DEVELOPMENT OF A PC-BASED TANK MODEL REAL-TIME FLOOD FORECASTING SYSTEM.

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A project report submitted in partial fulfillment of the requirements for the award of the degree of Masters of Civil Engineering (Civil - Hydraulic and Hydrology)

Faculty of Civil Engineering,
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By CHEOK HOU SENG

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This project is dedicated to my family, my supervisors and
to those who had given me tremendous support to contribute to
the betterment of the society.

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ABSTRACT

The Upper Klang catchment has been under-going rapid development which instigated many flash flood occurrences within the catchment, especially at the Kuala Lumpur City. A reliable and timely flood forecasting system is necessary to provide early warning to minimize the destruction caused by flash floods. Utilizing the publicly available online hydrological data combined with the most recent programming technologies, a PC-based a real-time flood forecasting system is developed for this purpose. The Tank Model is used as the hydrological model to simulate the catchment discharge while the Standard Step Method applied as the hydraulic model to simulate the water level profile of Klang River starting from the confluence of Klang and Ampang River to Jambatan Tun Perak. Integration of both models into a complete real-time hydro-dynamic flood forecasting system is programmed using the Microsoft Excel and Visual Basic For Application. Calibration and Verification of the model has proven that forecast generated by the system is highly reliable with an average Model Efficiency of 89.37% and a Mean Absolute Error of 0.23m. The system acquires real-time hydrological data from the Infobanjir server maintained by Department of Irrigation and Drainage Malaysia at 5 minutes intervals and is therefore able to provide a reliable and timely warning at 40 minutes before the flood peak reaches the city center.

ABSTRAK

Proses urbanisasi yang berlaku dengan pesat di kawasan tadahan Upper Klang telah menyebabkan kejadian banjir kilat melanda pusat bandar Kuala Lumpur yang terletak di bahagian hilir kawasan tadahan tersebut. Untuk mengurangkan kemysnahan akibat banjir kilat yang berlaku, satu sistem peramalan banjir "real-time" berasaskan computer peribadi harus dibangunkan untuk memberi amaran awal tentang kejadian banjir kepada penduduk-penduduk di kawasan pusat bandar. Dengan gabungan teknologi aturcara dan data hydrologi on-line yang disediakan oleh Jabatan Pengairan dan Saliran (JPS), suatu sistem peramalan banjir telah dibangunkan bagi tujuan tersebut. Dalam sistem yang dibangunkan, Model Tangki telah digunakan sebagai model hidrologi untuk meramalkan hidrograf discas dari kawasan kajian. Kaedah "Standard Step" pula digunakan untuk mensimulasikan aras air bagi sungai kajian iaitu Sungai Klang, bermula dari pertemuan Sungai Klang dan Sungai Ampang ke pertemuan Sungai Klang dan Sungai Gombak. Kedua-dua model ini kemudian diintegrasikan menjadi satu sistem peramalan banjir yang lengkap dengan menggunakan Microsoft Excel dan Aturcara Visual Basic For Application. Kalibrasi dan verifikasi model tersebut telah membuktikan bahawa ketepatan ramalan yang dihasilkan oleh sistem ini adalah memuaskan, dengan keberkesanan model sebanyak 89.67% dan purata perbezaan mutlak sebanyak 0.23mm. Sistem peramalan ini akan mengambil data hidrologi melalui internet pada sela masa setiap 5 minit dari server Infobanjir yang disediakan oleh JPS. Maka sistem ini boleh memberi ramalan banjir yang memuaskan 40 minit sebelum puncak banjir hidrograf sampai ke pusat bandar Kuala Lumpur.

