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## **PREPARATION OF EAP FOR UKAI DAM USING 1D/2D COUPLED HYDRODYNAMIC MODELING AND GOOGLE EARTH IMAGE**

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### **ABSTRACT**

Ukai is the second largest masonry gravity Dam after Sardar Sarovar Dam in Gujarat. Surat, the diamond hub of India and 2<sup>nd</sup> largest city of Gujarat state is situated 100 km downstream (D/S) of Ukai dam and 19.4 km upstream (U/S) from Arabian Sea. Surat city experienced the catastrophic flood in 1933, 1959, 1968, 1970, 1994, 1998, 2006 and 2013. It is estimated that the single flood event during August 7-14, 2006 in Surat and Hazira twin-city, caused a heavy damage and low lying areas such as Adajan and Rander of Surat were under submergence up to 4-5 m during flood in the year 2006, resulted in the death of 300 people and property damage worth INR 21000/- crores. The peak discharge of 25,768 m<sup>3</sup>/s recorded was the highest in the history and was responsible for disastrous flood in Surat city. To prevent such type of catastrophic situation in future Surat Irrigation Circle (SIC) has suggested the Levees (structural measures) expansion to increase the discharge carrying capacity near Surat city and reduce the flood inundation in future. To estimate the flood inundation under the levees condition and prepare the Inundation map as per the guideline of Emergency Action Plans (EAP) for Dams, a study has carried out using the 1D/2D coupled HEC-RAS based hydrodynamic model. 299 surveyed cross sections after 2006 flood have been considered for 1D modelling whereas 30 m SRTM for Lower Tapi Basin and a topographic map at 0.5 m contour interval were used to produce a 5 m grid for Surat city for 2D modelling. The release from the Ukai dam in 2006 was considered as the U/S boundary and Tidal level was considered as the D/S boundary. The model is simulated under the unsteady flow condition and maximum water surface elevation, water depth, velocity and wave arrival time of extreme flooding condition is prepared under the Levees condition. At last, the flood inundation for extreme flooding condition is superimposed over Google Earth image. In future, inundation map contained from the EAP guideline will be available to dam owners to prepare the rescue action plan in case of a dam/ levees failures or extremely large release of dam water during severe weather conditions. It will provide the additional time to the decision making authority to take the appropriate life-saving decisions during flooding.

### **1 INTRODUCTION**

India has 5,247 large dams across the country, out of which 440 dams are under construction and 196 are over 100 years old (Times of India report dated on 27/09/2017). These dams stores the 300 billion cubic meters of water in total. In Gujarat 29 dams are over 100 years old. The Ukai dam, constructed in 1972 at Surat district, is 35 year old and is multipurpose dam. The Ukai reservoir at its Full Reservoir Level (FRL) of 105.15 m (345 ft) has live storage capacity of 7369 Mm<sup>3</sup> with the water

spread of about 600 km<sup>2</sup> and maximum length of about 112 km. The reservoir is expected to attain maximum water level (MWL) of 106.99 m (351 ft) while passing the Probable Maximum Flood (PMF) of 59,920 m<sup>3</sup>/s (21.16 lakh cusecs). Operation of multipurpose reservoir is very complicated task; release of uncontrolled or excessive large amount of water at downstream side leads a devastating flood. Therefore it is important to develop Emergency Action Plan (EAP) through hydrodynamic modelling to reduce the loss of life and property damage in case of dam fail or extreme flooding condition (CWC, 2016).

Now a days, many hydrodynamic models are available for 1D, 2D and 1D/2D coupled hydrodynamic modeling, which allows the simulation of different flood scenarios (Quiroga et al., 2016). Hence, numerical models are important tools for understanding flood events, flood hazard assessment and flood management planning. (Salimi et al., 2008) have integrated the Hydrologic Engineering Centre's-River Analysis System (HEC-RAS) simulation model and Geographic Information System (GIS) to get the areal extent and depth of flooding. Several researchers worked out to simulate accurate prediction of river flow and hydraulic behaviour of river channels by a number of hydraulic models such as MIKE 11, 1D HEC-RAS, 1D-2D HEC-RAS, RAS Mapper, INFOWORK, FLOW-R2D, HSPF, UNET, WMS, LISFLOOD-FP, TELEMAC-2D and River CAD (Castellarin et al., 2009, Tsakiris and Bellos, 2014, Bates et al., 2000, Rahman et al., 2011, Han, 2011). In addition to this, a number of professional and user friendly software viz. WOLF 2D, MIKE-11 (Danish Hydraulics Institute), SOBEK, DAMBRK (NWS), RUBICON, FLDWAV etc. have been developed for simplifying the dam break analysis routing (Changzhi et al., 2014, Lodhi and Agrawal, 2012, Xiong, 2011, Butt et al., 2013). Out of all these models, Hydrological Engineering Centres River Analysis System (HEC-RAS) is used worldwide and is public domain software.

