A study of Disastrous Flash Flood in Khlong U-Tapao River Basin Utilizing a Combined Physical and Mathematical Simulation Model

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ABSTRACT: A severe flash flood, with no warning, occurred on the 21 st of November 2000 in Khlong U-Tapao river basin, in the Songkhla Lake Basin in southern Thailand, and it was four days before the waters subsided. This was the second such disaster, the first occurring in 1998.

The penultimate cause of the flood, which reached 2.5-3.0 meters above the normal river bank, was a north-east monsoon rainstorm which, in one day, dropped 352-420 mm of rain. It caused a least 6 deaths, flooded over 20,000 homes, and economic losses of over $300 million US. In an effort to understand more fully the processes that resulted in this disaster and take appropriate action to prevent a recurrence, both physical and mathematical simulation models were utilized to devise a flood warning system, which was eventually completed and known as the Protection-Mitigation Plan for the basin.

A large quantity of hydrological data were collected for the mathematical simulation model. It was found that the most sensitive parameters were the coefficient roughness of the channel (n), weighing factor (k) and the cross-sectional areas of the flow. These were adjusted in the model to render the best fit of the flood flow hydrographs. The models gave a better understanding and increased the predictability of flood events, and showed the consequences of environmental changes resulting from human activities. Similar studies in the future can utilize the model also, as southern Thailand is recognized as a critical flood area as the result of ENSO.

1. INTRODUCTION

Khlong U-Tapao river basin is of importance as a central area of burgeoning economic growth in the lower southern region of Thailand. The basin has an area of 2,300 km^2 with a population of more than 200,000 people. Its climate is primarily influenced by two monsoon seasons, and result in a primarily dry and a primarily rainy season where rainfall varies from 1,500-2,100 mm. The general topography of the basin is mountainous, with a mild slope from the south to the north. As the result of heavy, but irregular, rainfall, the basin has been faced with the threat of floods since 1959-2000, with floods lasting from 1-14 days when they occur. The most recent notable flood occurred from the 20-25th November 2000, peaking at between 2.0-3.5 meters above the river bank, and causing severe human and economic losses. Following the disaster, the government launched a flood mitigation and warning plan for the protection of Hatyai municipality, which was the major center impacted by the disaster. This study is a part of that plan, and uses a combined physical and mathematical simulation model to forecast the impact of various heavy rainfall situations.

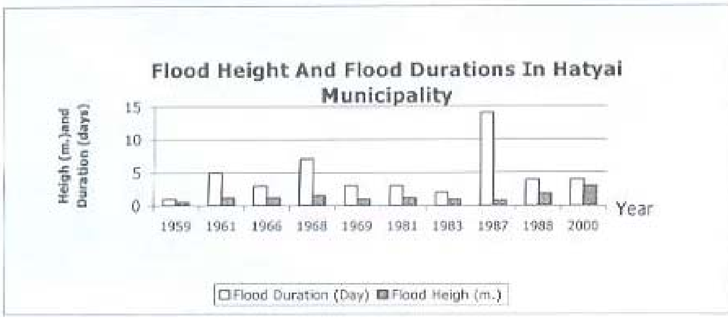

Figure 1. History of Serious Flood Events In Khlong U-Tapao Reiver (Hatyai Municipality Records)

2. FLOOD OCCURRENCE SEASON AND THE FAILURE OF THE OLD FORECASTING SYSTEM

The floods in the basin, when they occur, usually take place during November, at the latter part of the prevalent August-November monsoon season. An examination of the Hatyai municipality flood records shows that the floods have become more severe in recent years. It is believed the this is connected to uncontrolled urbanization and infrastructure building, and the related reduction in the amount of natural wet lands from dumping and draining. Although there were flood control systems in the area, the November 2000 flood was so unexpected and heavy that it completely overwhelmed this system in the area, the November 2000 flood was so unexpected and heavy that it completely overwhelmed this system without even an early warning the disaster was on the way. Post mortem analysis revealed that:

- Telemetering systems were not functioning,
- Rainfall data was not collected in a timely fashion due to the remoteness of the collection
  points
- The Channel Flow stations could not be reach during the crisis
- Hydrological technology was behind in development
- Lines of authority were unclear during the event

3. FIELD INVESTIGATION FOR PHYSICAL SIMULATION MODEL CONSTRUCTION

Preliminary site surveys on both land and water were conducted with a GIS system over the entire area of the basin, and focusing especially on the area along the canal. Some significant and sensitive parameters of channel flow characteristics, including channel flow rate, bed slope, side slope, vegetation and average topographic slope, were collected and/or calculated. GPS was employed in this work also in order to obtain the transactional slope of the water flow. Manning's roughness coefficient (n) was calculated, using both the formula and an experiment in a hydraulic loboratory to obtain an average value. The physical model was constructed under a different scale in order to render an appropriate vision and workable model. A scale of 1:6,000 of the X, Y plan was selected, with a Z plan of 1:150, which enable a model channel flow in laboratory experiments.

