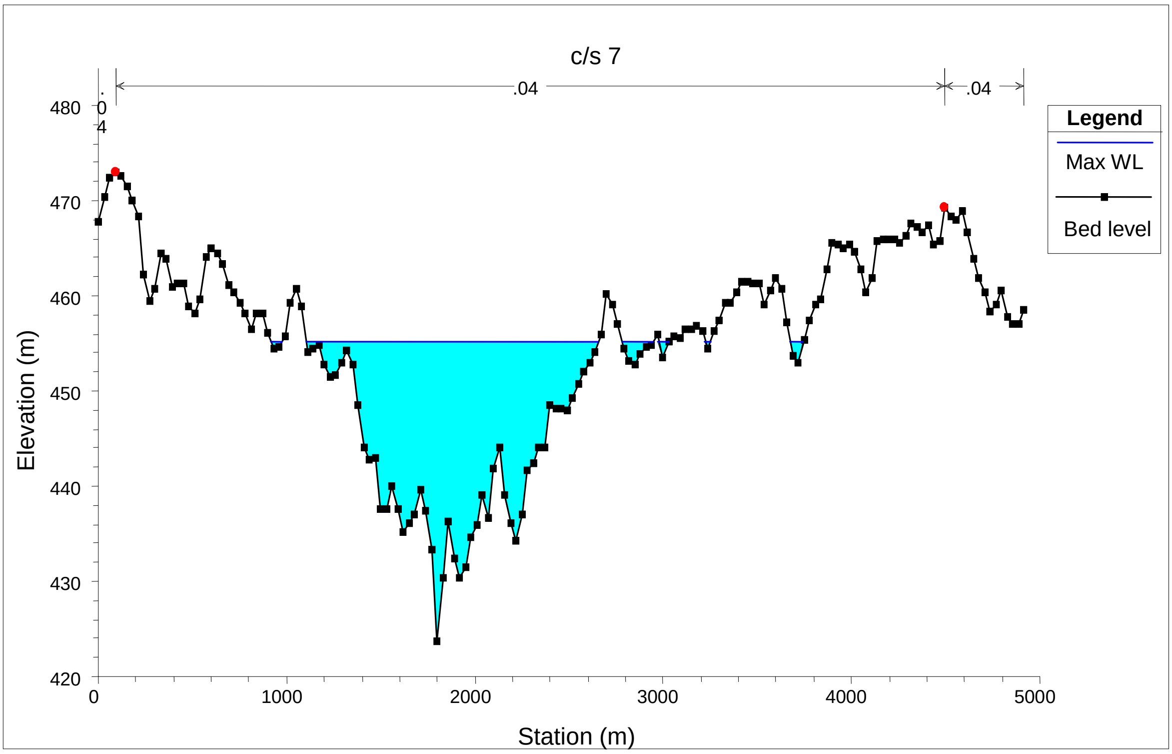

Figure 21: Cross Section of Kurelli Vaagu at 43358 m downstream of proposed dam showing maximum water level

10.0 INUNDATION MAP FOR THE WORST SCENARIO

The results estimated using 1-D mathematical model in HEC-RAS were further imported in ARC-GIS and Q-GIS for the preparation of inundation map for worst scenarios. The flood levels extracted from the water surface profiles were marked on the respective cross sections with reference to the contours using ARC-GIS. The flood levels were marked on the cross sections along the left and right banks of study reach of river Kurelli Vaagu. All marked flood points and cross sections of study reach were imported in to Q-GIS for the preparation of inundation map. The villages nearby the right bank and left bank of study reach were identified on topo map (1:50,000 scale). The locations of importance for flood rescue and evacuation had been identified and marked on flood inundation maps for emergency action planning for disaster management purpose. The details of the inundation maps for case1 is shown in Figure 22 and bifurcated into 4 parts A to D are shown in Figure 23 to fig 26 for more detail.