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DID	-	Department of Irrigaion and Drainage, Malaysia
JPS	-	Jabatan Pengairan dan Saliran, Malaysia
RF	-	Rainfall
Q	-	Flood Discharge
WL	-	Water Level
m R.L.	-	Meters Reduced Level
Ms Excel	-	Microsoft Excel
VB	-	Visual Basic
BASIC	-	Beginner’s All-Purpose Symbolic Instruction Code
GVF	-	Gradually Varied Flow
HTTP	-	HyperText Transfer Protocol
URL	-	Uniform Resource Locator
RFC	-	Request for Comments
PC	-	Personal Computer
WWW	-	World Wide Web
HTML	-	HyperText Marked-up Language
VBA	-	Microsoft Visual Basic for Application
GUI	-	Graphical User Interface
GIF	-	Graphic Interchange Format
API	-	Application Programming Interface

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The Upper Klang Catchment covers a total area of 108km^2 (excluding the Klang Gate catchment), which extends from the tip of Klang River until the confluence of Klang and Gombak River. The downstream of the catchment, which includes part of the Kuala Lumpur City Center is fully developed while the upstream part like Taman Melati, Wangsa Maju and Ulu Klang are being rapidly developed to accommodate the drastic increase in the capital's population.

With the rapid development, many areas have been paved impervious by roads and building which eventually reduces the amount of rainfall infiltrated into the ground and caused an increase in surface runoff (MASMA, 2000). Besides that, impervious areas like roads and concrete pavements have smoother surfaces compared to the undeveloped vegetation. This causes the reduction in the time of concentration of the catchment, which literally means that the rainfall will discharge much faster into the river, causing the water level in the river system to rise drastically during storm events. The combined effects due to the rapid development has contributed to an increase in the river discharge and thus caused many flash flood occurrences in the catchment for the past few years (refer Figure 1.1 and Figure 1.2).

Figure 1.1 flash flood occurrence in the Kuala Lumpur City Center due to a heavy downpour on the 26th April 2001

Figure 1.2 Photos showing the damages caused by the 10th June 2003 flash flood event at the Kuala Lumpur City Center.

These flash floods nuisance have forced the government to allocate a total of RM 2.7 billion from the Eighth Malaysian Plan to mitigate the problem (refer Figure 1.3). According to a study by The Drainage & Flood Mitigation Division of Drainage and Irrigation Department (DID) Malaysia in 2003, the flood mitigation projects implemented has successfully reduced the flood damages from RM1356 million to RM915 million. However most of these mitigation measures are structural river improvement works. In order to further reduce the flood damages caused, a timely and reliable flood forecasting system is important to provide early warning to evacuate people and properties from the flood-prone areas.

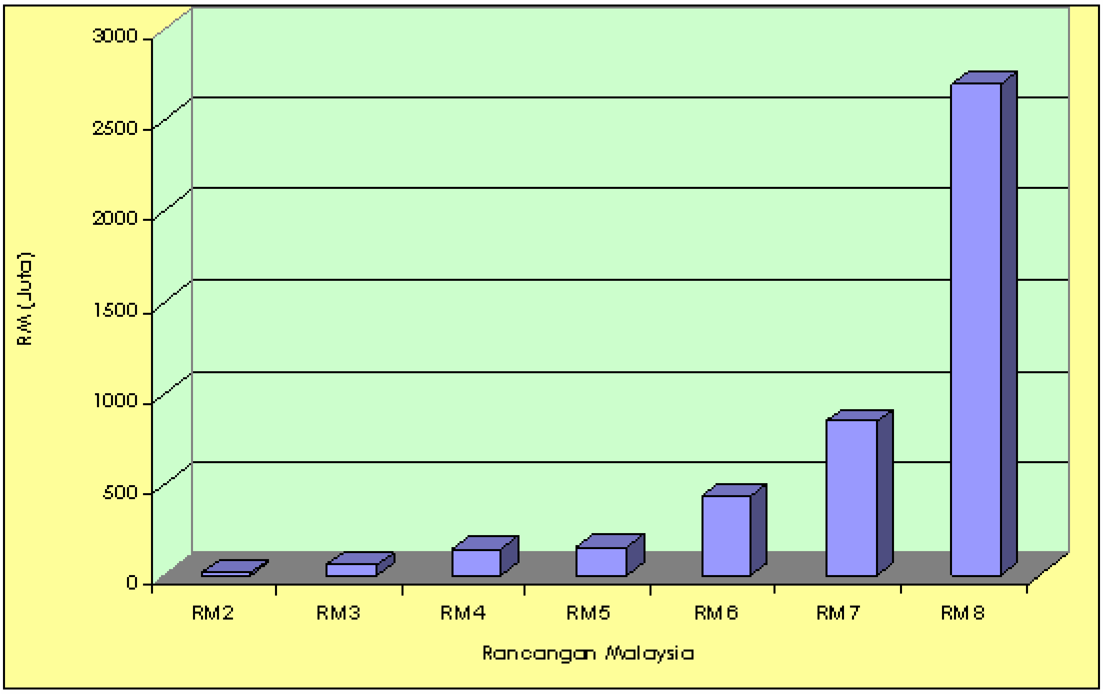

Figure 1.3 Budget allocated for flood mitigation projects by the government for past Malysian Plans.