To understand dam /levees breach or extreme flooding condition induced flood; Ukai dam at Gujarat, India is taken as a case study. Recently, the new HEC-RAS 5.0.3 has added the capability of 2D modelling along with 1D and it is freely available. Hence, it is a useful tool to construct 1D/2D coupled HEC-RAS based hydrodynamic model. This will provide the strong supportive evidence of the potentiality of new HEC-RAS 5.0.3 for flood inundation modelling. The assessment of the HEC-RAS with respect to this particular aspect will be an important step for the successful and improved development of the hydrodynamic model and thus can provide important assistance in building flood mitigation strategies like Emergency Action Plan (EAP) for any similar cased worldwide.

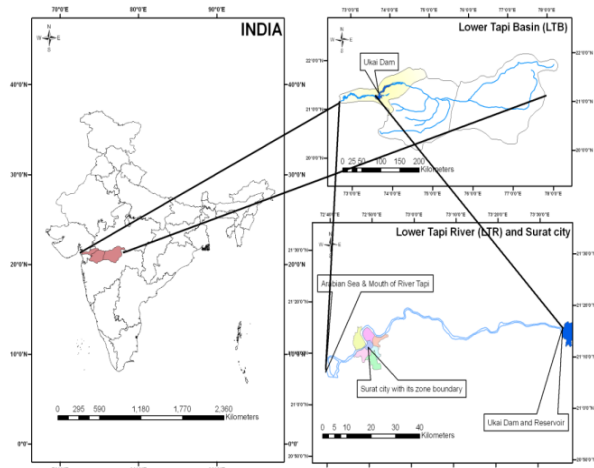
## **2 STUDY AREA AND METHODOLOGY**

### **2.1 Hydrologic Aspect**

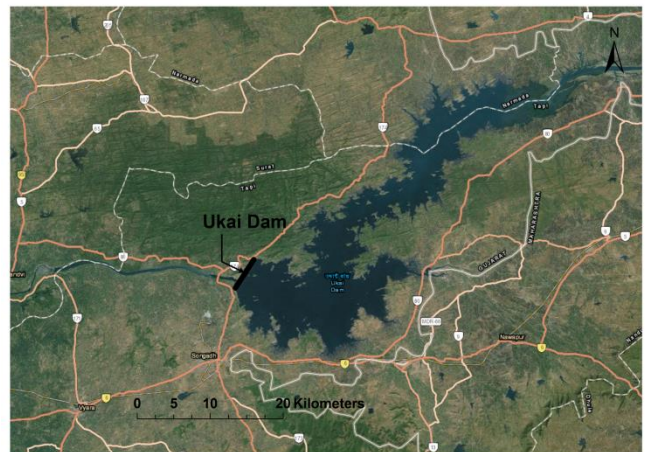
Tapi river has a total length of 724 km, out of which the 214 km is in Gujarat state and it meets the Arabian Sea in the Gulf of Cambay approximately at 19.2 km west of Surat city (Fig.1) (CWC, 2000-2001). The Lower Tapi river consists of 3 inline structures named Ukai Dam, Kakrapar weir and Singanpur weir as well as 5 major Bridges across river Tapi at Surat city (Patel and Srivastava, 2013). Ukai dam is a composite dam with maximum height of about 80.7 m above its deepest foundation level. The total length of dam is 4927 m of which 4058 m is earth dam of zoned fill type. Masonry gravity dam includes the 425 m long spillway. The spillway, located in the left bank of river, is provided with 22 no. of radial crest gates of 15.55 m X 14.78 m size. The maximum discharge capacity of the spillway at MWL is 46,270 m<sup>3</sup>/s (16.34 lakh cusecs) (Fig.2).