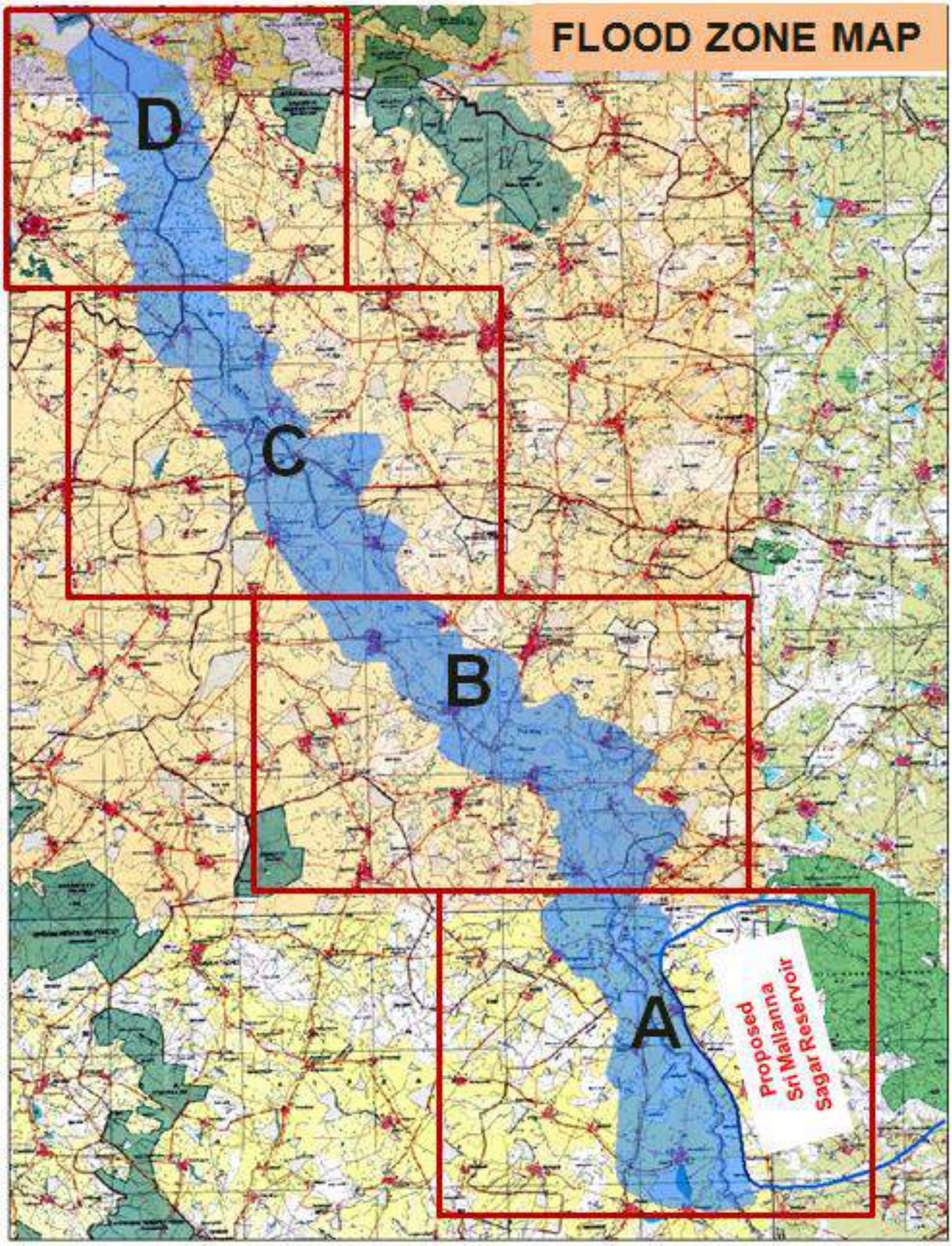

FIGURE 22: INUNDATION MAP OF MOST LIKELY FLOODING AREA UNDER STUDY FOR CASE 1

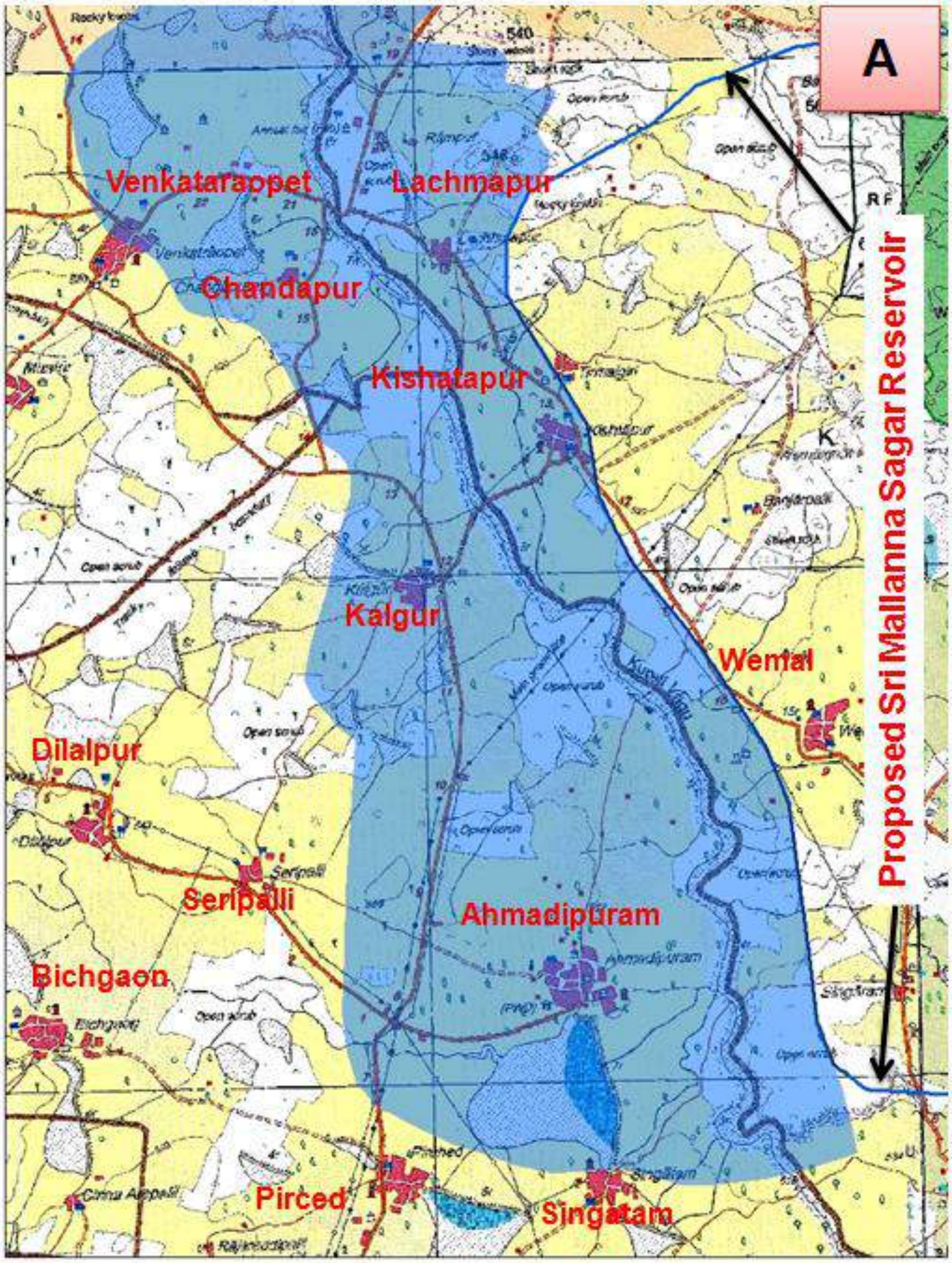

Figure 23: Detail of PART A of inundation map of most likely flooding area

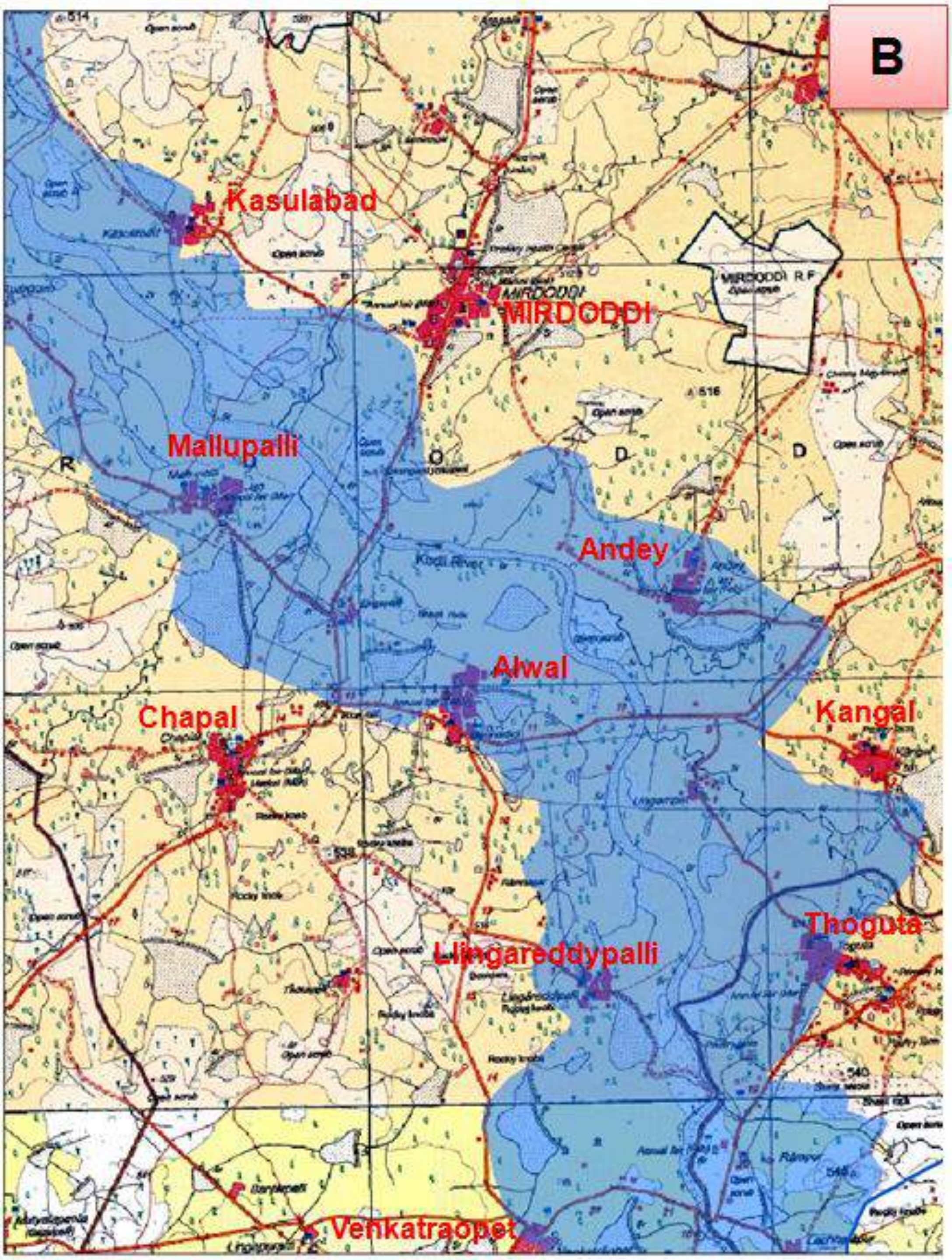

Figure 24: Detail of PART B of inundation map of most likely flooding area

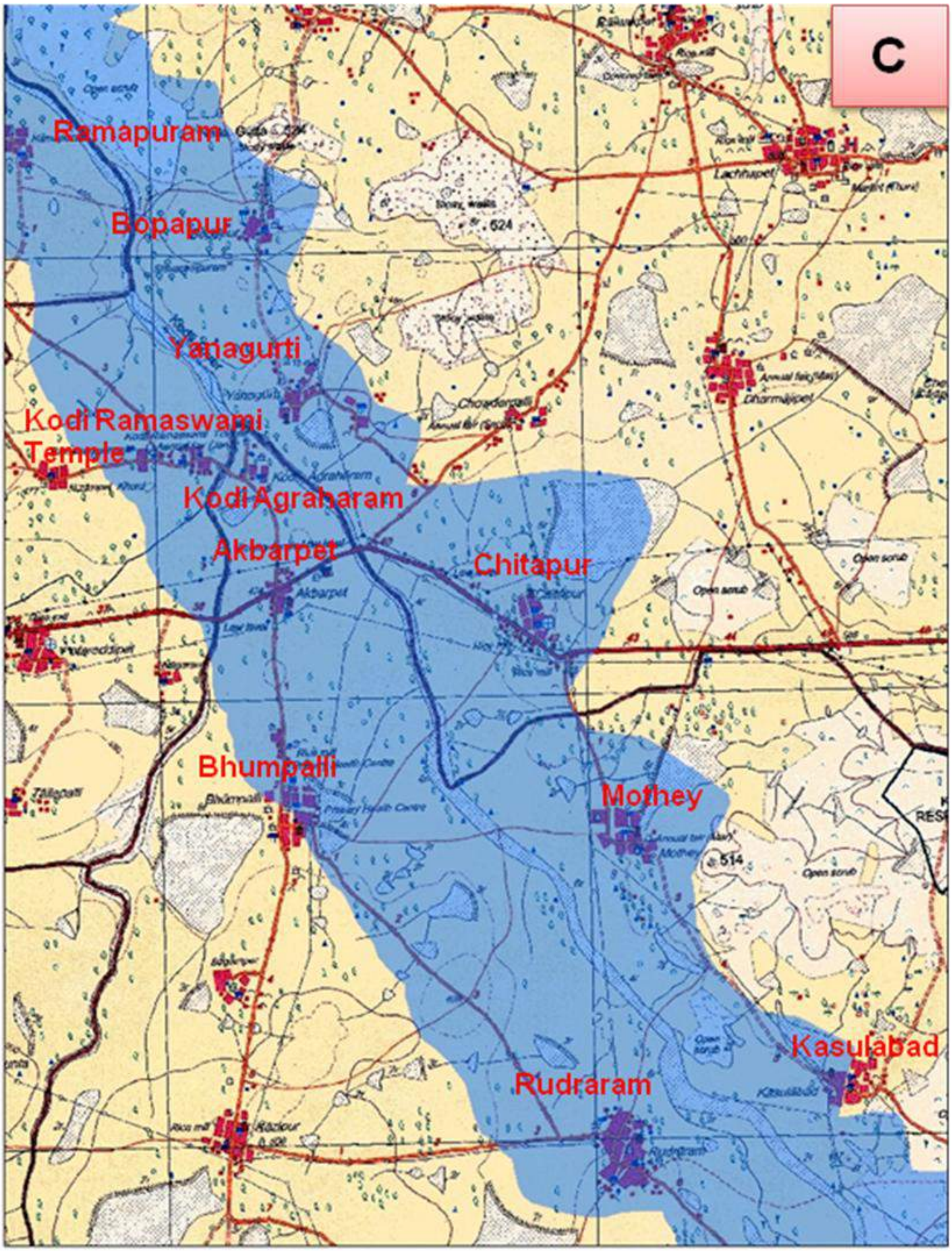

Figure 25: Detail of PART C of inundation map of most likely flooding area

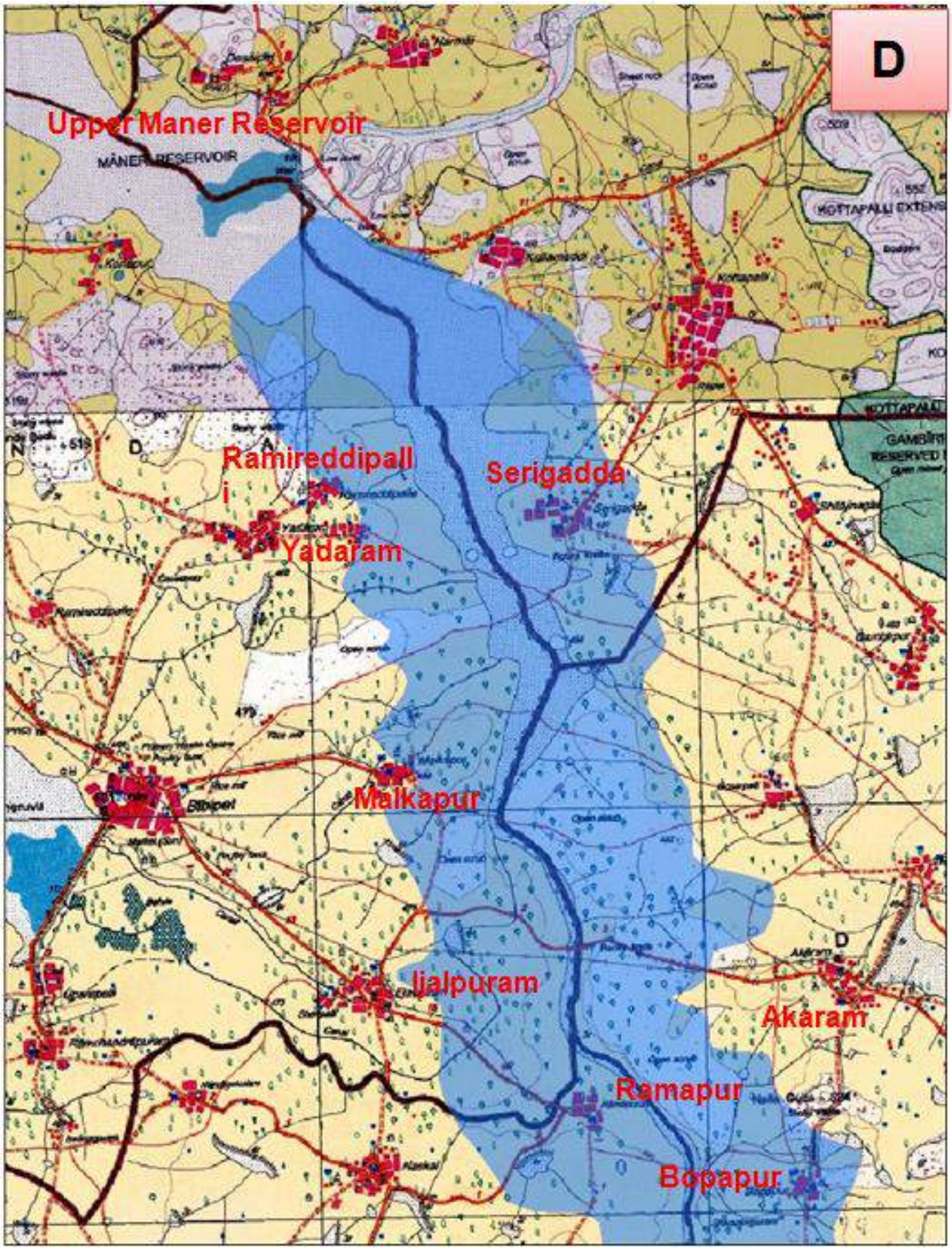

Figure 26: Detail of PART D of inundation map of most likely flooding area

11.0 EMERGENCY ACTION PLAN (EAP)

The general steps in developing an EAP are given below:

1. Identify those situations that would require initiation of an emergency action, specify the actions to be taken and by whom. An emergency may include such items as:
    - *A dam incident* - an abnormal condition or performance of the dam with the potential to endanger the safety of the dam but which is not expected to lead to a breach of the dam.
    - *A dam alert* - an abnormal condition or performance of the dam that, without swift and effective intervention could further degenerate with time and lead to a breach of the dam.
    - *A dam breach* - an actual breach or severe abnormal condition or performance of the dam that has a significant probability of leading to a breach of the dam.

2. Identify all jurisdictions, agencies and individuals including alternate who will be involved in implementing the EAP.
3. Identify primary and auxiliary communication systems, both internal (between persons at the dam) and external (between dam personnel and outside agencies).
