J. ENVIRONMENTAL SYSTEMS, Vol. 32(3) 201-219, 2005-2006

# FLOODPLAIN MAPPING AND VISUALIZATION FOR FLOOD RISK ASSESSMENT AND DECISION SUPPORT IN SARAWAK KANAN RIVER

**FREDERIK JOSEP PUTUHENA**

**DARRIEN YAU SENG MAH**

*Universiti Malaysia Sarawak*

**SAI HIN LAI**
*Universiti Sains Malaysia*

**ABSTRACT**

Sarawak Kanan River is one of the tidal rivers frequently affected by flood in Sarawak, Malaysia. Over the years, physical development has been concentrated in the middle valley town of Bau, where the center of administration and commerce for the district is located. The town of Bau and surrounding areas is a well known flood-prone area, for being geographically located in the floodplain of Sarawak Kanan River. Major floods of February 2003 and January 2004 had Bau and surrounding areas flood-stricken. The area has little hydrological information to ponder with, thus indicating a need of a flood visualization model to have a better explanation of the flooding scenarios in the floodplain areas. For this purpose, the flooding of Sarawak Kanan River was modeled using the InfoWorks RS one-dimensional hydrodynamic model. The inputs consist of observed discharge hydrographs of upstream Buan Bidi sub-catchment and lumped synthetic discharge hydrographs of ungauged sub-basins. Observed stage hydrographs measured at Siniawan were used as downstream input. This article outlined the methodology for flood mapping and visualization to enable flood risk assessment and decision support modeling for future development in floodplain protection and control. The model was capable of providing an acceptable estimate of flood depths with a correlation coefficient of 0.83.




doi: 10.2190/ES.32.3.b
http://baywood.com

## INTRODUCTION

Floodplains and flooding areas are typical geographical features (Correia, Saraiva, Da Silva, & Ramos, 1999; Gurnell & Montgomery, 1999). Therefore, most problems in such areas can be represented and analyzed in a geographical context using Geographic Information Systems (GIS). Both on global and local scales, scientists and planners have recognized the merits of this integrated and interdisciplinary system for providing a more complete understanding of the problems at hand and the alternative solutions to them (Star & Estes, 1990). This is certainly the case of floodplain planning and management.

InfoWorks River Simulation (RS), a Wallingford Software model, coupled with its embedded GIS application, had been used in this study to capture the hydraulic response of Sarawak Kanan River and its floodplain in extreme flooding conditions. This project is aimed to develop a methodology to reconstruct historical flood events at Sarawak Kanan River for floodplain mapping and visualization by utilizing a British modeling program InfoWorks RS on a Sarawakian river. The floodplain mapping scenarios are essential to provide information on areas that will be affected, the depth and duration of a flood with a certain probability. This information is important for a flood risk assessment.

## BASIN DESCRIPTION

Sarawak Kanan River, located southwest of Kuching city, is the right hand side principal tributary of Sarawak River (see Figure 1) which flows northward into South China Sea. The whole basin of Sarawak Kanan River (see Figure 2) is 630 $km^2$. The upstream sub-catchment of Buan Bidi is about 225 $km^2$. The average yearly precipitation in the basin is about 3500 mm. The rainy season typically occurs during the end of the year, starting November-December and extending till early the next year, around February-March, brought by the North-East Monsoon experienced in the region. Because of the presence of the urban town of Bau in the middle valley and Siniawan at the lower reach, flood risk is significant.

The Sarawak Department of Irrigation and Drainage (D.I.D.) regulates the hydrological monitoring system that consists of five rainfall measuring gauges (namely Kg Opar, Kg Monggak, Bau, Krokong, and Siniawan W.W.) and just two water level measuring gauges (Buan Bidi and Siniawan). Both water level gauges record data continuously each 30 minutes. No discharge measuring gauges exist in the basin but Buan Bidi water level gauging station had a developed rating curve for discharge computation which was developed based upon field measurements of velocity and channel geometry (KTA 1997), and allow for the conversion of stage data into flow data.

The gauging station at Buan Bidi is sited upstream of the tidal limit of Sarawak River. Siniawan gauging station is located downstream, measuring only the water


Figure 1. Sarawak River Basin.

level due to tidal influences. In between these two stations lies the town of Bau and several kampongs (see Figure 3) with approximate population of about 42,000. The area is left with little hydrological information to ponder with, thus indicating a need to reconstruct past flood events, particularly the February 2003 and January 2004 extreme floods, to have a better explanation of the flooding scenarios in the mentioned area. Devastating floods of February 2003 (with rainfall return period of 50 years order) and January 2004 (with rainfall return period of 100 years order) had hard hit Sarawak Kanan River valley. The river