## 2.2 Surat city

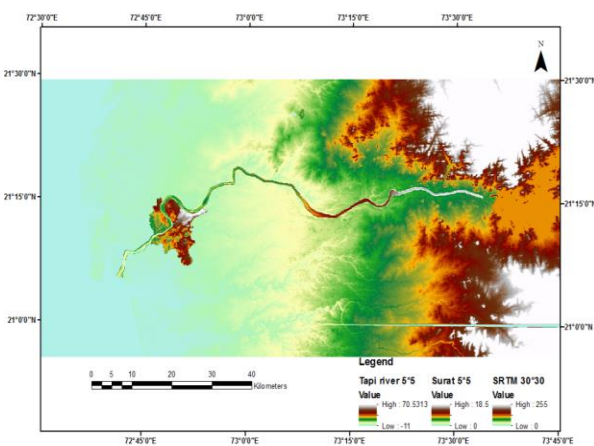
Surat city is located in Gujarat; it is known for its textile trade, diamond cutting and polishing industries, situated 100 km downstream of Ukai dam and 19.4 km upstream of the mouth of river Tapi. Surat is divided into 7 zones i.e. west zone, central zone, north zone, east zone, south zone, south east zone and south west zone (Fig.1). Its zone boundary covers 126.52 km<sup>2</sup> as per the SMC zone map of 2006. The Surat city is bounded by latitude 21° 06'' to 21° 15'' N and longitude 72° 45'' to 72° 54'' E (Fig. 1) and falls in Survey of India (SOI) map number 46C/15, 16. Surat had a population of 4.5 million in the 2011 census, making it the second largest city in the state of Gujarat, after Ahmedabad (<https://en.wikipedia.org/wiki/Surat>). The average annual rainfall of the city has been 1143 mm. The city has experienced the catastrophic floods in the years of 1933, 1959, 1968, 1970, 1994, 1998 and 2006. After the 2006 flood the Surat Irrigation department and SMC has carried out the embankment (levees) improvement work in and around Surat city. It is noted that a total of eight improvement schemes have been completed on the right bank whereas seven schemes have been completed at left bank side (Fig. 3-4). About 11,558 m and 8,700 m of bank protection work is completed on both the right and left banks of river Tapi. Approximately, INR 125.60 crores were spent on construction of embankments against the sanction amount of 146.00 crores.



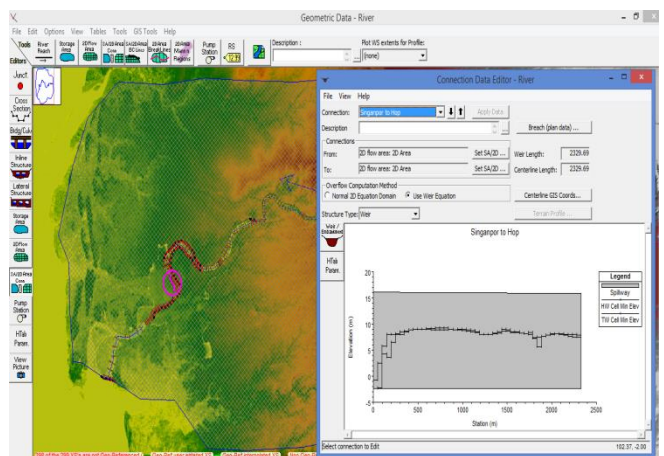
**Fig.1** Location of Tapi Basin, Lower Tapi basin, Ukai Dam, and Lower Tapi river with Surat city.



**Fig. 2** Vicinity map of Ukai Dam



**Fig. 3** DEM of Tapi river 5\*5, Surat 5\*5, SRTM 30\*30



**Fig. 4** HEC-RAS Geometry with Levees

## 2.3 Method and Modelling

In this study the unsteady, gradually varied flow simulation function of HEC-RAS is used, which depends on finite difference solutions of the Saint-Venant equations [Equations (1)-(2)].

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial(Q^2/A)}{\partial x} + gA \frac{\partial H}{\partial x} + gA(S_o - S_f) = 0 \quad (2)$$

here A = cross-sectional area normal to the flow; Q = discharge; g = acceleration due to gravity; H = elevation of the water surface above a specified datum, also called stage; S<sub>o</sub> = bed slope; S<sub>f</sub> = energy slope; t = temporal coordinate and x = longitudinal coordinate .