4. Identify all persons and agencies involved in the notification process, and draft a notification flowchart which shows whom should be notified, in what order and what other actions are expected of downstream agencies. Each central, state and local government agency involved may have its own general emergency plan. This plan would normally require amendments to include actions required as a result of dam break flooding.

The inundation map prepared with the study results of Dam Break analysis can be utilised as base information for Emergency Action Plan for Disaster Management Planning.

Because of the method, procedures, and assumptions used to determine the flooded areas, the limits of flooding shown and flood-wave travel times are approximate and should be used only as a guideline for establishing evacuation zones. Areas inundated in an actual event will depend on actual failure conditions and may differ from areas shown on the maps.

The general guidelines for preparation of EAP in case of Dam Break is given as an APPENDIX may be referred.

12.0 CONCLUSIONS

Based on the analysis of result of mathematical model studies using available data following conclusions are made:

1. Dam Break Analysis (DBA) for proposed Sri Komaravelli Mallana Sagar has been carried out using 1-D Dynamic mathematical model HEC–RAS for different breach parameters.
2. For topographical data required for mathematical model, DEM of study area was downloaded from USGS site and processed using ARC-GIS. The cross sections of study reach were extracted from the DEM and used as input for the dam break model. Unsteady flow simulations were carried out for the upstream and downstream boundary conditions for 3 different cases of breaching time viz. 18, 30 and 60 minutes. In all these cases rectangular breach of 300m width up to bottom at the most vulnerable point had been considered for study.
3. Estimated Dam Breach flood hydrographs due to the breach of proposed dam under different scenarios (breach time) have been presented in this report.
