UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF DISTRIBUTED GRID-BASED HYDROLOGICAL MODEL AND FLOODPLAIN INUNDATION MANAGEMENT SYSTEM

A'KIF MOHAMMED SALEM AL_FUGARA

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By

A'KIF MOHAMMED SALEM AL_FUGARA

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

August 2008

DEDICATION

To my dear parents, brothers and sisters

your patients and support has been my motivation

I love you all

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

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Chairman: **Associate Professor Thamer Mohammed, PhD**

Faculty: **Engineering**

A physical based, distributed hydrological model was developed to route overland flows during isolated HISD storms. The model has operated on a grid or cell basis and routed the excess rainfall over the grids, conforming to the DEM-derived drainage paths, to the basin outlet. The rainfall-runoff hydrological modelling was implemented in MATLAB 7.0. The system has integrated GIS, RS, DEM, data management capability and a dynamic basin model within a common Windows environment. The simulation algorithms of the rainfall-runoff model have operated on grid bases compatible with the MATLAB programming language, which has been used to write instructions to many grid-based operations. Due to the MATLAB architecture, the system has been proven successful for large-scale basin modeling, which requires high level resolution, record keeping and technical transfer. The model has estimated the runoff using the Soil Conservation Service-Curve Numbers (SCS-CN), determined by the land use/ land cover and the hydrological soil group

found in each grid. The overland flow mechanics were described by the diffusion wave approximation of St Venant equations, which were numerically solved for depth of flow and runoff by the finite volume method (FVM). The grid cell physical properties such as topography, land use, soil, and Manning's roughness' coefficient were extracted from published maps for discretized cells of the Klang River basin(KRB) using a GIS. The land use/cover classes were derived from interpreted information of Landsat TM imagery using the combined object-oriented segmentation - fuzzy logic algorithm. The DEM of 90m resolution, used to calculate slopes that generated runoffs, was derived from radar data sets (C-band) of the Shuttle Radar Topography Mission (SRTM) using the interferometric approach. Four criteria were used for the assessment of the model performance - Model bias, Nash–Sutcliffe and model efficiencies for both low and high flows during both calibration and validation periods. The results showed the advantages of integrating RS, DEM and GIS with hydrologic simulation in generating runoff processes in the spatial domain, attaining as well fairly high precision simulation with the general hydrologic trends well captured by the model.

This study has also involved the application of flood modeling, which has integrated the results of the grid-based overland flow routing model into MIKE11 one-dimensional hydrodynamic model. The discharge hydrographs were extracted from the grid-based overland flow routing model in ASCII format and imported into MIKE11 hydrodynamic modeling system. The MIKE11 model was developed based on surveyed, stream cross-section data to perform hydrodynamic simulation of the flooding process. The MIKE11 modeling was applied to the Klang River system comprising 9 main tributaries. The analysis has considered the river system with and

without Stormwater Management and Road Tunnel (SMART) project, which involve structural flood mitigations measures including retention ponds, bypass tunnel and flow diversions, where the river physical condition was modified accordingly. Hourly data for flow were created into compatible MIKE11 time series in a separate file as input to the parameter editors. Initial and boundary conditions were based on the inputs for MIKE11 operational analysis. It has been found that the modeled predictions of depth and discharge matched observed data. A good agreement between the simulated and observed data was achieved for rating curves with RMSE = 0.96, 0.94, 0.95, and 0.97 at respective calibration points. From the results revealed by the MIKE11 modeling simulation, there were evidences that SMART was useful for flood mitigation of Klang River Basin. For instance at Tun Perak Bridge, the normal level for the Klang River was 25m, the alert level was 28m and the danger level was 29.5m. The value from the simulation showed that the maximum water level without SMART was 32m. However this level with SMART was only 27.8m which did not exceed the alert and danger level at Tun Perak Bridge. This area is the most critical part of KL. Once the water level from the Klang River exceeds the flood wall, the whole KL will be badly flooded.

