UNIVERSITI PUTRA MALAYSIA

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By

HUANG YUK FENG

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Dedicated to the author's beloved Grandmother, Mother, Sisters, Brothers, and in memory of his beloved Father

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF A RESERVOIR INFLOW FORECASTING MODEL FOR AN UNGAUGED CATCHMENT

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Chairman: Associate Professor Ir. Lee Teang Shui, PhD

Faculty: Engineering

A user-friendly single-event distributed reservoir inflow forecasting model for the ungauged Batu Dam Catchment is presented. The Batu Dam Catchment located in the Gombak District, Selangor Darul Ehsan, approximately 20 km north of Kuala Lumpur, is a 50.7 km^2 tropical forested rural catchment. The model consists of five sub-models, namely the physical data input sub-model, the rainfall data input and excess rainfall computation sub-model, the rainfall runoff simulation sub-model, the baseflow volume computation sub-model and the reservoir water level increment simulation sub-model. The whole formulation of model was set up using the MapBasic and MapInfo Geographical Information System package. The catchment was delimitated based on the finite element concept. The rainfall losses in the catchment were assumed to be consistent throughout an event and uniform over the entire catchment. The catchment losses rate concept developed was assumed to be dependent on catchment antecedent soil moisture condition (catchment wetness index) and weighted average rainfall intensity. A catchment wetness index was formulated empirically based on the net total rainfall volume retained in the catchment cumulated from a five-day period prior to the simulated event following

the 5-day Antecedent Precipitation Index (API5) approach. This catchment losses rate works in conjunction with the areal reduction factor to compute excess rainfall. With excess rainfall as input, the rainfall runoff simulation sub-model was developed based on the one dimensional Saint-Venant equations with kinematic wave approximation and solved using the finite element standard Galerkin's residual method, and incorporating Manning's equation. The spurious oscillatory behaviour of the simulated direct runoff hydrographs when approximated by the standard Galerkin's residual method can be suppressed by using a one minute time increment based on investigations taking into consideration the Courant condition. An empirical equation for computating baseflow volume for reservoir water level increment simulation was developed based on the five previous day approach similar to that in the API5. The reservoir water level increment sub-model is used to simulate the reservoir water level increment, by considering all the other inflows and outflows of the reservoir.

Historical rainfall events from 1989 to 2001 were used for model parameter calibration and model verification purposes. One hundred and forty cases selected were divided into thirteen groups according to their weighted average rainfall intensities. Cases from each group were then further sub-divided randomly into two separate sets in order to form two sets of cases. One set was used for the calibration of the unknown parameter, catchment losses rate. The Catchment Losses Rate-Catchment Wetness Index-Weighted Average Rainfall Intensity (LWRI) curves were proposed. Seven LWRI curves were finalized and selected, and were programmed into the model for model verification and forecasting purposes. The accuracy of Manning's coefficients used in model parameter calibration was

confirmed by extending the 24-hour simulation period of the selected calibration cases to 48 hours. The 0.400 and 0.040 Manning's coefficients for overland and channels were confirmed to be accurate. This was supported with statistical tests on the simulated increment and the respective measured increment, where a very strong 0.9799 correlation coefficient from the correlation analysis, a relatively small mean absolute error that does not exceed 1.47 cm at 95% level of confidence from the single mean *t*-test, and not enough evidence to support that the means and the variances of simulated increments and measured increments are different through the paired *t*-test and the *F*-distribution variance ratio test respectively.

The other set of cases was used for LWRI curves verification and model verification purposes. The LWRI curves were found to be accurate in determining catchment losses rates. The model was verified to be able to simulate the reservoir water level increment accurately. This was supported by the results of the statistical tests carried out on the simulated and the respective measured increments. A very strong 0.9799 correlation coefficient from the correlation analysis, a relatively small mean of absolute error not exceeding 2.20 cm at 95% level of confidence from the single mean *t*-test, and not enough evidence to support the means and the variances between the simulated increment and the measured increment are different from the paired *t*-test and the *F*-distribution variance ratio test.

The model was evaluated by comparing it with the rational method. Results of statistical tests show the model performing much better than the rational method. The respective correlation coefficient and mean of absolute error for the rational method were found to be 0.8602 and does not exceed 12.58 cm at 95% level of

confidence, respectively, while the paired *t*-test shows that there is not enough evidence to support that the simulated increment and the measured increment are the same. The computed Theil's coefficients for the model and the rational method, which are 0.062 and 0.266 respectively, also show that the model is more reliable compared to the rational method.