4. The Kurelli Vaagu stream reach from Sri Komaravelli Mallanna Sagar upto Upper Maniar reservoir had been simulated considering appropriate roughness factor for Dam Break flood routing.
5. The predicted water surface profiles in figures and tables for all the 3 cases had been given in this report. The corresponding discharges and velocities are also presented in tabular form.
6. After reviewing the results of all three cases, the likely worst scenario was considered as case 1 where the breach time is 18 minutes.
7. For preparation of flood inundation maps for the study reach, required for the emergency action plan, the result of the worst scenario (case 1) has been used. The most probable flood inundation area have been demarcated on topo sheets of Survey of India (SOI) (1:50,000 scale) by the predicted water levels along the stream

and contours generated from DEM. As the inundation map generated has some inherent limitations and thus may be treated as a reference inundation map for EAP.

13.0 GENERAL LIMITATIONS

1) The cross sections and other topographical details of study reach of river were extracted from the SRTM 1 arc DEM downloaded from USGS site having resolution of 30m. It implies there is a limitation in the identification of topography of the area under study due to pixel size of sensor. Thus there can be inherent error in cross sections which may creep in some amount of uncertainty and may affect reliability of the final estimated flood levels to some extent.

2) It was postulated that the dam will breach in Rectangular shape with width and size of breach (300 m wide up to bottom) at the most vulnerable location with reference to some acceptable guidelines in this regard. The time of breach has been taken as 18 minutes for the worst case. The actual breach size and time cannot be identified precisely.