1.2 Statement of Problem

There are currently 2 flood forecasting models setup for Kuala Lumpur, namely the FloodWatch System and a Unit Hydrograph Model. However both models require cumbersome maintenance and are still being evaluated in their capability to provide reliable real-time flood warnings. Taking advantage of the online hydrological data for the Klang River Basin and utilizing the various programming technologies available, it is time to research into the development of a new personal computer-based flood forecasting model to provide timely and reliable flood forecast to prevent loss of lives and properties within the Kuala Lumpur City Center.

1.3 Objective of Study

The main objectives of the project are:

1. To develop and setup a hydrological Tank Model to simulate the discharge hydrograph of the Upper Klang catchment at Jambatan Tun Perak.
2. To develop and setup a hydraulic model, using the Standard Step Method to simulate the water level profile for Klang River starting from the confluence of Klang and Ampang River until Jambatan Tun Perak.
3. To develop a real-time PC-Based flood forecasting system with user-friendly graphical user interface (GUI) for easy model updating, calibration and flood forecasting operations.

1.4 Scope and Limitation of Study

1. To obtain and process relevant hydrological data of various historical storms which are used for calibration and verification purposes of the developed models.
2. To calibrate the Tank Model based on historical flood events to provide reliable simulation of flood discharges at Jambatan Tun Perak.
3. To obtain and process all relevant hydraulic data which are used for the Standard Step Method Model to simulate the water level profile within the study channel.
4. To develop a PC-based system to integrate both the Tank Model and the Hydraulic Model into a complete Hydro-dynamic model for the Upper-Klang catchment.
5. To develop a software module to acquire hydrological data at 5 minutes interval from the Infobanjir web site to be inputted into the PC-based forecasting system to provide real-time flood forecast at Jambatan Tun Perak.
6. The main limitation of the study is the availability of reliable and error-free hydrological data. Therefore the scope of the study is only limited to the Upper Klang catchment because of the inadequacy of well-established on-line hydrological data in other catchments.
7. The scope of the hydraulic model development is limited to the determination of water level profile for a river channel with one inflow and one outflow. Modelling of complicated river networks with lateral inflow is not covered in this study.
8. The hydraulic model can model river channel without any flow control structures. The modeling of water level profiles regulated by flow control structures are not covered in this study.

1.5 Importance of Study

The developed system synergizes the most recent engineering modeling techniques with the technologies in software and the internet programming in order to achieve the objective of providing an accurate and timely flood forecast to the masses. The developed system, given the name Tank-SStep Model uses the hydrological Tank Model to simulate the catchment discharge hydrograph while the water level profile within the Klang River is generated using the Standard Step Method. It also includes a data acquisition module to continuously acquire rainfall and water level data from the Infobanjir web server as input to the model. The generated output of flood forecast warnings can then be disseminated using various communication technologies like through the internet, cell phones and other wireless devices.

CHAPTER 2

THEORETICAL BACKGROUND

2.1 INTRODUCTION

The project of developing a real-time PC-based flood forecasting system requires a sound knowledge in hydrology and hydraulic engineering and the manipulation of the latest programming technology. Hydrology modeling allows us to simulate the discharge hydrograph generated by the study catchment in response to a rainfall event while hydraulic modeling is capable of simulating the water level profile along the river channel. Utilizing the programming technologies available for internet and PC-based programming, we can setup an automated real-time flood forecasting system to provide early flood warning to the citizens in the Kuala Lumpur City Center.

The advancement in Information Technology has caused the proliferation of various modeling and programming techniques which can be applied in the study. However deliberate study is critical in selecting the most suitable hydrological and hydraulic model, as well as the programming technologies to be adopted in order to effectively achieve the objectives of the project. This chapter outlines the fundamental concepts and theoretical background for the modeling techniques and programming technologies applied in the course of the study.