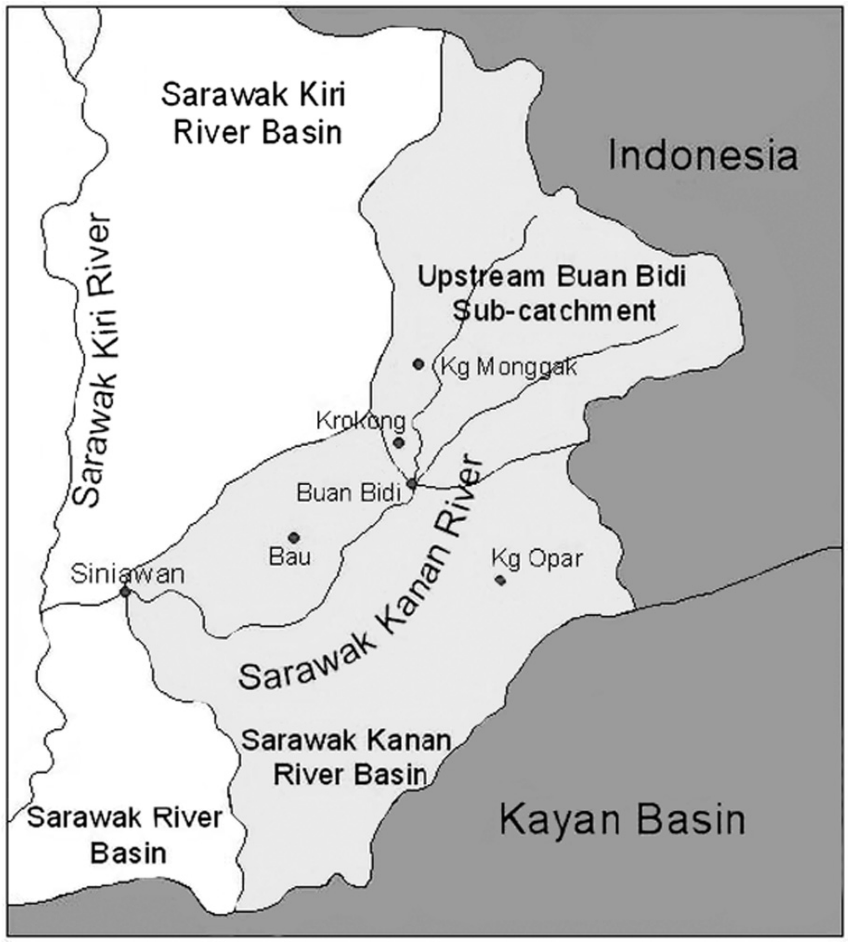



Figure 2. Sarawak Kanan River Basin.

channel was overtopped where the town and agricultural areas were heavily flooded (see Figures 4 and 5).

## RIVER REGIME

Sarawak River has historically undergone significant geomorphology change, especially downstream area. In the lower reaches, the implementation of the Sungai Sarawak Regulation Scheme in 1998 has changed the predominantly tidal flow regime into a regulated flow regime by constructing a barrage near estuary

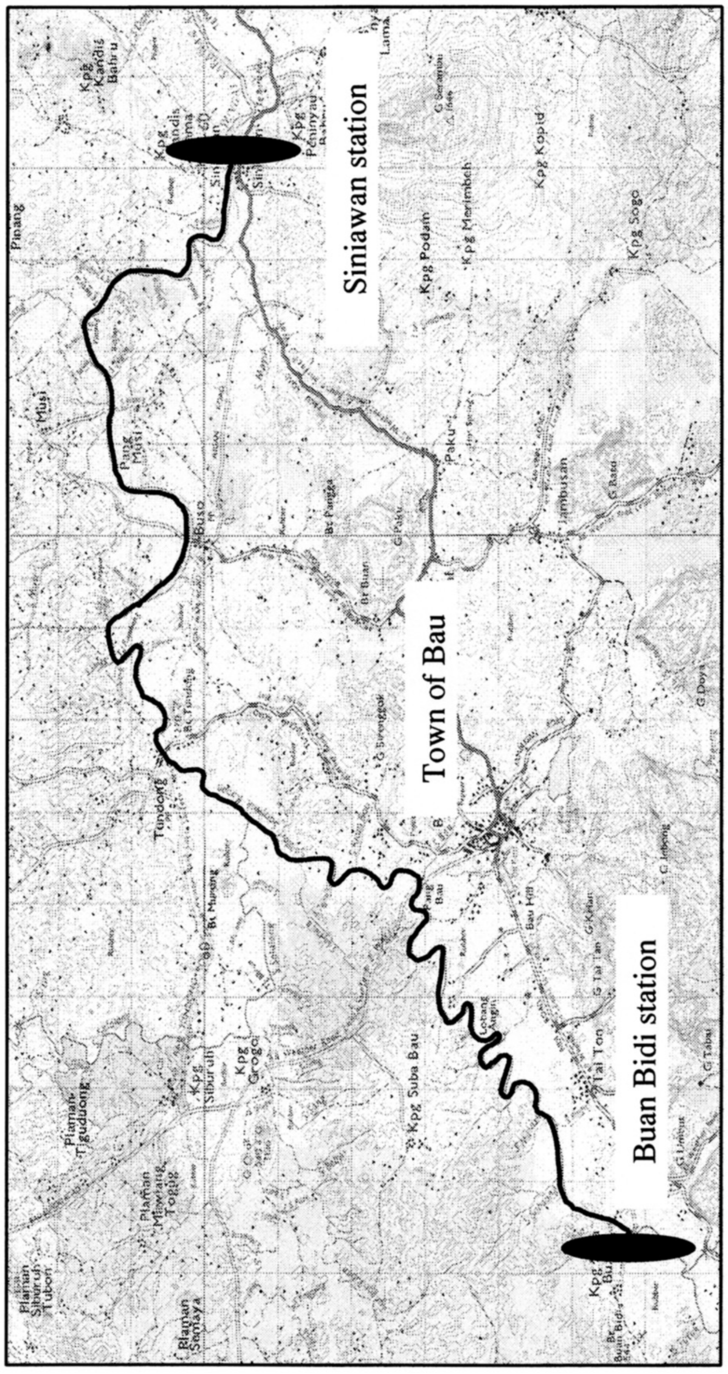
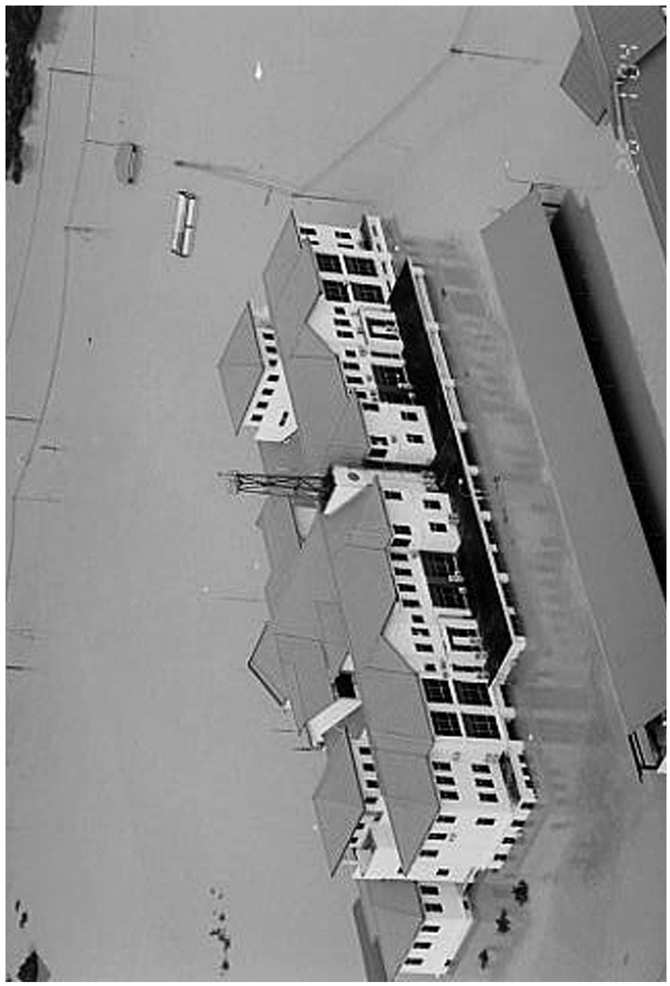