3) The results were superimposed on SoI topo map of scale 1:50,000 having contour interval of 20 m for preparation of inundation map.Toposheets of the scale 1:15000 or 1:25000 having 1m contour interval were not available for identification of villages and other critical locations for flood plain mapping as generally used in detailed Emergency Action Planning.

4) One-dimensional mathematical model has a limitation of providing only depth and discharge as output at every computational cross section along the river. In order to obtain a two dimensional map of the inundated area, one dimensional model results needs to be converted into two dimensional maps by interpolating outputs between 1D model cross sections, based on digital elevation maps. The interpolation process may introduce errors in unsteady simulations, especially over relatively flat terrain. In the case of highly transient flows, the interpolation process does not respect the mass conservation principle. This is an inherent limitation of the model used for this study.

ACKNOWLEDGEMENT

We wish to express our deep sense of gratitude to Dr. (Mrs.) V. V. Bhosekar, Director Incharge CWPRS for her encouragement and valuable suggestions during the course of this study. Our sincere thanks are due to S/Shri Hari Ram, C.E (Kaleshwaram Project), T.Venu, S.E (Project), Chandrasekhar, S.E (Design), K.N. Anand, E.E (Project), Srinivas, E.E (Design) and their staff for their support and co-operation during site visit and discussions. Efforts extended in assisting data processing and preparation of report by staff members of Surface Water Hydraulics Division, CWPRS are appreciated.

REFERENCES

1. Chow, V. T. (1959), “Open Channel hydraulics”, Tata McGraw-Hill, Inc. New York
2. U.S. Army Corps of Engineers, USACE (August 2014), “Using HEC-RAS for Dam Break Studies” (TD-39)
3. U.S. Army Corps of Engineers, USACE (2016) version 5.0.3, “HEC-RAS River Analysis System, Hydraulic Reference Manual”, Hydraulic Engineering Center Report CPD-69, Davis, CA
4. Central Water Commission, MoWR,RD & GR, Govt. of India (Feb 2016), “Guidelines for Developing Emergency Action Plans for Dams”

APPENDIX

GUIDELINES FOR PREPARATION OF EMERGENCY ACTION PLAN (EAP) FOR DISASTER MANAGEMENT PLANNING

1.0 INTRODUCTION

The increasing use of the risk assessment process as a planning and decision-making tool has highlighted the need for improved embankment breach analysis tools. Risk assessment analyses of Reclamation dams consider all possible loadings and failure scenarios for a dam, the probability of those loadings and sequences of events needed to cause failure and the consequences of failure. The development of effective emergency action plans and design of early warning systems might reduce or eliminate consequences of failure.

An EAP is a formal written plan that identifies the procedures and processes to be followed by the dam authorities in the event of an emergency at a dam. The emergency could be failure of essential components such as spillway and sluice gates, slope failure which may cause failure of dam, or a complete failure of the dam caused due to overtopping, earthquake or piping. By its nature EAP is site specific.

The identification of whether a dam poses a hazard to downstream areas and, hence requirement of a formal EAP is desirable. For example, a large dam retaining a large volume of storage within a confined valley containing significant habitation would clearly need an EAP. Conversely, a small dam in a relatively uninhabited area usually would not. If inhabited areas are potentially affected, a EAP must be prepared.

The consequences should be assessed in terms of loss of life, economic value of other losses, damage to property, facilities, and other utilities of the dam, loss of power generation, irrigation, water supply or tailing storage. Other consequences related to environmental, social and cultural aspects which cannot be described in economic terms, may require consideration on a site specific basis subject to any applicable regulatory approval process. Estimation of potential losses both with and without dam failure should be based on inundation and other studies and considers existing and anticipation future downstream development and land uses. For dams where there is an uncertainty about the consequences of a dam break, a simplified and conservative analysis should be used to make a preliminary assessment. If this analysis demonstrates a potential hazard a more sophisticated analysis should then be undertaken.

2.0 UTILISATION OF DAM BREAK ANALYSIS FOR PREPARATION OF THE EAP

For the preparation of Disaster Management Plan, the results of the Dam Break analysis need to be extracted along the following lines:

- Prepare plan showing inundated area on a contour map drawn to a suitable scale usually ranging from 1:15,000 to 1:25,000 with the contour interval of 1 to 2 m depending upon the area covered.
- Mark cross sections used for study in the plan
- Mark HFL at the cross sections
- Mark important towns, structures etc.
- Mark ground levels at important locations
- Prepare a statement showing the maximum depth of water at important locations
- Prepare a statement showing the time taken by the wave front to travel from the dam site to various locations.
- Prepare a statement showing the time taken to reach the maximum water level at the locations.
- Prepare stage hydrographs and discharge hydrographs
- Prepare a statement showing the total duration of inundation
- Indicate clearly the areas where the flood velocities are likely to be high

3.0 DEVELOPMENT OF EMERGENCY ACTION PLAN (EAP)

The steps in developing an EAP generally are as below:

1. Identify those situations that would require initiation of an emergency action, specify the actions to be taken and by whom. An emergency may include such items as:

- *A dam incident* - an abnormal condition or performance of the dam with the potential to endanger the safety of the dam but which is not expected to lead to a breach of the dam.
- *A dam alert* - an abnormal condition or performance of the dam that, without swift and effective intervention could further degenerate with time and lead to a breach of the dam.
- *A dam breach* - an actual breach or severe abnormal condition or performance of the dam that has a significant probability of leading to a breach of the dam.

2. Identify all jurisdictions, agencies and individuals including alternate who will be involved in implementing the EAP.
3. Identify primary and auxiliary communication systems, both internal (between persons at the dam) and external (between dam personnel and outside agencies).
4. Identify all persons and agencies involved in the notification process, and draft a notification flowchart which shows whom should be notified, in what order and what other actions are expected of downstream agencies. Each central, state and local government agency involved may have its own general emergency plan. This plan would normally require amendments to include actions required as a result of Dam Break flooding.
5. Develop a draft of the EAP

4.0 Central Water Commission (CWC) Guidelines for preparation of EAP

The *Guidelines for Developing Emergency Action Plans for Dams (2016)* prepared by CWC describes all elements of an EAP and comprehensively covers requirements for notification flow charts, emergency conditions, inundation maps, emergency detection, evaluation and classification, emergency preparedness and implementation methodologies. Managing the contingencies caused by a failure of a dam or by uncontrolled release of water due to flooding, requires coordinated efforts of both dam owning/operating agencies and also disaster management authorities, namely District Magistrate/Collector, Armed Forces, Paramilitary Forces, Project Authorities and other Central/State Agencies. An EAP also contains inundation maps to show the disaster management authorities the critical areas for providing necessary relief and taking rescue actions in case of an emergency. For these reasons, EAPs provide a mechanism for coordination among all the agencies and defines their roles and responsibilities and the actions to be taken to minimize loss of life and damage to environment and property.