The work is further extended in the 1D/2D environment. The HEC-RAS 5.0.3 is fully solved in using the 2D Saint Venant equation (Quiroga et al., 2016, Manual, 2016, Brunner, 2016, Patel et al., 2017):

$$\frac{\partial \xi}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0 \quad (1)$$

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left( \frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left( \frac{pq}{h} \right) = - \frac{n^2 pg \sqrt{p^2+q^2}}{h^2} - gh \frac{\partial \xi}{\partial x} + pf + \frac{\partial}{\rho \partial x} (h\tau_{xx}) + \frac{\partial}{\rho \partial y} (h\tau_{xy}) \quad (2)$$

$$\frac{\partial q}{\partial t} + \frac{\partial}{\partial y} \left( \frac{q^2}{h} \right) + \frac{\partial}{\partial x} \left( \frac{pq}{h} \right) = - \frac{n^2 qg \sqrt{p^2+q^2}}{h^2} - gh \frac{\partial \xi}{\partial y} + qf + \frac{\partial}{\rho \partial y} (h\tau_{yy}) + \frac{\partial}{\rho \partial x} (h\tau_{xy}) \quad (3)$$

where h is the water depth (m), p and q are the specific flow in the x and y direction (m<sup>2</sup>/s), ξ is the surface elevation (m), g is the acceleration due to gravity (m/s<sup>2</sup>), n is the Manning resistance, ρ is the water density (kg/m<sup>3</sup>), τ<sub>xx</sub>, τ<sub>yy</sub> and τ<sub>xy</sub> are the components of the effective shear stress and f is the Coriolis (1/s<sup>1</sup>) (Quiroga et al., 2016, Patel et al., 2017)

Initially, a 2D computation mesh is generated for Lower Tapi basin. The 30 m x 30 m cell spacing is selected for 2D flow area generation for LTB for DEM (SRTM 30\*30) (Fig. 3) which generated the total 4484708 grid cells. At the second stage SA/2D Area connect option is used to locate the levees and retaining wall inside the of 2D flow areas (Fig.4). 11643.58 m and 10123.94 m long levees are created on right and left bank of Tapi surrounding Surat city. 1391.11 m and 6,606.2 m long retaining wall are created on right and left bank of Tapi. For 1D simulation, the release from the Ukai dam in 2006 (Flood Hydrograph) and Tidal level in the sea are considered for the upstream-downstream boundary conditions along with T.S. gate opening for Singanpur weir under the unsteady flow condition. Whereas flow hydrograph (Ukai dam release) and stage hydrograph (Tidal level) is considered for upstream and downstream boundary conditions for 2D simulation. The roughness resistance was estimated based on supervised classification scheme in ERDAS IMAGINE 10. In order to ensure the stability of the model, the time steps were estimated according to the Courant-Friedrichs-Lewy condition (Manual, 2016, Brunner, 2016, Patel et al., 2017):

$$C = \frac{V\Delta T}{\Delta x} \leq 1.0 \text{ (With maximum } C = 3.0) \quad (4)$$

Or

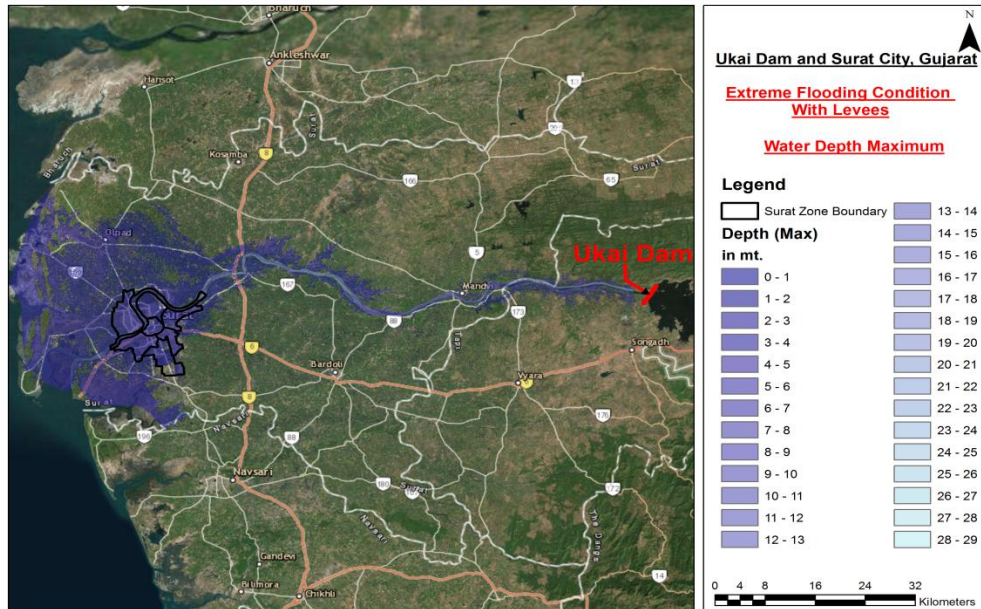
$$\Delta T \leq \frac{\Delta x}{V} \text{ (With } C = 1.0) \quad (5)$$