From the sensitivity analyses, the impact of changing Manning's Coefficient of overland on the simulated direct runoff hydrograph, as well as the reservoir water level increment, is higher than the impacts of changing Manning's Coefficient of the channels. The study reveals that more caution and effort should be emphasized in deciding Manning's coefficient of overland than that of channels. The results also show that the impact decreases with increasing rainfall intensity. The impact of catchment wetness index on the catchment losses rate and the corresponding reservoir water level increment was found can be moderately high, but is case dependent.

Keywords: ungauged reservoir inflow forecasting model, finite element rainfall runoff simulation, catchment wetness index, catchment losses rate, baseflow.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PEMBANGUNAN MODEL PERAMALAN ALIRAN MASUK TAKUNGAN UNTUK TADAHAN TAK-TERUKUR

Oleh

HUANG YUK FENG

April 2005

Pengerusi: Profesor Madya Ir. Lee Teang Shui, PhD

Fakulti: Kejuruteraan

Satu model peramalan aliran masuk takungan teragih berperistiwa tunggal untuk tadahan tak-terukur Empangan Batu ditunjukkan. Tadahan Empangan Batu yang terletak di Daerah Gombak, Selangor Darul Ehsan, lebih kurang 20 km ke utara dari Kuala Lumpur, merupakan sebuah tadahan berhutan tropika yang berkeluasan 50.7 km^2. Model terdiri daripada lima buah sub-model, iaitu sub-model masukan data fizikal, sub-model masukan data hujan dan pengiraan lebat hujan lebihi, sub-model penyelakuan hujan air larian, sub-model pengiraan isipadu aliran dasar dan sub-model penyelakuan tokokan paras air takungan. Perumusan keseluruhan model diperbangunkan dengan menggunakan pakej MapBasic dan Sistem Maklumat Geografi MapInfo. Tadahan telah dibahagi berdasarkan konsep unsur terhingga. Kehilangan hujan dalam tadahan dianggap tetap sepanjang peristiwa dan seragam di keseluruhan tadahan. Konsep kehilangan tadahan yang dibangunkan dianggap bergantung kepada keadaan kelembapan tanah tadahan dahulu (indeks kebasahan tadahan) dan keamatan hujan purata berpemberat. Indeks kebasahan tadahan dirumuskan empirik berdasarkan hasil bersih jumlah isipadu hujan ditahankan di dalam tadahan dilonggokkan daripada satu jangkamasa lima-hari sebelum peristiwa

diperselakukan mengikut pendekatan Indeks Curahan Dahulu (API5). Kadar kehilangan tadahan ini berfungsi bersama-sama dengan faktor pengurangan luasan demi untuk mengira lebat hujan lebihi. Dengan lebat hujan lebihi sebagai masukan, sub-model penyelakuan hujan air larian dibentukkan berdasarkan persamaan-persamaan Saint-Venant berdimensi satu bersama anggapan ombak kinematik dan diselesaikan dengan menggunakan kaedah unsur terhingga baki Galerkin piawaian, serta termasuk persamaan Manning. Kelakuan ayunan lainan grafhidro air larian langsung yang diselakukan apabila ditaksirkan dengan kaedah baki Galerkin piawaian boleh ditindas dengan menggunakan tokokan masa sebanyak satu minit berdasarkan kajian-kajian yang mempertimbangkan keadaan Courant. Satu persamaan emprik untuk mengira isipadu aliran dasar dalam penyelakuan tokokan paras air takungan telah dibangunkan berdasarkan pendekatan lima hari dahulu sama dengan yang terdapat di dalam API5. Sub-model tokokan paras air takungan digunakan untuk menyelaku tokokan paras air takungan, dengan mempertimbangkan kesemua aliran masuk dan aliran keluar dari takungan.