Figure 3. Locality of Buan Bidi, Bau, and Siniawan.



Figures 4 and 5. Inundation of Bau Police Station in January 2004, with a record of 3 m flood depth.

(KTA, 1997). After the full operation of barrage, the effect of tidal influx in Sarawak Kanan River is slightly diminished but not completely eliminated (Jurutera Jasa, 2003). Some variations in water level upstream of the barrage still occur dependant on the prevailing river flow and tidal conditions. For that reason, Siniawan as the downstream limit of the Sarawak Kanan River model was modeled as tidal-effected. The modeling approach was concentrated on post-barrage conditions.

## MODELING APPROACH

Because of the absence of any gauging in between Buan Bidi and Siniawan, it was resorted to use flood routing methodology on the 23 km studied river stretch. The upstream hydrograph was routed through the reach to predict changes of hydrograph shape and timing. Hydraulic models, in general, are more physically based since they only have one parameter (the roughness coefficient) to estimate or calibrate. Roughness coefficients can be estimated with some degree of accuracy from inspection of the waterway (Chow, Maidment, & Mays, 1988), which makes the hydraulic methods more applicable to ungauged situations in between Buan Bidi and Siniawan. Among the hydraulic models, hydrodynamic methodology solves the complete unsteady flow equations and is known capable of solving a wide range of open channels from steep to extremely flat slopes (Chadwick & Morfett, 1993). Since the length scale of Sarawak Kanan River is much higher than the width scale, a one-dimensional (1-D) model had been applied (Menozzi, Plazz, & Schippa, 1997). In order to supply the routing model to be drawn up with the necessary inputs, Sarawak Kanan River basin was divided into seven hydrological sub-basins (see Figure 6).

The river water level series observed at Buan Bidi were transformed into a time series of equivalent lumped discharge hydrograph of the upstream catchment. The flow hydrographs were treated as input to the hydrodynamic model as inflow hydrographs. The ungauged tributaries were simplified into sub-basins for the purpose of estimating the tributaries flows, which were injected to the flood routing model. Among the several existing tributaries, Selalang River, Saoh River, Musi River, and Pinang River are more significant rivers. Less significant tributaries were simplified into Bau and Siniawan sub-basins.

The well-studied upstream Buan Bidi catchment had catchment parameters that can be transposed for the computation of synthetic hydrographs for the neighboring tributaries sub-basins. By using the Snyder's methodology, rainfall excess was converted to surface runoff (Chow et al., 1988). The equivalent lumped synthetic hydrographs of sub-basins flows were estimated externally and supplied to the routing model for all confluence points along the river. The hydrodynamic routing model was used in combination with lumped discharge hydrographs for the seven hydrological sub-basins and observed stage hydrographs at Siniawan, as presented in Figure 7, for the reconstruction of historical flood events.