where, C is the Courant Number, V is the flood wave velocity (m/s), ΔT computational time step(s) and Δx is the average cell size (m) (Brunner, 2016). The model is simulated under the unsteady flow condition and the flood inundation (depth), flood velocity, water surface elevation (WSE), arrival time, duration for each hour are obtained.

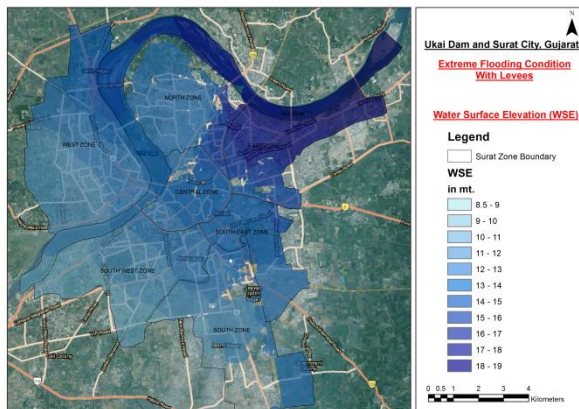
### 3 RESULT AND ANALYSIS

#### 3.1 Flood Inundation Map Superimpose on Google Earth Image

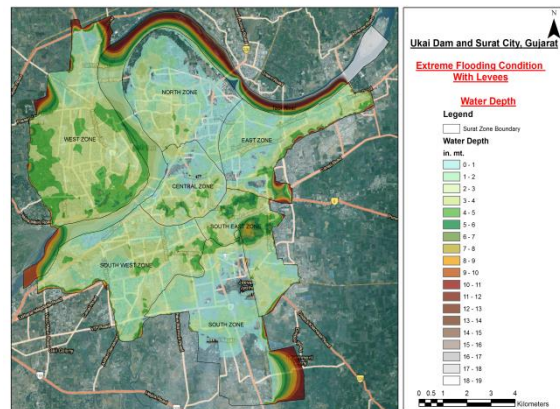
HEC-RAS 5.0.3 is being used to run the extreme flooding event. Water release  $25768 \text{ m}^3/\text{s}$  in 2006 flood is considered for preparation of Water Surface Elevation, Water Depth, Velocity and Arrival time under the Levees condition (Fig. 5-9).



**Fig. 5** Maximum Water Depth map for Ukai Dam, Lower Tapi Basin



**Fig. 6** Maximum Surface Elevation map for Surat city



**Fig. 7** Maximum Water Depth map for Surat City

Fig. 5 shows the maximum water depth from Ukai dam to Surat city. For further exploring the possibility of inundation and identify the probable area, road, street and known milestone the entire simulation is super imposed on Google Earth Image. It has been seen that the west zone is the low lying area of Surat city and areas of Rander, Usmani park, Choksiwadi, Yoginagar and Adajan near Morarji Road is under inundation of 4-5 m (Fig. 6-7) , corresponding released of  $25768 \text{ m}^3/\text{s}$ . Similar the centre zone is under inundation of 2-3 m (Fig. 7) . Velocity of water is marked 0.51 m/s in west zone from Singanpurweir to in downstream at Sardar bridge, whereas at upstream maximum velocity was 1m/s. In south, south east, south west, east and north zones maximum velocity observed was 0.51 m/s (Fig. 8). Looking to lower velocity in major part of flood prone area, water was retained and will be affected the people and their valuables significantly.