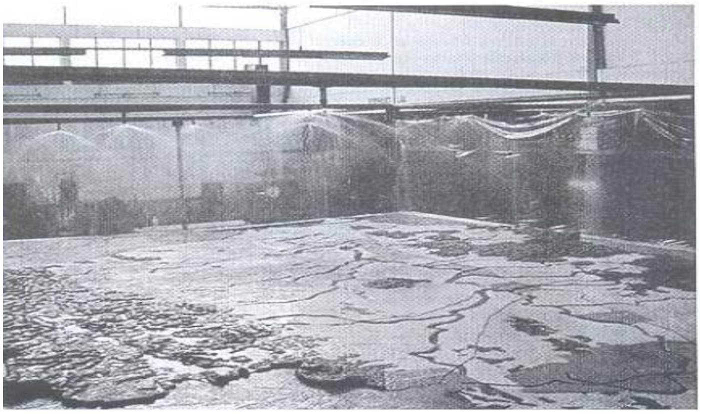

Figure 2. The Flood Peak In 1988 In The Upper And Lower Basins In Khlong U-Tapao

$$F_M = F_P$$

$$U_R \quad U_M / U_P = \sqrt{\frac{G_M L_M}{G_P L_P}} = \sqrt{G_R L_R} = \sqrt{L_R};\ G_R = 1$$

$$T_R = \frac{L_R}{\sqrt{Y_R}}$$

$$Q_R = L_R Y_R^{1.5}$$

The simulated storms will be related to actual storms using the above equations from the physical simulation model. It was found that the storms which drop more than 250 mm of rain in a short period of time, with an average of 70% of the catchment in the upper stream, will cause severe floods downstream with various inundated durations from 2-10 days.

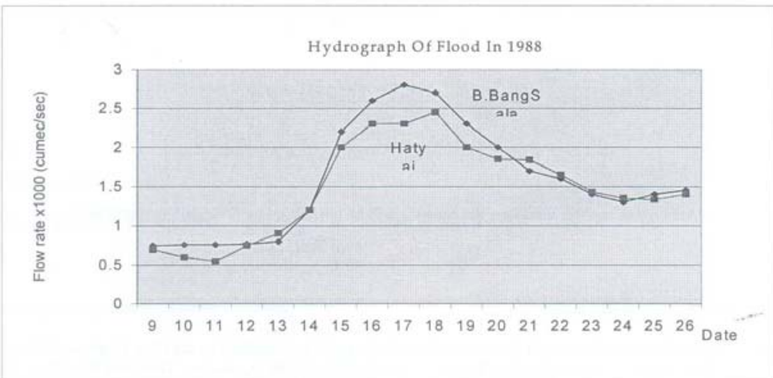

Figure 3. A Physical Model Of The Khong U-Tapao River Basin

4. MATHEMATICAL SIMULATION MODEL

Various mathematical simulation models were deployed to visualize a graphical flood depth along the channel flow. The following mathematical model were utilized in the study:

- Flood Routing (Distributed Flow Routing) Model
- Finite Difference Approximation Model
- Depth-Area Flow rate model

4.1 Flood Routing (Distributed Flow Routing) Model

Distributed Flow Routing is composed of:

$$\frac{\partial Q}{\partial X} + B\frac{\partial H}{\partial t} - q = 0 \qquad (1)$$

Momentum Equation

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\beta\frac{Q^2}{A}\right)}{\partial x} + g.A\left(\frac{\partial y}{\partial x} - S_0 + S_t + S_e\right) - \beta q.V_x + W_f B = 0 \qquad (2)$$

4.2 Finite-Difference Approximations

Numerical Solution of The Kinematic Wave with one parameter, Q:

$$\frac{\partial Q}{\partial X} + \alpha.\beta.Q^{\beta-1}\cdot\frac{\partial Q}{\partial t} = q \qquad (3)$$

$$\frac{Q_{i+1}^{j+1} - Q_i^{j+1}}{\partial X} + \alpha\beta\left(\frac{Q_i^j + Q_i^{j+1}}{2}\right)^{\beta-1}\left(\frac{Q_{i+1}^{j+1} - Q_{i+1}^j}{\Delta t}\right) = \frac{q_{i+1}^{j+1} + q_{i+1}^j}{2} \qquad (4)$$