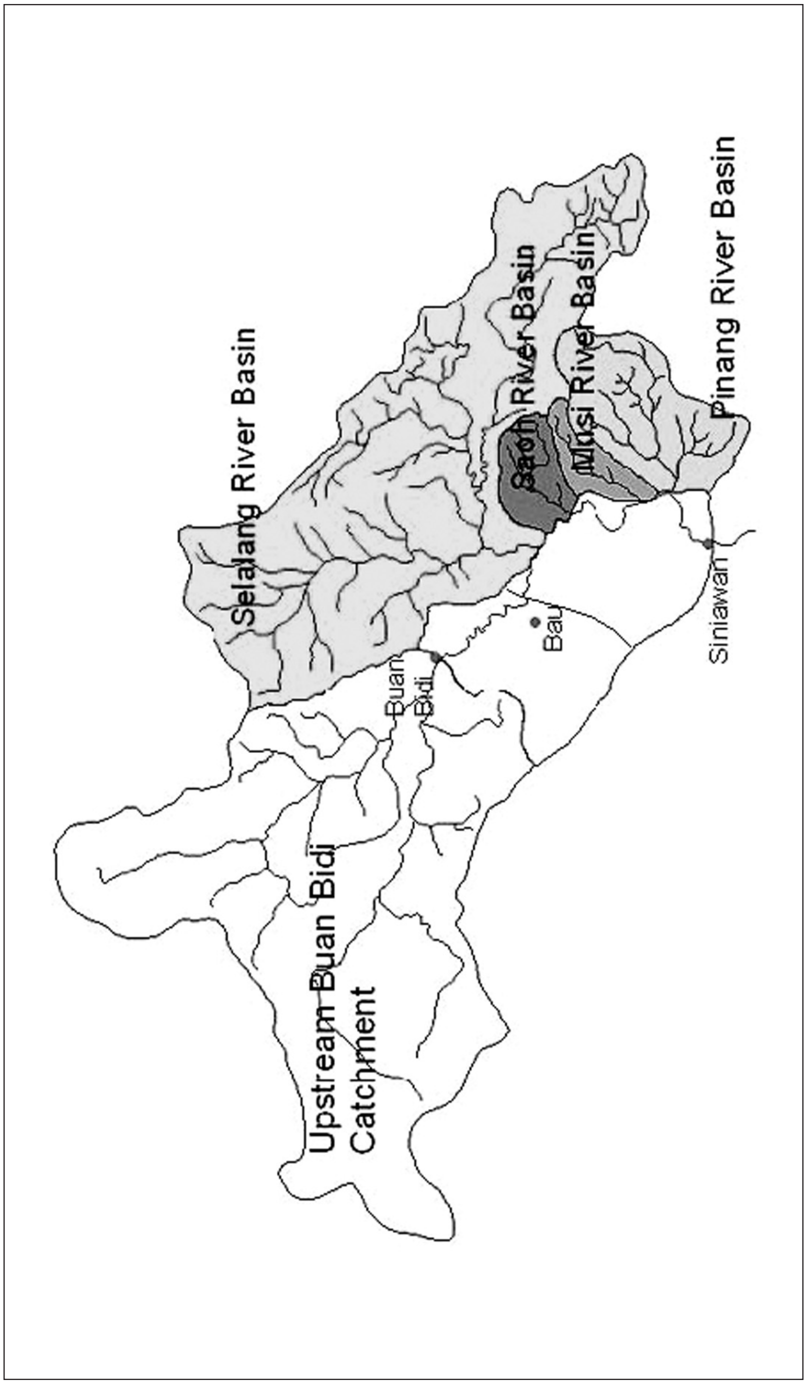



Figure 6. Hydrological Sub-Basins of Sarawak Kanan River.

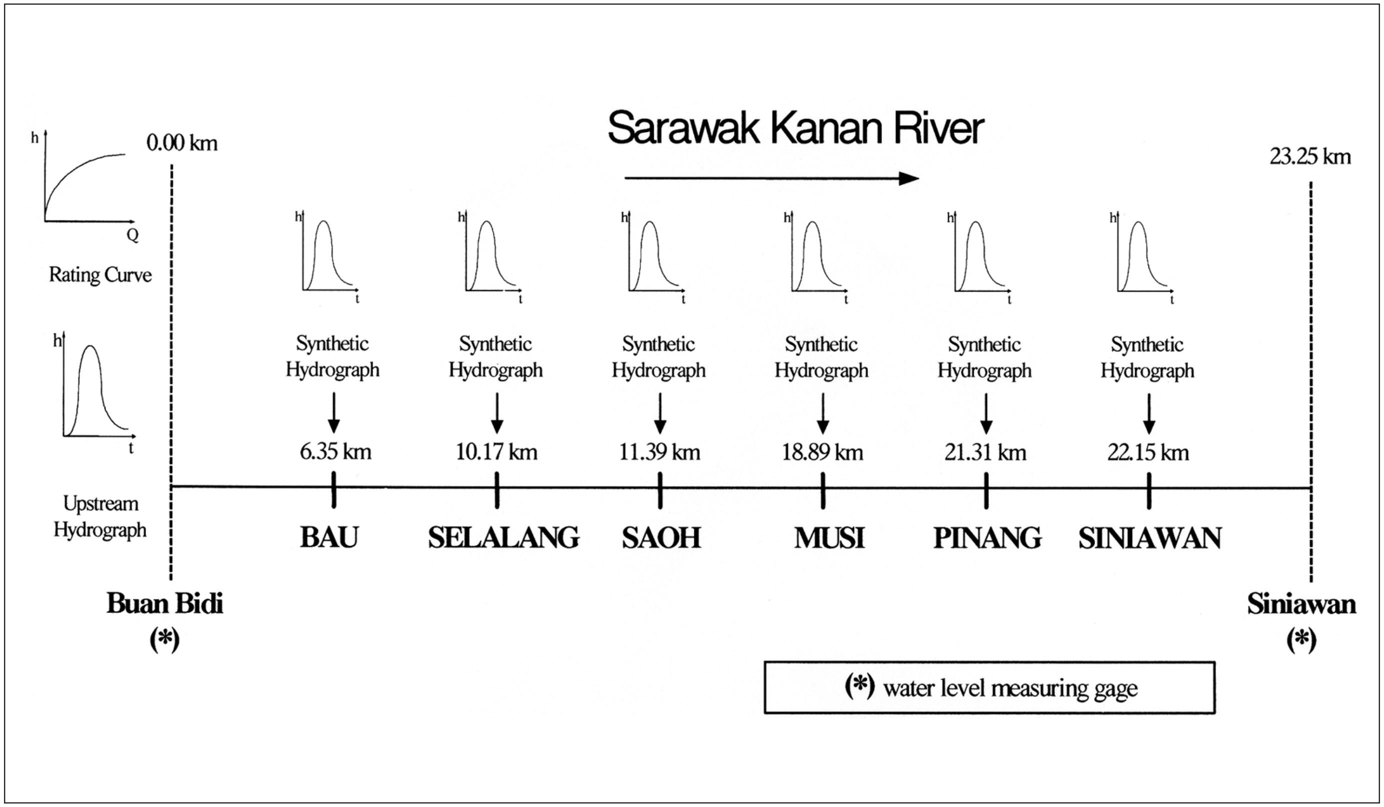



Figure 7. Schematic diagram for Sarawak Kanan River model.