The EAP guidelines also provide a template for emergency action plans to facilitate dam authorities in developing their EAPs in a consistent way. All dam authorities in India are advised to use these guidelines for developing EAPs for their dams, or for updating their existing EAPs, and for implementing them. In a nutshell, it outlines “who does what, where, when and how” in an emergency situation or unusual occurrence affecting the dams.

The primary goal of the Central Dam Safety Organisation (CDSO) of the Central Water Commission (CWC) is to encourage and facilitate dam safety practices that will help ensure operation of dams to their full capacities and intended purposes, and also to reduce the risk to lives and property from the consequences of both structural and operational dam incidents and failures. Although most dam authorities have a high level of confidence in the structures they own and are certain their dams will not fail, history has shown that on occasion dams do fail and that often these failures cause extensive damage to property, and sometimes loss of life. Dam authorities are responsible for keeping these threats to acceptable levels. A carefully conceived and implemented Emergency Action Plan (EAP) is one positive step dam authorities can take to accomplish dam safety objectives, protect their investments, and reduce potential liabilities.

An EAP for a dam is a written document prepared by the dam authorities, or the dam operator, describing a detailed plan to prevent or lessen the effects of a failure of the dam or appurtenant structures. An emergency action plan is not a substitute for proper maintenance or remedial construction, but it facilitates recognition of dam safety problems as they develop and establishes nonstructural means to minimize the risk of fatalities and reduce property damage.

The EAP is intended to interface with the emergency operation plans of other Local, District and State agencies to ensure effective and timely implementation of response action. Every EAP has to be thus tailored to site-specific conditions and to the requirements of the dam owning/ operating agency and the local emergency management authorities. These guidelines define the requirements of an acceptable EAP and facilitate its preparation, distribution, annual update, testing, and periodical revision.

Emergency action plans proposed by the Dam Safety Bill, 2010 (introduced in the Lok Sabha on August 30, 2010) will be put into effect as and when conditions arise that are likely to be hazardous to a dam or potentially hazardous to public safety, infrastructure, other property, or the environment.

4.1General Procedure for Developing an EAP:

Development of an EAP generally follows the steps listed below.

Step 1. Determine the potentially inundated area by defining flood profiles downstream from the dam for conditions that may include the following:

- Dam failure with the reservoir level at normal storage elevation (a so-called “fair weather” failure).
- Inflow design flood both with and without dam failure.
- Extremely large spillway flows resulting from severe weather and emergency conditions.

Step 2. Prepare inundation maps that clearly depict the flooded areas from a dam failure. The time of arrival of wave front, maximum depth of inundation, and maximum velocity of flow may also be estimated for areas of high impact. For dams with limited downstream development, a generalized inundation map and narrative description may suffice.

Step 3. Identify situations or events that could trigger an emergency condition and require action.

Step 4. Evaluate the warning time available for the various triggering events.

Step 5. Identify all jurisdictions, agencies, and people who will be involved in the EAP. Contact the local District Disaster Management Authority (DDMA) / District Collector for assistance. Coordinate the development of the EAP with all involved parties.

Step 6. Identify primary and auxiliary communications systems, both internal (between persons at the dam) and external (between dam personnel and outside entities).

Step 7. List all the persons and entities that need notification in case of dam distress, prioritize the order of notification, and draft the notification flowcharts.

Step 8. Develop a draft of the EAP.

Step 9. Hold one or more coordination meetings with all local agencies and other parties on the notification list to receive their review and comments on the draft EAP.

Step 10. Submit a draft to the State Dam Safety Organization (SDSO) for review. For dams of national importance, the CDSO may be approached for review.

Step 11. Make any necessary revisions, obtain the necessary signatures for plan approval, and distribute the EAP to those who have responsibilities under the plan (EAP to include the Distribution List). Information about the EAP may also be made available on the websites of dam authorities / operator and the SDSO.

Step 12. Update the EAP annually for correcting the contact addresses, and share the updates with all concerned as per EAP Distribution List. Carry out a tabletop drill to test the efficacy of EAP at least once every five years. Revise the EAP, as and when required, in line with the outcomes of tabletop drill or the implementation hurdles observed during actual extreme events or other emergencies.

4.1 Outline of the EAP Five-Step Response Process:

Five steps should generally be followed when an unusual or emergency incident is detected at a dam. These steps constitute the EAP response process as outlined below:

Step 1. Event Detection

Step 2. Emergency Level Determination

Step 3. Notification and Communication

Step 4. Actions to be Taken

Step 5. Termination and Follow-up

The five steps to take during an unusual event or emergency are illustrated in the flowchart shown in Figure 1. Responses for each alert type (Internal Alert for **BLUE** level emergency, or External Alert for **ORANGE** or **RED** level emergencies) contain all five steps. Depending on the type of alert to be issued, these steps will contain different notification lists and procedures. Careful preparation and review of all five steps will provide guidance during an unusual event or emergency.