Solving Q_{i+1}^{j+1}

$$Q_{i+1}^{j+1} = \frac{\left[\frac{\Delta t}{\Delta x}Q_i^{j+1} + \alpha\beta Q_{i+1}^j\left(\frac{Q_{i+1}^j + Q_i^{j+1}}{2}\right)^{\beta-1} + \Delta t\left(\frac{q_{i+1}^{j+1} + q_{i+1}^j}{2}\right)\right]}{\left[\frac{\Delta t}{\Delta x} + \alpha\beta\left(\frac{Q_{i+1}^j + Q_i^{j+1}}{2}\right)\right]} \qquad (5)$$

Nonlinear Kinematic Wave Scheme

$$\frac{Q_{i+1}^{j+1} - Q_i^{j+1}}{\Delta x} + \frac{A_{i+1}^{j+1} - A_{i+1}^j}{\Delta t} = \frac{q_{i+1}^{j+1} + q_{i+1}^j}{2}$$

$$\frac{\Delta t}{\Delta x} Q_{i+1}^{j+1} + \alpha\left(Q_{i+1}^{j+1}\right)^{\beta} = \frac{\Delta t}{\Delta x} Q_{i}^{j+1} + \alpha\left(Q_{i+1}^{j}\right)^{\beta} + \Delta t\left(\frac{q_{ii+1}^{j+1} + q_{i+1}^{j}}{2}\right) \tag{6}$$

Newton's Method was applied, therefore; the equation will be formulated by finite-different grid point

$$C = \frac{\Delta t}{\Delta x} Q_{0}^{j+1} + \alpha\left(Q_{i+1}^{j}\right)^{\beta} + \Delta t\left(\frac{q_{i+1}^{j+1} + q_{i+1}^{j}}{2}\right) \tag{7}$$

4.3 Depth-Area-Flow rate model

The solution will render the flow in the channel and this flow will be calculated by the Flow Depth and Velocity Theory. Thus, flood forecasting will be feasible when the flow depths are known. There are two Flows into channel to be considered:

- Overland Flow
- Channel Flow

4.3.1 Overland Flow

The Continuity Equation

$$\iint_{cs} v dA = f * L_0 \cos\theta + V * y - i * L_0 \cos\theta = 0$$

Leteral flow = q_0

q_0 = V* y = (i – f) L0 cos θ

V = Average flow

$$v = \frac{g * s_0 * y^2}{3v}$$

$$s_0 = s_t = \frac{h_t}{L}$$

$$h_t = \frac{24 vLV^2}{V * y * 4y * 2g}$$

$$h_t = f\left(\frac{L}{24R}\right)\left(\frac{V^2}{2g}\right)$$

Reynolds number Re = (4 VR/v)

If Re < 2000 Laminar Flow

f	=	C1/Re
C_1	=	$96 + 108(I)^{0.4}$
i	=	Intensity, inch
h_f/L	=	Uniform Flow

Flow depth

$$y = \left[\frac{\left(fq_0^2\right)}{8gs_0}\right]^{\frac{1}{3}}$$

$$q_0 = VY$$

If Re > 2000 Turbulent Flow

$$v = \frac{1.49}{n} S_f^{\frac{1}{2}} R^{\frac{2}{3}}$$

R = y

Sf = S0

q_0 = VY

$$Y = \left(\frac{nq_0}{1.49\ S_0^{\frac{1}{2}}}\right)^{\frac{3}{5}}$$

Y = Unit in Feet

4.3.2 Channel Flow

From Manning's equation, then

$$Q = \frac{1.49}{n} * S_0^{\frac{1}{2}} * A * R^{\frac{2}{3}}$$

Solving the equation by Newton's Method:

$f(y_j)$ = $Q_j - Q_{actual\ flow}$

$$\frac{df(y_j)}{dy_j} = \frac{dQ_j}{dy_j} - 0$$

$$\frac{df(y_j)}{dy_j} = \left(\frac{1.49}{n} S^{\frac{1}{2}} A_j R_j^{\frac{2}{3}}\right) / dy_j$$

$$= \left[\frac{1.49}{n} S^{\frac{1}{2}} A_j R_j^{\frac{2}{3}}\right] * \left[\frac{2}{3}\frac{1}{R}\frac{dR}{dY} + \frac{1}{A}\frac{dA}{dY}\right]_j$$

$$= Q_j \left[\frac{2}{3}\frac{1}{R}\frac{dR}{dY} + \frac{1}{A}\frac{dA}{dY}\right]_j$$

$$= \left(\frac{df}{dY}\right)_j = \frac{0 - f(y)_j}{y_{j+1} - y_j}$$

$$y_{j+1} = y_j - \frac{f(Y_j)}{\left(\frac{df}{dy}\right)_j}$$

$$y_{j+1} = y_j - \left[\frac{\left(1 - \frac{Q}{Q_j}\right)}{\left(\frac{2}{3}\frac{1}{R}\frac{dR}{dY} + \frac{1dA}{Ady}\right)} \right]$$

