UNIVERSITI PUTRA MALAYSIA

FLOOD SIMULATION MODELS FOR A RIVER SYSTEM IN A TROPICAL REGION: THE CASE OF LINGGI RIVER, MALAYSIA

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By

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FLOOD SIMULATION MODELS FOR A RIVER SYSTEM IN A TROPICAL REGION: THE CASE OF LINGGI RIVER, MALAYSIA

By

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June 1998

Chairman: Associate Professor Salim Bin Said, Ph. D.

Faculty: Engineering

Flooding of a river system in a tropical region is predicted using mathematical simulation models in this study. The proposed models were categorized as hydrologic model, hydraulic model and sedimentation model.

Two methods of hydrologic models were used to simulate the peak streamflow in a river system of a tropical region. The first hydrologic model is the river model, which is a first order linear autoregressive model, AR (1). The second hydrologic model is called the basin model which is a deterministic model based on a linear relationship between rainfall and runoff. The basin model is also described as a distributed model in which the river basin is divided into a number of subbasins whereby the rainfall and the runoff at each subbasin is simulated separately and then combined to get the river basin response. The Linggi River system in Seremban, Malaysia was used as a case study. The Linggi River system

consists of a main river which is called Linggi, and it's six tributaries called the Batang Penar, Paroi, Temiang Diversion, Temiang, Anak Rasah and Kepayang. The total catchment area of the Linggi River system up to the point of interest is 127.7 km^2. Recorded hydrologic data for the Linggi River basin was used in the evaluation and testing of the proposed models. Models evaluation involved calibration, verification and sensitivity analysis. Models testing was implemented using the Theil's technique. The calculated value of Theil's coefficient was 0.028, 0.17 and 0.01 for the basin model, river model and the hydraulic model respectively. A computer program was written to especially perform the calculations of the basin model. This computer program is called BSHYMD.

The hydraulic model was used to predict the water surface profile in the river system based on the numerical solution of the one dimensional energy equation. The verification of the hydraulic model showed that there was substantial agreement between the predicted and recorded water surface profile. The average error between the predicted and recorded water surface profiles for Linggi River using the hydraulic model was 2.28%. The HEC-2 computer package and HEC-RAS computer package were used to perform the calculations of the water surface profile for Linggi River. The hydraulic model was sensitive to changes in the Manning's coefficient of roughness, with an increase of 0.001 in the value of that coefficient would lead to an average increase of 2.5 cm in the predicted water surface elevation in the Linggi River. The linkage between the hydrologic model and the hydraulic model was performed successfully in this study.

Detention ponds could be used for flood alleviation in river systems to enhance the water quality of the floodwater, which carries a high sediment load from the upstream basin of the river system. The analytical sedimentation model was proposed to predict the sediment concentration in the outflow water from a detention pond of a river system. The analytical sedimentation model was based on the hydrologic continuity equation of the flow of water and sediment through the pond. The first order linear differential equation resulting from the simplification of the hydrologic continuity equation was solved analytically in this study. The verification of the analytical sedimentation model was implemented using numerical sedimentation model. The analytical sedimentation model is a general model which can be applied to any detention pond or sedimentation basin. The verification process showed that the predicted sediment concentration from the analytical sedimentation model and that predicted by the numerical sedimentation model were in agreement. A computer program was written in this study to perform the calculation of the analytical sedimentation model. This computer program is called as ANASDM. Based on the efficiency of the detention pond in trapping the sediment, it was found that the pond was highly efficient in reducing the coarser sediment load (over 90% efficiency), while for the finer sediment, the efficiency was about 50%.

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MODEL SIMULASI BANJIR UNTUK SISTEM SUNGAI DI KAWASAN TROPIKA: KES SUNGAI LINGGI, MALAYSIA

Oleh

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Di dalam kajian ini, bencana banjir yang berlaku pada sistem sungai di kawasan tropika diramal dengan menggunakan model simulasi matematik. Model yang dicadangkan dapat dikategorikan kepada model hidrologi, model hidraulik dan model pemendapan.