2.2 Hydrological and Hydraulic Model Selection

Many different flood forecasting models, ranging from simple stage regression techniques to sophisticated physically-based distributed hydrologic models have been developed and used to forecast floods. A flood forecasting model is one specific type of hydrologic model developed to simulate catchment responses to precipitation and generate forecasts of the water level and stream flow. Generally flood forecasting model can be categorized into three types:

1. Distributed physics-based models (e.g. SHE, TOP-model)
2. Lumped conceptual models (e.g. Sacramento, Tank, CLS)
3. Black box models (e.g. stage-regression, Unit Hydrograph, LTF)

From the various types of models available, the selection of a suitable flood forecasting model has to be carried out with caution depending on the catchment characteristics especially due to urbanization and the balance between the model complexities versus the accuracy of the forecast required. According to Pilgrim (1987), the factors which need to be considered in the choice of flood estimation method are:

i. The form and structure of available methods, the factors they consider, their theoretical basis, and their accuracies.
ii. The data available for calibration. The amount and range of the data on which the relationships in the methods are based, and their applicability to the design catchment.
iii. The type and importance of the work for which the design is required, the cost of the structure, and the design risk of surcharge. These affect the desired

accuracy and the type of information required, such as whether a peak discharge is adequate or a complete hydrograph is needed.

iv. The time that can be spent on obtaining an estimate.

v. The expertise available. The more complex methods generally require more expertise for their valid use and interpretation.

Answering these factors, the Tank Model has been identified as the best solution to model the hydrological processes of the Upper Klang Catchment due to the advantages below:

1. The structure of the model using a series of storage tanks can reliably depict the physical hydrological processes such as infiltration, base flow, river discharge, evaporation, tank storages etc.
2. The available data for this study is the online rainfall and water level data provided by the Infobanjir server, maintained by the DID. No soil investigation study has been carried out for the catchment. Because the Tank Model only requires the rainfall data as input and historical water level data for model calibration purposes, it is adequate for the model to simulate the hydrological processes with the available data.
3. For flood forecasting purposes, the progression of the flood against time is very important especially in determining the available lag time for an early warning and the inundation period of the flood if the banks are over spilled. With a complete rainfall hyetograph, the Tank Model is able to simulate the complete discharge hydrograph of the catchment.
4. The tank model uses simple mathematical equations which can be easily programmed and calculated with an electronic spreadsheet such as Microsoft Excel. Therefore the forecast can be calculated within less than one second after the rainfall data is inputted into the system.
5. Because of its simple model structure and minimal input parameters, it can be easily understood, operated and maintained by flood operating personnel with a fundamental knowledge in hydrology and flood forecasting.

For the hydraulic model, the Standard Step Method has been identified as the suitable model for the study channel based on the following reasons:

1. The study river has a mild slope without any regulating control structures along the channel, making it a channel with a gradually varying flow. Therefore all assumptions for a gradually varied flow are valid and the Standard Step Method can be applied to simulate the water levels within the study channel.
2. The method can be applied to nonprismatic channels and is best suited to computations for natural channels (Lejeune, 1994). With the cross section data collected for the channel stretch, the flow depth at all of the cross sections can be calculated iteratively by a trial and error process.
3. The Standard Step Method be is an iterative computation that can be easily tabulated and programmed into an electronic spreadsheet (Chaudry, 1993).

2.3 Hydrological Tank Model

For the purpose of this study, the TANK model by Sugawara (1979) is proposed due to its various advantages over other models. It is a linear conceptual model which uses a series of storage tank configuration to simulate the hydrological processes that occur in a catchment. It is simple to use but at the same time, capable of depicting the physical hydrological processes like evaporation, groundwater infiltration, precipitation, and stream flow to a considerable accuracy (Chong, 1998).

Each storage tank literally represents one soil layer. The upper-most tank is used to model the hydrological processes occurring in the top soil layer including rainfall precipitation, evaporation, surface runoff and also infiltration and exfiltration between the top soil and the sub soil layer. Because most of the discharge in the river is contributed by the surface runoff, the first tank has the most influence in the simulated discharge. Similarly, the subsequent tanks in the vertical tank series is used