The modeled out-of-bank flooding scenarios enabled InfoWorks RS model to perform flood mapping capability based on sophisticated flood-interpolation models overlaid onto a ground surface model. As presented in Figure 8, the topographic data was processed through ESRI ArcView. This processed topographic data was exported as an input to hydrodynamic model InfoWorks RS. Hydrological data like the boundary conditions and calibration parameters were directly provided to InfoWorks RS. After model was calibrated and verified, the model was used to reconstruct the devastating February 2003 and January 2004 floods.

## MODEL BUILDING

Direct links between InfoWorks RS and ESRI ArcView enable data to be converted directly into the InfoWorks RS model database for model build. A 1:50,000 scaled topographical map of 50 ft. (about 15 m) contour intervals featuring the Sarawak Kanan River project area was used to create a digital GIS map using ESRI ArcView v3.1 software, as shown in Figure 9. The Digital Terrain Model (DTM) of the project area was constructed as a Triangulated Irregular Network (TIN), an alternative to raster. In order to create DTM as an input into the InfoWorks RS model, the digital map was converted into TIN surface model using ESRI ArcView 3D-Analyst Extension v1.0, as shown in Figure 10.

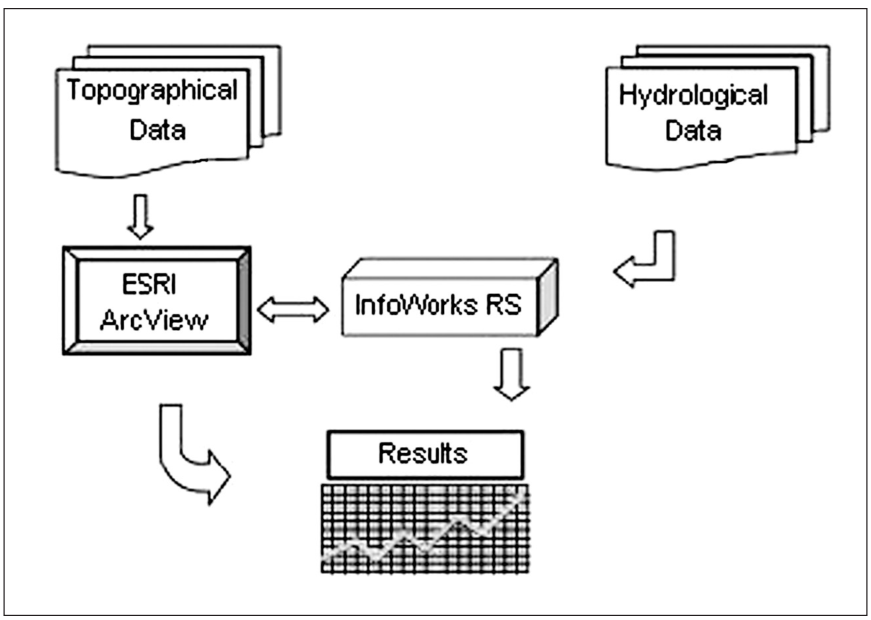



Figure 8. Organization chart of modeling scheme.