Finally, the results of the runoff modeling were integrated in MIKE-GIS model for flood inundation mapping. A digital planimetric view and topographic mapping of the floodplain was developed using the three-dimensional floodplain visualization approach through the integration of a digital terrain model. This model was synthesized from MIKE11 stream cross-sectional coordinate into a digital surface model, generated from aerial stereo pair photos using Ortho Engine PCI image processing software. The resulting formulated surface model provided a good

representation of the general landscape and contained additional details within the stream channel. Integration of 3D-GIS and spatial analytical techniques together with hydrologic and hydraulic modeling processes has enhanced the visualization and display techniques for visual presentation and generation of flood inundation maps for early warning and contingency planning.

Abstrak tesis yang dibentangkan kepada Senat Universiti Putra Malaysia untuk memenuhi keperluan ijazah Kedoktoran Falsafah

PEMBANGUNAN MODEL TABURAN HIDROLOGI BERASASKAN GRID DAN SISTEM PENGURUSAN DATARAN BANJIR

Oleh

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Ogos 2008

Pengerusi: **Professor Madya Thamer Mohammed, PhD**

Fakulti: **Kejuruteraan**

Suatu model taburan hidrolik berasaskan fizikal telah dibangunkan untuk menentukan arahan aliran air permukaan tanah semasa peristiwa HISD yang terpencil. Model dapat beroperasi berasaskan grid atau sel dan menentukan arahan aliran air hujan berlebihan dipermukaan sel, mengikut arahan–arahan pengaliran yang berasal daripada DEM kepada jalan keluar lembangan. Pemodelan hidrolik hujan-larian permukaan telah dilaksanaan dalam MATLAB 7.0. Sistem itu dapat menyepadukan GIS, RS , DEM, keupayaan pengurusan data dan suatu model lembangan yang dinamik dalam satu persekitaraan WINDOWS yang umum. Algoritma-algorithma model simulasi hujan – larian permukaan dapat beroperasi berasaskan grid, yang dibaca dalam bahasa program MATLAB, yang pula di gunakan untuk menulis suruhan-suruhan menjalankan operasi-operasi berasaskan grid. Oleh kerana rekabentuk MATLAB, sistem ini dapat dijayakan dalam

pemodelan lembangan berskala besar, yang memerlukan resolusi tahap tinggi, penyimpanan rekod dan pemindahan teknik. Larian permukaan dapat dianggarkan oleh model dengan penggunaan *Soil Conservation Service-Curve Numbers (SCS-CN)* yang ditentukan oleh jenis guna tanah / litupan tanah dan kumpulan jenis tanah hidrologi pada setiap grid.

Mekanisma aliran permukaan tanah dapat digambarkan oleh *Diffusion Wave Approximation* dengan persamaan - persamaan *St Venant* , yang diselesaikan secara berangka untuk pendalaman aliran dan larian permukaan oleh keadah *finite volume* (FVM). Ciri-ciri fizikal setiap grid seperti topografi, guna tanah, jenis tanah, dan *Manning's roughness' coefficient* dapat diperolehi daripada peta-peta yang telah diterbitkan untuk sel *discretized* bagi lembangan Sungai Klang dengan peggunaan Sistem Maklumat Geografi (GIS). Kelas-kelas gunatanah / liputan tanah telah dihasilkan melalui maklumat penafsiran data Landsat TM dengan penggunaan kedah gabungan *object-oriented segmentation - fuzzy logic algorithm*. DEM berresolusi 90m, yang digunakan untuk perkiraaan kecerunan-kecerunan yang menghasilkan larian permukaan, dapat diperolehi dengan data radar (jaluran C) daripada *Shuttle Radar Topography Mission (SRTM)* melalui penggunaan keadah interferometric. Empat kriteria dapat digunakan untuk menilai prestasi model, iaitu *Model bias* , Nash–Sutcliffe dan kecekapan-kecakapan model bagi kedua-kedua aliran rendah dan tinggi dalam tempoh- tempoh kalibrasi dan pengesahan (*validation*). Hasil penilaian ini telah menunjukkan kebaikan – kebaikan penyepaduan RS, DEM dan GIS dengan simulasi hidrolik dalam proses-proses menghasilkan larian permukaan dalam domain spatial dan terus pula mencapai kejituan simulasi yang agak tinggi dengan ciri-ciri am hidrolik dilitupi lengkap oleh model.