A combined flow depth will be compared with the river bank elevations at each observed station along the channel flow. Thus, earlier warning will be possible

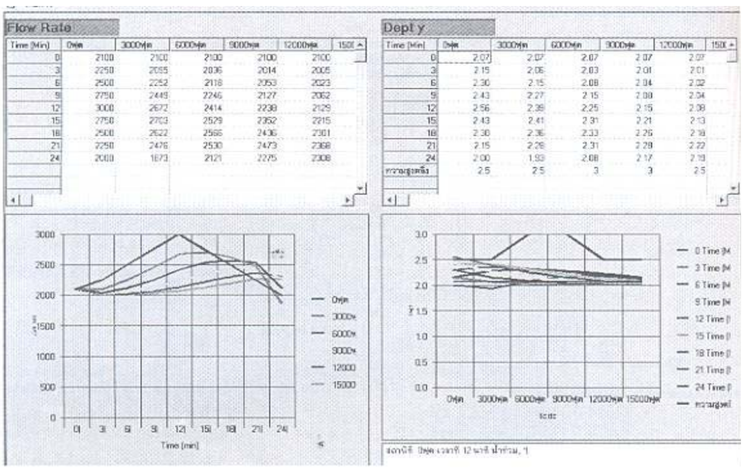

Figure 4. Showing the graphically simulated flow depth in Khlong U-Tapao Canal

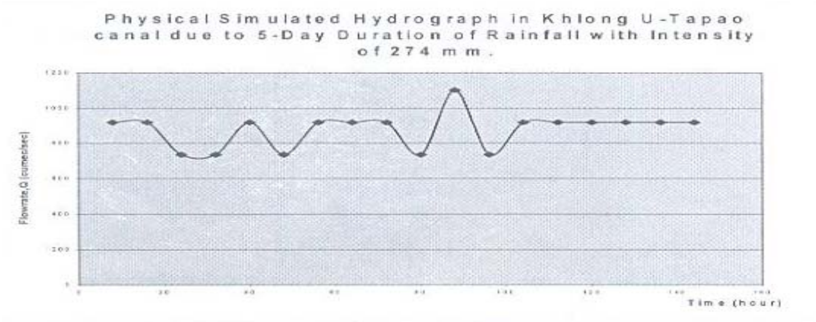

Figure 5. Physical simulation hydrograph in Khlong U-Tapao canal due to rainfall intensity of 250 mm.

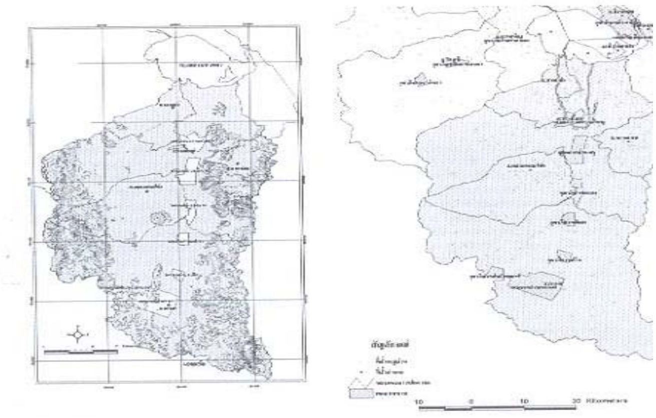

Figure 6. Impacted area in Khlong U-Tapao River basin following a heavy storm which released over 250 mm of rain

5. CONCLUSION

In this study, the experimental calculation indicate that if there is a prevalent storm releasing over 250 mm of rain, in the southern region of the river basin, with the precipitation covering over 70% of the catchment area, it will probably cause a severe flash flood in adjacent areas and northern regions of the basin. The flow rate in the physical model will be measured by electrical sensor instruments mounted at focused stations. The measured flow rates will be simultaneously calculated from the flow depths. From the mathematical simulation model, the channel flow depth along the flow will be calculated and compared with the river bank elevations. In this study there still are some erros arising in the mathematical calculations such as the channel flow area characteristics, channel slope and Manning's roughness(n). These parameters are sensitively significant and only average values were employed. In general, the combination of both models seems to work rather well; unfortunately, there were no historic flow rates recorded during the flood peak events of the November 2000 flood, and therefore, in the study, it was impossible to compare the actual flow depth with the simulation in models.

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