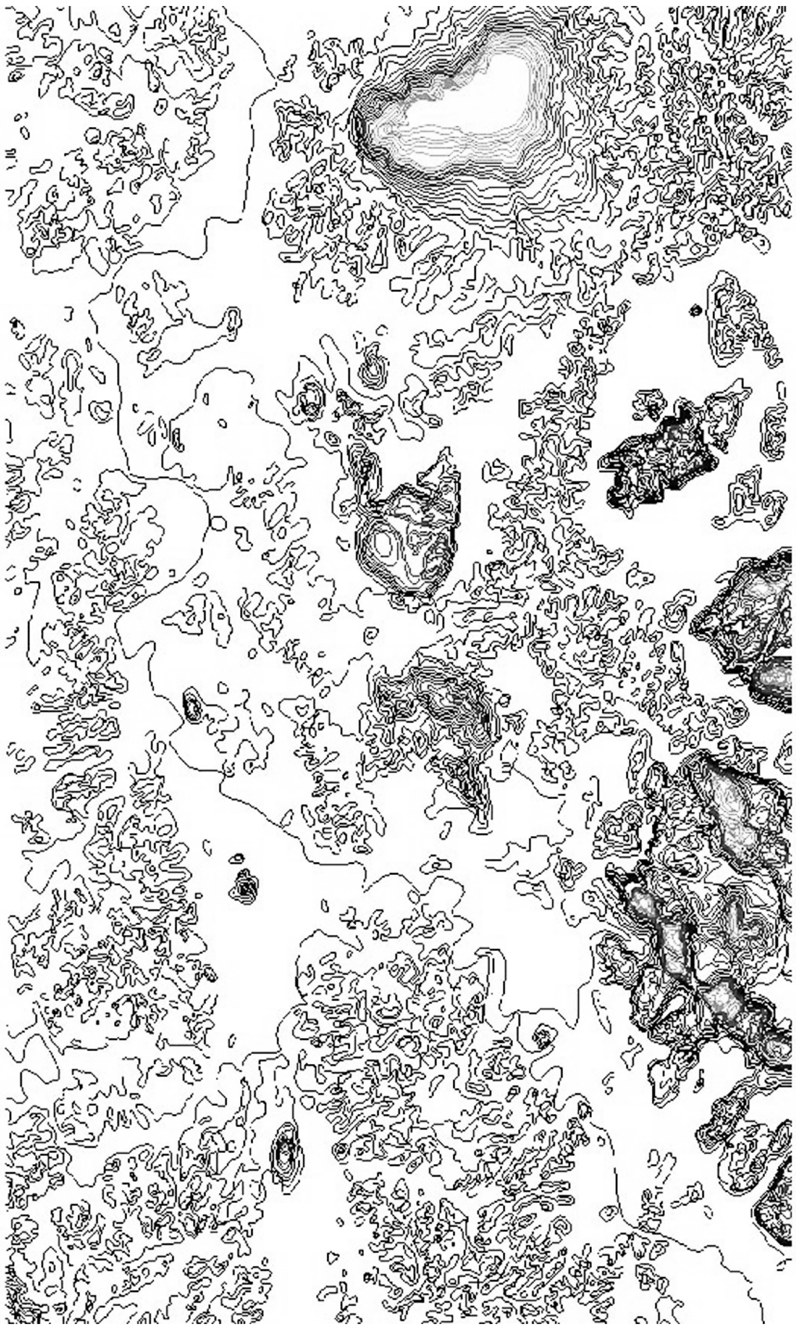


Figure 9. Elevation contour map of Sarawak Kanan River.

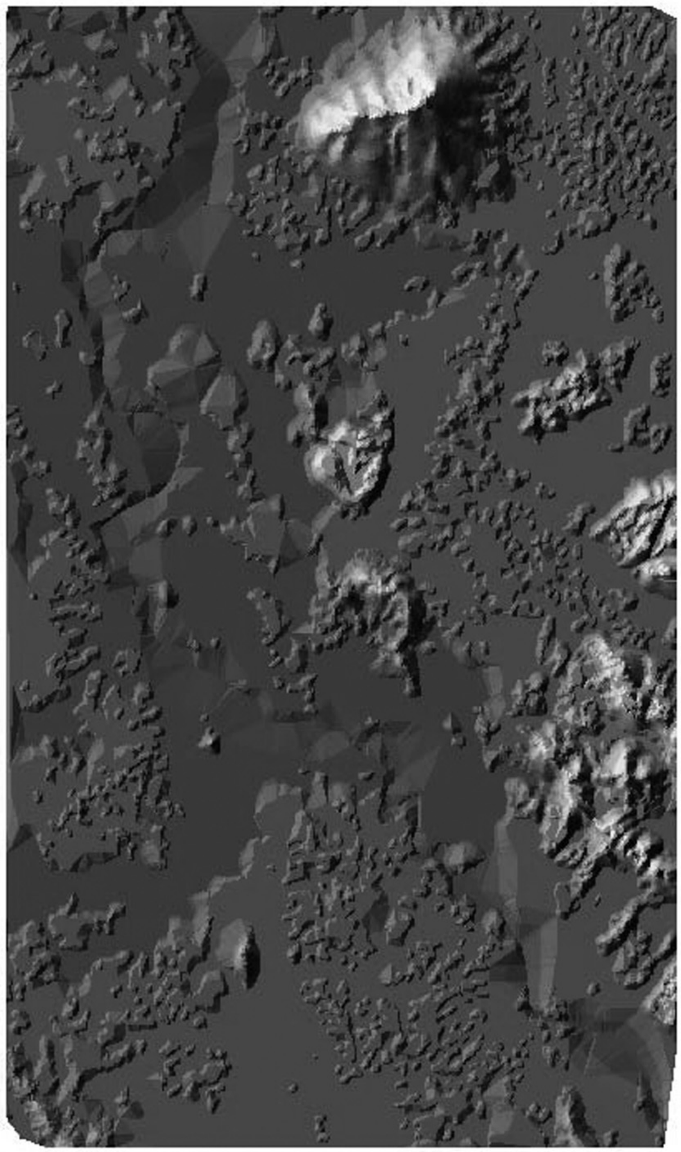


Figure 10. TIN surface model of Sarawak Kanan River.

The imported TIN into InfoWorks RS network was interacted through the embedded GIS tool—Geographical Plan (GeoPlan)—where Sarawak Kanan River network was developed through the on-screen creation of model nodes and links in conjunction with a digital GIS map background. Using TIN elevation data in InfoWorks RS enabled the direct take-off of elevation data to facilitate the extraction of model sections and floodplain storage properties based on overlaid section locations and boundaries. The TIN was also used to generate and display ground level contours, and formed the basis for dynamic flood mapping.

## MODELING PARAMETERS

The upstream inflow hydrographs of Buan Bidi were treated as a Flow-Time Boundary where it modeled a discharge hydrograph specified as a boundary condition. The Flow-Time Boundary specifies a set of data pairs comprising flows and times, usually applied at the upstream end of a network. A tidal Stage-Time Boundary was used as downstream boundary in Siniawan. The Stage-Time Boundary is in essence a rating curve that allows the input of a stage hydrograph as a boundary condition. This boundary condition is usually applied at the downstream end of a network. Internal boundaries for the tributaries and sub-basins flows were modeled as Rainfall Boundary. The estimated average rainfall and synthetic flows were fed in as rainfall-runoff relationship to this boundary condition. The Rainfall Boundary assists in modeling an inflow hydrograph from a sub-catchment. The hydrograph then becomes a boundary condition equivalent to a Flow-Time Boundary.