Kajian ini telah juga melibatkan aplikasi pemodelan banjir, yang telah menyepadukan hasil-hasil model aliran atas permukaan tanah yang berasaskan grid di dalam MIKE11 model hidrodinamik satu dimensi. Hidrograf-hidrograf keluaran (*discharge)* telah diperolehi daripada model arahan aliran atas permukaan tanah yang berasaskan grid dalam format ASCII dan dimasukkan ke dalam sistem MIKE11 model. Model MIKE11 telah dibangunkan berasaskan data siasatan keratan lintang sungai untuk menjalankan simulasi hidrodinamik bagi proses banjir.

Model MIKE11 telah digunakan dalam sistem sungai Klang yang mengandungi 9 anak sungai utama. Analisa telah mengambil kira sistem sungai dengan atau tanpa projek *Stormwater Management And Road Tunnel (SMART)* yang melibatkan langkah-langkah berstruktur yang meringankan banjir, termasuk kolam penyimpanan air, terowong pintasan dan pemesongan aliran –aliran , yang mana keadaan fisikal sungai dapat diubahsuai sewarjanya. Data aliran setiap jam telah diwujudkan mengikut siri masa MIKE11 dalam satu fail berasingan sebagai input bagi penyunting-penyunting parameter. Keadaan-keadaan permulaan dan sempadan telah berasaskan input-input untuk analisa operasi MIKE11. Didapati bahawa ramalan-ramalan model bagi pendalaman dan keluaran adalah sama dengan data yang di perhatikan. Persetujuan baik diantara data simulasi dan data yang diperhatikan telah dicapai bagi *rating curves* yang mempunyai RMSE = 0.96, 0.94, 0.95, dan 0.97 pada titik-titik kalibrasi masing-masing. Daripada hasil-hasil yang ditunjukkan oleh model simulasi MIKE11, terdapat bukti-bukti bahawa SMART adalah berguna untuk meringankan banjir bagi lembangan sungai Klang. Sebagai contoh, di Jambatan Tun Perak, terdapat paras air biasa Sungai Klang ialah 25m, paras air amaran ialah 28m dan paras air bahaya ialah 29.5m. Nilai yang diperolehi dari simulasi menunjukkan

bahawa paras air maksima tanpa SMART ialah 32m. Walaubagaimanapun terdapat paras ini dengan SMART ialah 27.8 m sahaja, yang tidak melebihi kedua-dua paras amaran dan bahaya di Jambatan Tun Perak, yang merupakan kawasan yang paling kritikal di KL. Sekiranya paras air di Sungai Klang melibihi ketinggian dinding

.

Pada akhirnya hasil pemodelan larian permukaan dapat disatukan dalam model MIKE –GIS bagi tujuan pemetaan banjir. Satu pemandangan pelan yang berdigit dan pemetaan topografi bagi dataran banjir telah juga dibangunkan dengan menggunakan keadah penggambaran dataran banjir secara 3 dimensi melalui penyepaduan model bentuk muka bumi digital. Model ini dapat ubahkan melalui sintesis dari kordinat-kordinat keratan lintang sungai MIKE11 ke model permukaaan berdigit, yang pula dihasilkan dari foto udara berpasangan stereo dengan penggunaan perisian pemprosesan imej Ortho Engine PCI.

Hasil model permukaan yang dirumus dapat memberi satu perwakilan yang baik bagi landskap am dan mangandungi butiran tambahan pula dalam saluran sungai. Penyepaduan 3D-GIS dan teknik analisa spatial bersama proses- proses model hidrolik dan hidraulik telah meningkatkan teknik penggambaran dan pertunjukan bagi tujuan pembentangan dan penghasilan peta-peta banjir bagi tujuan pemberian amaran awal dan perancangan kontingensi.

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I certify that and Examination Committee has met on 29th August 2008 to conduct the final examination of A'kif Mohammed Salem Al_Fugara on his PhD thesis entitled "Development of Distributed Grid-Based Hydrological Model and Floodplain Induation Management" 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 Doctor Philosophy.

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

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Date: 13 November 2008

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently submitted for any other degree at Univirsiti Putra Malaysia or at any other institution.

A'KIF AL_FUGARA

Date: 20 November 2008

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