Peristiwa-peristiwa hari hujan sejarah dari 1989 ke 2001 telah digunakan dalam penentukuran parameter model dan tujuan pentahkikan model. Seratus empat puluh kes yang terpilih dibahagikan kepada tiga belas kumpulan mengikut keamatan hujan purata berpemberat masing-masing. Kes-kes daripada setiap kumpulan kemudian dibahagikan lagi secara rawak kepada dua set berasingan untuk membentuk dua set kes-kes. Satu set digunakan dalam penentukuran parameter yang tidak diketahui, iaitu kadar kehilangan tadahan. Lengkungan-lengkungan Kadar Kehilangan Tadahan-Indeks Kebasahan Tadahan-Keamatan Hujan Purata Berpemberat telah dicadangkan. Tujuh lengkungan LWRI telah dilukis dan dipilih untuk diprogramkan

ke dalam model bagi tujuan pentahkikan model dan peramalan. Kejituan pekali Manning yang digunakan dalam penentukuran parameter model telah dikenalpasti dengan memperpanjangkan jangkamasa penyelakuan 24-jam kes-kes terpilih kepada 48-jam. Pekali Manning 0.400 dan 0.040 untuk permukaan tanah dan terusan masing-masing telah dikenalpasti betul. Ini disokong oleh ujian-ujian statistik keatas tokokan yang diselakukan dan tokokan terukur masing-masing, dimana satu pekali sekaitan kuat 0.9799 daripada analisis keyakinan, satu ralat mutlak purata nisbi kecil yang tidak melebihi 1.46 cm pada paras keyakinan 95% daripada ujian-*t* purata tunggal, serta tiada bukti yang mencukupi untuk menyokong bahawa kedua-dua purata dan varians tokokan yang diselakukan dan tokokan terukur adalah berbeza, melalui ujian-*t* berpasangan dan taburan-*F* ujian nisbah varians masing-masing.

Set kedua telah digunakan untuk tujuan pentahkikan lengkungan LWRI dan pentahkikan model. Lengkungan LWRI didapati jitu dalam penentuan kadar kehilangan tadahan. Model ditahkikkan mampu menyelaku tokokan paras air takungan dengan tepat. Ini disokong oleh keputusan ujian-ujian statistik yang dijalankan keatas tokokan yang diselakukkan dan tokokan yang diukur masing-masing. Satu pekali sekaitan kuat 0.9799 daripada analisis keyakinan, satu ralat mutlak purata nisbi kecil yang tidak melebihi 2.20 cm pada paras keyakinan 95% daripada ujian-*t* purata tunggal, serta tidak terdapat bukti yang mencukupi demi untuk menyokong bahawa kedua-dua purata dan varians tokokan diselakukan dan tokokan terukur adalah berbeza melalui ujian-*t* berpasangan dan taburan-*F* ujian nisbah varians.

Model tersebut dinilaikan dengan membandingkannya dengan kaedah rasional. Keputusan ujian-ujian statistik menunjukkan bahawa model tersebut lebih baik jika dibandingkan dengan kaedah rasional. Pekali sekaitan dan ralat mutlak purata kaedah rasional didapati bersamaan dengan 0.8602 dan tidak melebihi 12.58 cm pada tahap paras keyakinan 95% masing-masing. Sementara itu, ujian-*t* berpasangan menunjukkan bahawa tidak terdapat bukti yang mencukupi untuk menyokong bahawa kedua-dua tokokan diselakukan dan terukur adalah sama. Pekali Theil yang dikira untuk model dan kaedah rasional didapati bersamaan dengan 0.062 dan 0.266 masing-masing. Ini juga menunjukkan bahawa model tersebut lebih boleh dipercayai dibandingkan dengan kaedah rasional.

Daripada analisis-analisis kepekaan, impek perubahan pekali Manning permukaan tanah keatas hidrograf air larian langsung yang diselakukan, serta tokokan paras air takungan, adalah lebih besar daripada yang disebabkan oleh perubahan pekali Manning terusan. Daripada kajian ini, didapati bahawa lebih perhatian dan ikhtiar perlu ditumpukan semasa memilih pekali Manning permukaan tanah jika dibandingkan dengan pekali Manning terusan. Keputusan-keputusan juga menunjukkan bahawa impek berkurangan dengan peningkatan keamatan hujan. Impek indeks kebasahan tadahan keatas kadar kehilangan tadahan dan tokokan paras air takungan sepadan didapati sederhana tinggi, akan tetapi ia bergantung kepada keadaan kes.

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I certify that an Examination Committee met on 06 April 2005 to conduct the final examination of HUANG YUK FENG on his Doctor of Philosophy thesis entitled "Development of a Reservoir Inflow Forecasting Model for an Ungauged Catchment" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

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HUANG YUK FENG

Date:

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