It has been seen from the analysis and observed map, the west zone, south west zone and central zone are low lying areas. The 84 % area of west zone is under inundation at the discharge of  $10101 \text{ m}^3/\text{s}$

released from the Ukai. The simulated results show that the west zone has the maximum chance to get flooded in such a future flood event whereas the North zone is safe.

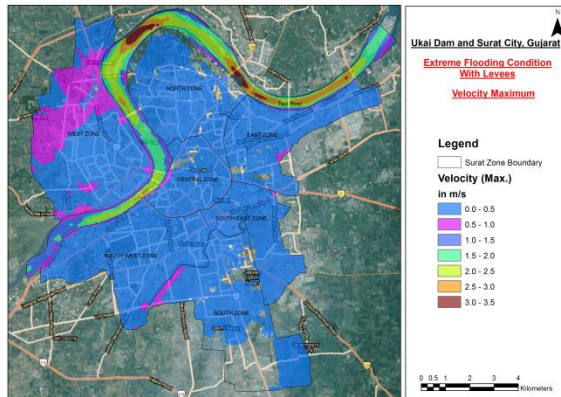


Fig. 8 Maximum Velocity map for Surat City

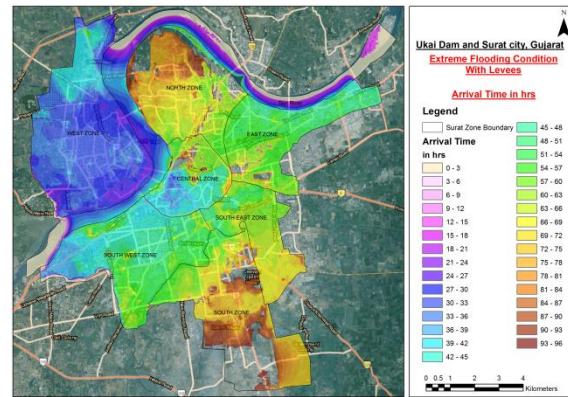


Fig. 9 Maximum Arrival Time map for Surat City

To prepare the detail EAP and evacuate the people from low lying area, it is important to identify the flood arrival time to the Surat city. Fig. 9 shows that the arrival time of flood in different zones. It is clearly indicated that the west zone will be affected first and 90-95 % will be under inundation within 30-33 hrs so it is important to start the rescue operation from west zone. Furthermore, the maps are overlaid on Google Earth image so it is easy to identify the roads and rail network during the emergency exit, and reduce the death toll at Suart city.

#### 4 CONCLUSION

Ukai dam and its prepared EAP in present study is an important case study for developing an EAP for any other large dams in India under the DRIP project. It is observed that the Surat is frequently affected by the flood and it is important to include it under the existing DRIP project to develop the effective EAP of Ukai dam in future. The HEC-RAS version 5.0.3 is an applicable tool to develop the Water surface elevation, depth, velocity and arrival time map for similar case worldwide. Some outcomes from the 1D/2D couple hydrodynamic modeling under the extream flooding condition for Surat city are cited here: 1) West zone is the low laying area in Surat city and it has high chances to inundate in a future flood of the similar size to the 2006 flood. Flood rescue process for this zone must be started first to reduce the death ratio; 2) Presently, at 14,429.68 m<sup>3</sup>/s, major zones of Suart city are safe against flood inundation. If water rises and accelerates gradually then the same inundation conditions will be followed as in 2006. It shows that present levees are not enough to fully protect the Surat city against 25,770 m<sup>3</sup>/s release from Ukai; 3) The flood maps overlaid on Google Earth Image are useful to prepare the escape routes thus applicable to prepare the detail EAP.

It is important to develop regional 'Centre of Excellence for EAP' under the DRIP project, which in future provides the common platform to the young researchers to compare the modelling work. In a nutshell, it will remove the uncertainty and help to produce potential 1D/2D coupled flood modelling to apply for similar cases of the coastal urban flood in the world. The study will also provide guidance to the Ukai dam authorities for significant dam operation and expansion of levees in future. It is significant to perform Dam and levee breach analysis to prepare the detailed EAP for Ukai dam.

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