Dua jenis model hidrologi telah digunakan bagi simulasi aliran puncak di dalam sebuah sistem sungai kawasan tropika. Model hidrologi pertama ialah model sungai iaitu sebuah model autoregresif linear kelas satu, AR(1). Model hidrologi kedua dipanggil model kawasan tadahan di mana ia merupakan model penentuan berdasarkan kepada hubungan linear di antara air hujan dan air larian. Model kawasan tadahan juga boleh dihuraikan sebagai model pembahagian di mana kawasan tadahan sesebuah sungai tersebut dibahagikan kepada beberapa sub-kawasan tadahan di mana air hujan dan air larian pada setiap sub-kawasan tadahan

disimulasikan secara berasingan dan kemudian digabungkan bagi mendapatkan reaksi kawasan tadahan tersebut. Sistem Sungai Linggi di Seremban, Negeri Sembilan, Malaysia dipilih sebagai kajian kes untuk kajian ini. Sistem Sungai Linggi terdiri daripada sungai utama iaitu Sungai Linggi dan enam cabangnya iaitu Sungai Batang Benar, Sungai Paroi, Sungai Temiang Diversion, Sungai Temiang, Sungai Anak Rasah dan Sungai Kepayang. Jumlah keluasan kawasan tadahan bagi sistem Sungai Linggi ialah 127.7 km^2 . Data dari rekod hidrologi bagi kawasan tadahan Sungai Linggi telah digunakan di dalam proses menilai dan menguji model-model yang dicadangkan. Penilaian model-model merangkumi kerja-kerja kalibrasi, pengesahan dan analisis kepekaan. Pengujian model telah dilaksanakan dengan menggunakan teknik Theil. Selain daripada itu, nilai pekali Theil ialah 0.028, 0.17 dan 0.01 bagi model kawasan tadahan, model sungai masing-masing dan model hidraulik.

Model hidraulik digunakan bagi meramal profil permukaan air sungai berdasarkan kepada penyelesaian numerikal daripada persamaan tenaga satu dimensi. Pengesahan model hidraulik menunjukkan bahawa terdapat persetujuan yang kuat di antara profil permukaan air yang diramal dan yang direkod. Kesilapan purata di antara profil permukaan air yang diramal dan direkod untuk Sungai Linggi dengan menggunakan model hidraulik adalah sebanyak 2.28%. Pakej komputer HEC-2 dan HEC-RAS telah digunakan bagi pengiraan profil permukaan air untuk Sungai Linggi. Model hidraulik ini amat sensitif kepada pekali kekasaran permukaan Manning di mana pertambahan sebanyak 0.001 pada pekali tersebut akan menghasilkan pertambahan purata sebanyak 2.5 cm pada paras permukaan air

Sungai Linggi. Kaitan di antara model hidrologi dan model hidraulik telah dilaksanakan dengan baik di dalam kajian ini.

Kolam takungan tetap boleh digunakan bagi mengurangkan kesan banjir pada sistem sungai dan dapat membersihkan air banjir daripada beban keladak tinggi yang dibawa dari kawasan hulu tadahan. Di dalam kajian ini, model pemendapan analitikal telah dicadangkan bagi meramal konsentrasi keladak di dalam air yang mengalir keluar daripada kolam takungan sesebuah sistem sungai. Model pemendapan analitikal ini berdasarkan kepada persamaan berterusan hidrologi bagi aliran air dan keladak melalui kolam takungan. Persamaan pembezaan linear kelas pertama hasil daripada persamaan berterusan telah diselesaikan secara analitikal dengan menggunakan penyelesaian piawai bagi persamaan pembezaan jenis ini. Pengesahan model pemendapan analitikal telah dilaksanakan dengan menggunakan model pemendapan numerikal yang dicadangkan oleh Hall (1993). Model pemendapan analitikal adalah model umum di mana ia boleh diaplikasikan kepada mana-mana kolam takungan atau takungan keladak. Proses pengesahan menunjukkan bahawa terdapat persetujuan yang baik di antara konsentrasi keladak yang diramal daripada model pemendapan analitikal dan model pemendapan numerikal. Berdasarkan kepada pengiraan keberkesanan kolam takungan memerangkap keladak, didapati bahawa kolam tersebut adalah berkesan dalam mengurangkan beban keladak yang kasar (keberkesanan melebihi 90%) manakala untuk keladak yang lebih halus, keberkesanannya lebih kurang 50%.