Each cross-section is separated from the next by a distance $\Delta x$; likewise the solution is carried forward in time by a series of discrete time steps $\Delta t$ (Boutayeb, El-Badraoui, & Mahfoud, 1995). InfoWorks RS uses the weighting factor $\theta$ as the numerical model parameter. To satisfy the weighting factor $\theta$ requirement corresponding to the 4-point implicit Preissmann scheme, the time step $\Delta t \geq 9$ s and distance $\Delta x < 1000$ m provided adequate resolution.

## MODEL CALIBRATION AND VERIFICATION

Model calibration and verification were performed by taking into account water level data in the lower course Siniawan due to the absence of data along the middle course. Roughness coefficients for InfoWorks RS model is in the form of Manning's *n* values. The analysis carried out indicated that a Manning's *n* of approximately 0.05 was appropriate for Sarawak Kanan River main channel and its floodplains, a Manning's *n* of 0.12 was appropriate. Calibration was carried out simulating three storm events: November 18, 2000 (3-hour); January 25, 1999 (7-hour); and February 04, 2000 (18-hour) storm events. Following calibration, the model was tested to measure its performance under different two sets of storm data: January 28, 2001 (11-hour) and February 16, 2001 (19-hour) storm events.

The model showed consistent results in simulating all calibration and verification events with correlation of observed and modeled data between 0.87–0.98. The differences of observed and modeled peak water levels were within the allowable limit of ± 0.10 m. A summary was presented in Table 1.

## MODELING APPLICATION RESULTS

GIS played a vital role throughout the entire project. It was used for data preparation, data unification, visualization, and most important, for data modeling. The existing TIN model of Sarawak Kanan River was used for generation of flood maps. Model results were overlaid onto the underlying TIN to generate accurate and reproducible flood extent maps, showing flood extent and depth to show the progression of a flood event (Davies, 2002; Hassan, 2004; Wallingford, 2004). Looking at Figure 11, the available resolution of flood map was of course due to limited resources. Observed flood depths along Sarawak Kanan River were compared to modeled flood depths (see Tables 2 and 3). The model was capable of providing an acceptable estimate of flood depths with a correlation coefficient of 0.83. The observed data was taken from the Department of Irrigation and Drainage Sarawak Flood Report for Kuching 2003 and 2004. Observed flood depths were for some low laying localities in the

Table 1. Error Estimation for Model Calibration and Verification Results

| | Calibration events | | | Verification events | |
|---|---|---|---|---|---|
| Siniawan results | Nov. 18, 2000 | Jan. 25, 1999 | Feb. 04, 2000 | Jan. 28, 2001 | Feb. 16, 2001 |
| Correlation coefficient | 0.90 | 0.98 | 0.95 | 0.87 | 0.89 |
| Peak error | 0.00597 | 0.00183 | 0.00315 | –0.01083 | –0.00880 |
| Observed peak (m LSD) | 5.530 | 5.996 | 8.245 | 6.277 | 7.504 |
| Simulated peak (m LSD) | 5.563 | 6.007 | 8.271 | 6.209 | 7.438 |
| Difference (m) | 0.033 | 0.011 | 0.026 | –0.068 | –0.066 |
| Date and time of peak | 19/11/00 0:55 | 26/1/99 12:25 | 5/2/00 22:10 | 28/1/01 23:00 | 18/2/01 5:00 |

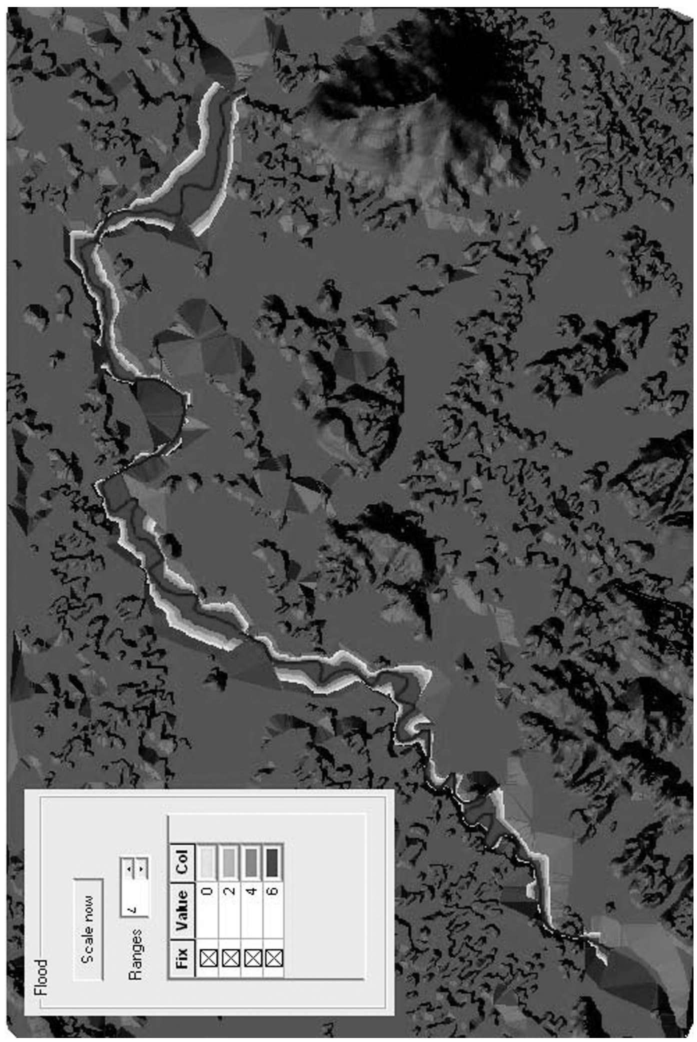



Figure 11. Flood map of Sarawak Kanan River for Jan. 2004 flood event.