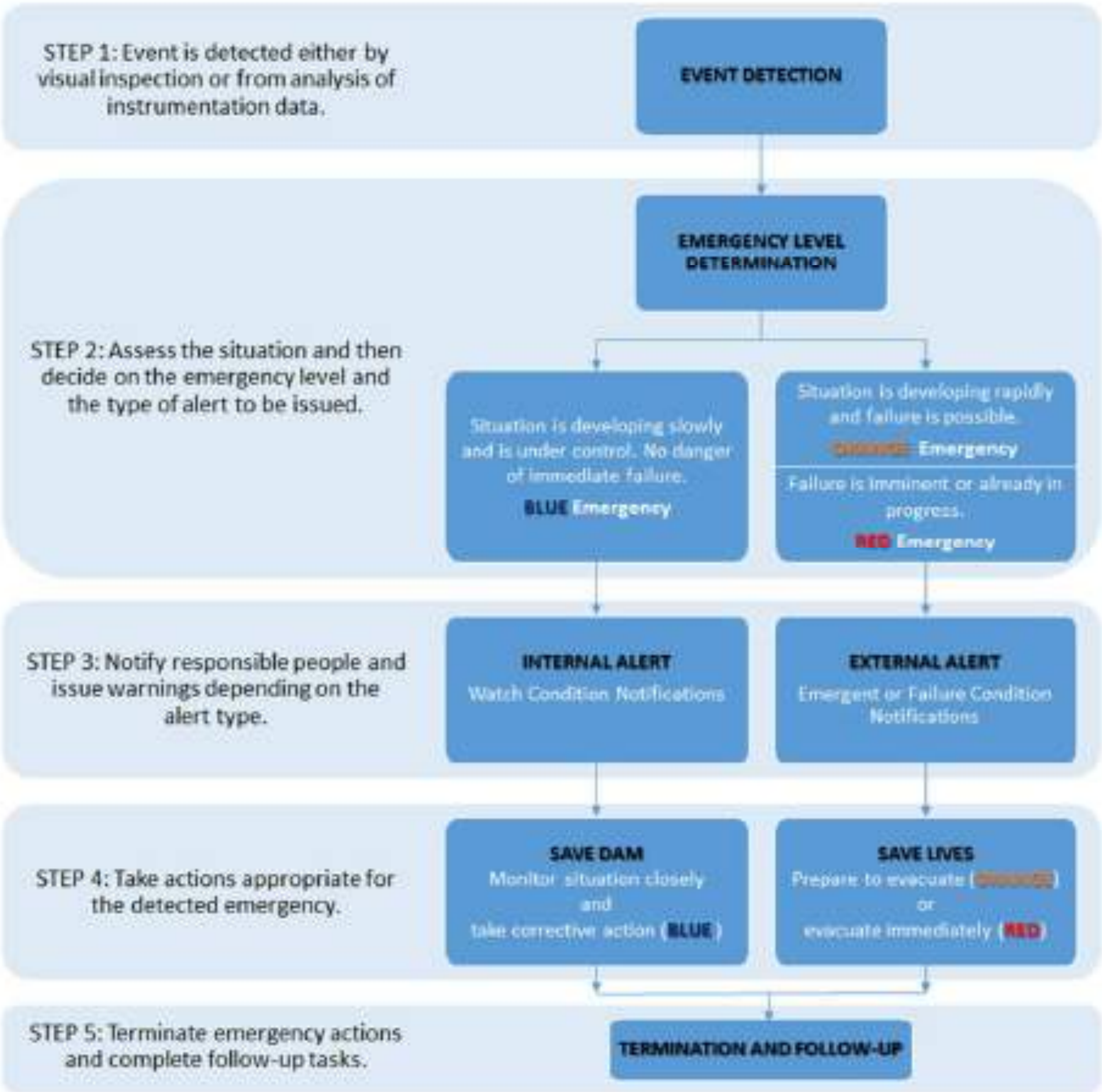

Figure 1: Flowchart showing the five-step response process of an EAP for a dam.

Table 1: Description of Emergency Alert Levels and Notification Types

Type of alert	Emergency level	Situation	Actions to be taken
INTERNAL ALERT (Watch Condition Notifications)	**BLUE**	Existence of anomalies or events that are either harmless or might compromise to some degree the structural or operational safety of the dam or the dam observation system. The situation is stable or is developing extremely slowly. Existing problems must lead to the belief that no serious consequences are expected downstream of the dam, and impacts (if any) will be small and confining to immediate downstream areas of the dam. Events leading to such a slowly developing situation include the following: 1. Existence of adverse meteorological conditions; 2. Existence of minor foundation problems	1. Issue Watch Condition notifications with a **BLUE** emergency level alert. 2. Monitor situation closely. 3. Take corrective measures to solve the problem
EXTERNAL ALERT (Failure Condition Notifications)	**ORANGE**	Situations with a high probability of dam failure, with the belief that it might not be possible to control the situation and might cause serious consequences downstream of the dam. Events leading to such a rapidly developing situation include the following: 1. Detection of severe anomalies in- dam structural elements, or- in dam operational elements 2. Existence of severe foundation problems 3. Occurrence of extremely large floods Under these conditions the dam authorities or operator might call for assistance from outside agencies. "Some amount of time" will be available for analysis, decisions, and mitigation before off-site impact will probably occur.	1. Issue Failure Condition notifications with an **ORANGE** emergency level alert. 2. Take corrective emergency measures to solve the problem. 3. Warning – Population downstream of the dam to prepare for evacuation.
	RED	Situation of inevitable catastrophe described asfollows: 1. Imminent dam failure because of flood waters overtopping the dam crest, or appearance of large flows through channels (piping) eroded through the embankment. 2. Dam failure in progress. No time will be available for analysis, decisions, and mitigation to be made before downstream impacts occur	1. Issue Failure Condition notifications with a **RED** emergency level alert. 2. Issue the most severe evacuation warning. Focus on evacuating first those most at risk. 3. Warning – Immediate evacuation.

Table 2: Description of Authorities and Actions to be taken at different Alert levels

Sl. No.	Alert Level	Official / authority responsible	Response / Actions to be taken
1.	**BLUE**	Dam Operation Office, Manager (Civil), PCD	1. Measures to solve problem. 2. Give internal alert signal of blue level. 3. Inform to: a. Dam Supervisor, AGM (PC) b. Dam authorities, CMD, M/s KIOCL
		Dam Supervisory Office, AGM (PC) /Dam authorities	Get full report and satisfy himself / herself regarding appropriateness of the measures being taken to solve the problem.
2.	**YELLOW**	Dam Operation Office, Manager (Civil), PCD	1. Measures to solve problem. 2. Give internal alert signal of blue level. 3. Inform to: a. Dam Supervisor, AGM (PC) b. Dam authorities, CMD, M/s KIOCL
		Dam Supervisory Office, AGM (PC) /Dam authorities	1. Get full report and satisfy himself / herself regarding appropriateness of the measures being taken to solve the problem. 2. Seek expert advice, if considered necessary. 3. Inform civic administration / local disaster management authority for their preparedness.
3.	**ORANGE**	Dam Operation Office, Manager (Civil) / Dam Supervisory Office, AGM (PC) /Dam authorities	1. Measure to solve problem. 2. Give external alert signal of orange level 3. Review preparedness as per para 2.5. 4. Inform to (a) District Collector & S.P. (b) State Flood Control Cell Warning – Population downstream the dam to be ready for evacuation
		Local Disaster Management Authority	1. Review preparedness as per para 2.5 2. Inform all officers responsible for District Disaster Management for preparedness 3. Inform all residents of affected regions through their leaders / representatives / local radio / wireless etc.
4.	**RED**	Dam Operation Office, Manager (Civil) / Dam Supervisory Office, AGM (PC) /Dam authorities	1. Give external alert signal of red level. 2. Inform to: (a) Local Disaster Management Authority (b) State Flood Control Cell Warning - Population downstream of the dam to evacuate quickly.
		Local Disaster Management Authority	1. Take actions as per para 2.5. 2. Get all officers responsible for District Disaster Management in action. 3. Inform all residents through their leaders / representatives / local radio / wireless etc. 4. Initiate search, rescue and relief operations

4.2 Elements of an EAP:

At a minimum, an EAP needs to contain the following items:

- title page
- purpose
- general description of dam
- responsibilities
- notification flowcharts
- inundation maps
- possible emergency conditions
- preventive actions to be taken
- supplies and resources
- implementation procedures

4.3 Dam Safety and Maintenance Manual:

Based on standard recommended guidelines for the safety inspection of dams a manual should be prepared by the project proponents in respect of dam safety surveillance and monitoring aspects. This should be updated with the availability of instrumentation data and observation data with periodical review. The need for greater vigil has to be emphasized during first reservoir impoundment and first few years of operation. The manual should also cover on the routine maintenance schedule of all hydro-mechanical and electrical instruments. It should cover quantum of specific construction material needed for emergency repair along with delineation of the suitable locations for its stocking and also identify the much needed machinery and equipment for executing emergency repair work and for accomplishing the evacuation plan.