CHAPTER I

INTRODUCTION

Flood plains and riverbanks have played important roles for mankind because man has been dependent on these areas for lodging and food production since the ancient ages. Although the ancient man was able to move away from the flooded river plain during a flood period as a temporary measure, he also made many attempts to control the flood. Man attempted to control the flooding of rivers by constructing simple structures across these rivers or digging side canals or through other activities. Flood control and management is not a new practice but it is as old as civilization itself. Practices used by modern man for flood management and control are different from that used by the ancient man; the difference is attributed to the use of new practices, which apply modern technologies.

As the population increased, the number of people living in the areas near to the rivers increased as well. The economic investment in flood plains has therefore grown throughout the world, and consequently annual damages produced by the floods have continually increased.

Not only that but other developments in the river basins kept on increasing until now and this brings the flood problems into sharper focus in recent years. Thus, although the investment to reduce the limit of flood damage has increased rapidly during the past decades, annual damages have also increased. The flood damages are created when the river flows are large enough to cause flooding of these areas that are less often covered by water than the main channel of the flowing river.

Flooding occurs as a result of rainfall in tropical regions while in the temperate regions it is the result of rainfall and simultaneous snowmelt. Malaysia is a tropical country, receiving more than 2500 mm of rain annually (Said, 1989). The flooding of Malaysian rivers is mainly due to the high amount of rainfall at their basins. The worst flood in Malaysia was recorded in 1926 which has been described as having caused the most extensive damage to the natural environment. Subsequent major floods were recorded in 1931, 1947, 1954, 1957, 1967, and 1971. Floods of lesser magnitude also occurred in 1973, 1979 and 1983 (Ann, 1994). Table 1.1 shows the extent of the areas subjected to the river floods in Peninsular Malaysia. The figures given are only approximate and were based on flood maps (Framgi and Gary, 1977).

The total cost of the flood to the Malaysian economy justifies the attention paid by the government to flood mitigation and prevention problems, and to encourage engineers to study and alleviate these problems. The total cost of the flood comprises the cost of flood mitigation projects and the cost of flood damage. The average cost of the annual flood damage in Malaysia is estimated to be

RM 100,000,000 (Ann, 1994). Table 1.2 shows the total cost of the flood in Malaysia for the period 1966-1995. Annual flood damage can be computed using numerical integration (Beard, 1997). On the other hand, analytical modelling can also be used for estimating the annual flood damage of a levee (Goldman, 1997).

Table 1.1: Areas Endangered by the Flood in Peninsular Malaysia

State	Area endangered by the flood (km^2)	Year
Kedah	440	1971
Perlis	-------------------------	
Penang	52	1971
Perak	1295	1967
Selangor	958	1971
Pahang	8029	1971
Trengganu	1683	1966-1967
Kelantan	2124	1966-1967
Negri Sembilan	220	1971
Malacca	453	1971
Johor	2072	1969-1970

Source: Framgi and Gray (1977)

Rapid development in Malaysia has increased in the last decade and recorded flows in the Malaysian rivers have increased as well. The increase in the amount of the flow to these rivers from their basins is attributed to the changes in landuse. In Malaysia many detention ponds are used to alleviate the flood in river systems.

The function of a detention pond is to reduce the impact of the peak flow in the river. Unfortunately, the high sediment load carried by the floodwater to the pond reduces the storage capacity and also increases the consequences of the flood impacts.

Table 1.2: Cost of the Flood in Malaysia for the Period of 1966 –1995

Period (Years)	Mitigation Coast (Millions of RM)	Average Annual Damage Cost (Millions of RM)	Total Cost (Millions of RM)
1966-1970	5.83	100.0	105.83
1971-1975	16.60	100.0	116.60
1976-1980	56.0	100.0	156.0
1981-1985	164.10	100.0	264.10
1986-1990	210.0	100.0	310.0
1991-1995	504.20	100.0	604.20

Source: Ann (1994)

Flood forecasting or predicting is important because it helps in reducing the flood damage in terms of cost and losses, including the loss of human life. As a result of advances in the numerical methods and computer technologies, many mathematical models were developed and used in flood simulation studies. A flood simulation model, which is used to predict the peak streamflow, is called the hydrologic model. A large number of hydrologic models were proposed by various researchers to estimate the streamflow in a river system. Based on the concept and the approach used in the formulation of the hydrologic model, it can be classified