Table 2. Modeled and Observed Flood Depths for February 2003 Flood

| Locations | Approx. bankfull stage | Flood peak level (m LSD) | | Flood depth (m) | | Comparison to historical floods | |
|---|---|---|---|---|---|---|---|
| | | Modeled | Observed | Modeled | Observed | 1963 | 1976 |
| Buan Bidi | 18.9 | 16.210 | 16.08 | No flood | — | — | 18.29 |
| Tundong | 7.8 | 9.012 | — | 1.2 | 0.6-1.2 | 15.18 | 11.59 |
| Buso | 6.9 | 8.244 | — | 1.3 | 1.5-2.0 | 13.50 | 13.08 |
| Siniawan | 4.5 | 7.190 | 7.19 | 3.0 | 2.8-3.0 | 10.89 | 8.50 |

Table 3. Modeled and Observed Flood Depths for January 2004 Flood

| Locations | Approx. bankfull stage | Flood peak level (m LSD) | | Flood depth (m) | | Comparison to historical floods | |
|---|---|---|---|---|---|---|---|
| | | Modeled | Observed | Modeled | Observed | 1963 | 1976 |
| Buan Bidi | 18.9 | 17.076 | 17.25 | No flood | — | — | 18.29 |
| Tundong | 7.8 | 10.968 | — | 1.5 | 1.5-2.0 | 15.18 | 11.59 |
| Buso | 6.9 | 10.201 | — | 3.3 | 2.0-3.0 | 13.50 | 13.08 |
| Siniawan | 4.5 | 9.720 | 9.71 | 4.0 | 3.0-3.2 | 10.89 | 8.50 |

affected area based on general visual observation. Somehow the exact locations and time of observation were not known.

The modeling effort also enabled the prediction of the following hydrological information at key locations:

- stage hydrographs with maximum and minimum water level data;
- flood discharge hydrographs and their parameters of peak discharge, time to peak, lag time, time base, and flood volume;
- sub-basins flow contributions and their volume; and
- velocities of flood flow.

## CONCLUSIONS

In the absence of discharge measurements, the quality of model application had to take into account both maximum water stage and water level time evolution during the flood in order to represent both flow resistance and discharge time evolution respectively. The InfoWorks RS 1-D numerical model herein adopted was capable in these purposes and led to consistent results. This makes the model a valuable tool for analyzing the many proposed flood management options for supporting decisions on how to manage future floods in the Sarawak Kanan River catchment. The conclusions being drawn were:

- Model performs well with limited topographic information. The type and resolution of topographic data currently available for Sarawak Kanan River was enough to setup a 1-D model for flood routing purposes.
- Lesser topographic data requirement to define model along with continuity and momentum equations made the task of setup and running the model efficient.
- Outputs of model were water levels and discharges along the direction of flow in Sarawak Kanan River.
- Water level and discharge information is only available at points where cross sections are defined. In this case, the distance between cross sections is about 1 km apart.

## REFERENCES

Boutayeb, N. E., El-Badraoui, M. H., & Mahfoud, J. (1995). *Hydraulic modeling of the Ourika Valley.* Proceedings of 2nd DHI Software User Conference, June 9-11. Available from: http://www.dhi.dk/usercon/abstr/22.doc [Accessed January 19, 2004].

Chadwick, A., & Morfett, J. (1993). *Hydraulics in civil & environmental engineering* (2nd ed.). London: E & FN SPON.

Chow, V. T. , Maidment, D. R., & Mays, L. W. (1988). *Applied hydrology.* New York: McGraw-Hill.

Correia, F. N., Saraiva, M. D. G., Da Silva, F. N., & Ramos, I. (1999). Floodplain management in urban developing areas. Part II. GIS-based flood analysis and urban growth modeling. *Water Resources Management, 13,* 23-27. Kluwer Academic Publishers.

Davies, T. C. (2002). *Case studies of water & sewer modeling in a fully integrated GIS environment using MapObjects and ArcView GIS.* Available from: http://gis.esri.com/library/userconf/proc00/professional/papers/PAP359/p359.htm [Accessed January 17, 2004].

Gurnell, A. M., & Montgomery, D. R. (1999). *Hydrological application of GIS.* Great Britain: John Wiley & Sons.

Hassan, A. J. (2004). *Analyzing floods on the Kerian River, Malaysia. User case studies.* Available from: http://www.wallingfordsoftware.com/news/fullarticle.asp?ID=243 [Accessed July 20, 2004].

Jurutera Jasa (Sarawak) Consultant for DID. (2003, February). *Sungai Sarawak Flood Mitigation Options Study* (Vol. I, II, & III) – Main Report.

KTA Consultant with CMPS & F Pty Ltd, DHI & UNIMAS for NREB/DID. (Mac 1997). *Sungai Sarawak Environmental Control & River Management Study* (Vol. 3) – Flood Mitigation Plan.

Menozzi, R., Plazz, M., & Schippa, L. (1997). *1-D Numerical Model Applied To Flood Routing In Presence of Large Flooded Areas Connected To The River: The Case Study of Senio.* Proceedings of 2nd DHI Software User Conference, June 9-11.

Star, J., & Estes, J. (1990). *Geographic information systems: An introduction.* New Jersey: Prentice Hall.

Wallingford Software. (2004). InfoWorks RS Models the Juru River, Malaysia. User case studies. Available from: http://www.wallingfordsoftware.com/news/fullarticle.asp?ID=244 [Accessed July 20, 2004].

Direct reprint requests to:

Frederik Josep Putuhena
Department of Civil Engineering
Faculty of Engineering
Universiti Malaysia Sarawak
94300 Kota Samarahan
Sarawak, Malaysia
e-mail: fjputuhena@feng.unimas.my