4.4 Administration and Procedural Aspects:

The administrative and procedural aspects of the Emergency Action Plan consist of flow chart depicting the names and addresses of the responsible personnel of project proponent and the District Administration. In order of hierarchy, the following system will usually be appropriate. In the event that the failure is imminent or the failure has occurred or a potential emergency condition is developing, the observer at the site is required to report it to the Junior Engineer who will report to the Superintending Engineer/ Divisional Engineer for their reporting to the Chief Engineer through fastest available fastest communication system. The Engineer-in- Charge will keep the district administration informed regarding the developing situation. Each personnel are to acknowledge his/her responsibilities under the EAP in an appropriate format at a priority. The technical aspects of the EAP consist of preventive action to be taken with regards to the structural safety of the dam. The EAP is drawn at a priority for the regular inspection of the dam. For this purpose, providing an adequate and easy access to the dam site is a necessity. The dam, its sluices, overflows and non-overflow sections should be properly illuminated for effective operations during night time. Whenever sinkholes, boils, increased leakages, movement of masonry rock, gate failure, rapid rise or fall of the level in the reservoir, rise in the level of reservoir beyond the maximum working level, or wave overrun of the dam crest are observed, the personnel on patrol is required to inform immediately to the Assistant Engineer (AE)/Sub-Assistant Engineer (SAE) for initiation of the execution of EAP. They are required to inform the Engineer-in-Charge and the local administrative authorities. It is desirable that the downstream inhabitants are warned using siren, if available, so as to make them aware of the likely imminent danger.

4.5 Preventive Action:

Once the likelihood of an emergency situation is suspected, action has to be initiated to prevent a failure. The point at which each situation reaches an emergency status shall be specified and at that stage the vigilance and surveillance shall be upgraded both in respect of time and level. At this stage a thorough inspection of the dam should be carried out to locate any visible sign(s) of distress. Engineers responsible for preventive action should identify sources of equipment needed for repair, materials, labour and expertise for use during an emergency. The amount and type of material required for emergency repairs should be determined for dam, depending upon its characteristics, design, construction history and past behavior. It is desirable to stockpile suitable construction materials at appropriate sites. The anticipated need of equipment should be evaluated and if these are not available at the dam site, the exact location and availability of these equipments should be determined and specified. The sources/agencies must have necessary instructions for assistance during emergency. Due to the inherent uncertainties about their effectiveness, preventive actions should usually be carried out simultaneously with the appropriate notification on alert situation or a warning situation.

The other preventive measures may include availability of sufficient number of sandbags at several selected downstream locations and logs (for holding sandbags) and at the dam site, one tractor, two motor boats, gas lanterns, Manila ropes and life jackets. Areas from where the labour can be mobilized should be chalked out at a priority. In addition to these, public participation in the process of execution of the EAP may further help in amelioration of the adverse impacts of the likely disaster. For this, it is necessary that the public should be made aware of its responsibilities.

4.6 Communication System:

An effective communication system and a downstream warning system are absolutely essential for the success of an emergency preparedness plan. The difference between a high flood and dam-break situation must be made clear to the downstream population.

4.7 Evacuations Plans:

Emergency Action Plan includes evacuation plans and procedures for implementation based on local needs. These could be: - Demarcation / prioritization of areas to be evacuated. - Notification procedures and evacuation instructions. - Safe routes, transport and traffic control. - Safe areas/shelters. - Functions and responsibilities of members of evacuation team.

Any precarious situation during floods will be communicated either by an alert situation or by an alert situation followed by a warning situation. An alert situation would indicate that although failure of flooding is not imminent, a more serious situation could occur unless conditions improve. A warning situation would indicate that flooding is imminent as a result of an impending failure of the dam. It would normally include an order for evacuation of delineated inundation areas.

4.8 Evacuation Team:

The Engineer-in-Charge will be responsible for the entire operation including prompt determination of the flood situation time to time. Once the red alert is declared the whole state machinery will come into swing and will start evacuating people in the inundation areas delineated in the inundation maps. For successful execution, annually demo exercise will be done. The District Magistrare is to monitor the entire operation.

Public Awareness for Disaster Mitigation: In addition, give guidelines that have to be followed by the inhabitants of flood prone areas, in the event of flood resulting from dam failure, which form part of public awareness for disaster management.

4.9 Notifications:

Notification procedures are an integral part of any emergency action plan. Separate procedures should be established for slowly and rapidly developing situations and failure. Notifications would include communication of either an alert situation or an alert situation followed by a warning situation. An alert situation would indicate that although failure or flooding is not imminent, a more serious situation could occur unless conditions improve. A warning situation would indicate that flooding is imminent as a result of an impending failure of the dam. It would normally include an order for evacuation of delineated inundation area.

4.10 Notification Procedures:

Copies of the EAP that also include the inundation map are displayed at prominent locations, in the rooms and locations of the personnel named in the notification chart. For a regular watch on the flood level situation, it is necessary that the flood cells be manned by two or more people so that an alternative person is always available for notification round the clock. For speedy and unhindered communication, a wireless system is a preferable mode of communication. Telephones/cell phones may be kept for back up, wherever available. It is also preferred that the entire flood cells, if more than one, are tuned in the same wireless channel. It will ensure communication from the dam site to the control rooms. The communication can be established by messenger service in the absence of such modes of communication.

4.11 Management after receding of Flood Water:

It is to be accepted that in the event of dam break, even with maximum efforts, the loss of human lives, livestock and property would be inevitable. Under such a scenario, a massive effort would be taken by various government agencies to provide various relief measures to the evacuees.

4.12 Training:

Training of the people involved in the EAP should ensure that they are thoroughly familiar with all elements of the plan, the availability of equipment, and their responsibilities and duties. Again, the level of detail involved in training depends on the size and complexity of a dam. For small dams with simple EAPs, training may simply involve having responsible persons read the EAP and submit written confirmations annually.

In the case of larger, more complex dams, training will be much more involved. Schedule training for employees associated with the dam to familiarize them with the EAP by addressing the following elements of the plan:

- How to use the EAP;
- How to identify the severity of a problem;
- How to use the notification procedures and the communication equipment;
- What resources are available;
- The importance of employees' roles during emergencies; and
- The importance of updating downstream information.

Train enough people to guarantee adequate coverage at all times. Mock Drills simulating dam failures are excellent training mechanisms for ensuring readiness. It is advisable to cross-train people for more than one responsible position. Keep a record of training completed by key personnel.