USE OF INFOWORKS RIVER SIMULATION (RS) IN SUNGAI SARAWAK KANAN MODELING

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ABSTRACT

The main purpose of this project was to reconstruct historical flood events at the flood-prone Sungai Sarawak Kanan to obtain flood hydrographs to provide explanation to the flooding of Bau town and surrounding areas. The Sungai Sarawak Kanan and its floodplains were modeled using one-dimensional hydrodynamic modeling approach, by utilising the Wallingford Software model - InfoWorks River Simulation (RS), coupled with its embedded GIS applications, to capture the hydraulic response of the river and its floodplains in extreme flooding conditions. InfoWorks RS was applied on 23 km of Sungai Sarawak Kanan between Buan Bidi and Siniawan. The model was calibrated with 3 storm events, verified with another 2 sets of storm data and applied on reconstructing 2 extreme events of February 2003 and January 2004 floods where the correlation of observed and simulated data at Siniawan were between 0.87 – 0.98. The differences of observed and modeled peak water levels were within the allowable limit of ± 0.10 m. Similar efficiency had been achieved in the interpretation on the simulation of reconstruction results through analysis of flood depths and flood watermarks. The model was managed to estimate the flood depths and flood watermarks within the observation range by Department of Irrigation and Drainage Sarawak. This shown that InfoWorks RS is an appropriate model for flood modeling in Sungai Sarawak Kanan.

Keywords: *Flood, GIS, Hydrodynamic, InfoWorks RS, Sungai Sarawak Kanan*

1.0 SUNGAI SARAWAK KANAN

Sungai Sarawak Kanan, located south-west of Kuching city, is a right hand side principal tributary of Sungai Sarawak which flow north-ward into South China Sea. The whole basin of Sungai Sarawak Kanan is 630 km^2. The upstream sub-catchment of Buan Bidi is about 225 km^2. Sungai Sarawak Kanan springs from Bungoh Range of Sarawak-Kalimantan border and flows 65 km downstream before confluences with Sungai Sarawak at Batu Kitang. Sungai Sarawak Kanan drains the upper catchment of Sungai Sarawak of mountainous region and passes through the rural townships of Bau, Siniawan and surrounding villages (see Figure 1). Due to the presence of the urban town of Bau in the middle valley and Siniawan at the lower reach, flood risk is significant (see Figure 2).

The Department of Irrigation and Drainage (DID) Sarawak regulates the hydrological monitoring system that consists of 5 rainfall measuring gauges and only 2 water level measuring gauges. 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 has been developed based upon field measurements of velocity and channel geometry, and allow for the conversion of stage data into flow data [1]. The gauging station at Buan Bidi is sited upstream of the tidal limit of Sungai Sarawak. Siniawan gauging station only measures the water level due to tidal influences [1]. Table 1 highlighted the distribution of hydrological monitoring stations over the river basin.

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 the early of the next year, around February – March, brought by the North-East Monsoon experienced in the region.

Table 1: Measuring gauges available in Sungai Sarawak Kanan Basin

Measuring Gauges of Department of Irrigation and Drainage (DID) Sarawak [2]				
Station	Type	DID Station Number	Established Since	Remarks
Bau	Rainfall	1401005	1969	
Krokong	Rainfall	1301074	1970	
Siniawan W.W.	Rainfall	1402001	1983	
Kg Monggak	Rainfall	1301001	1990	
Kg Opar	Rainfall	1400001	1990	
Siniawan	Water Level	1402401	1990	
Buan Bidi	Water Level	1301427	1970	With Rating Curve $Q = 13.18\ H^{1.55}$

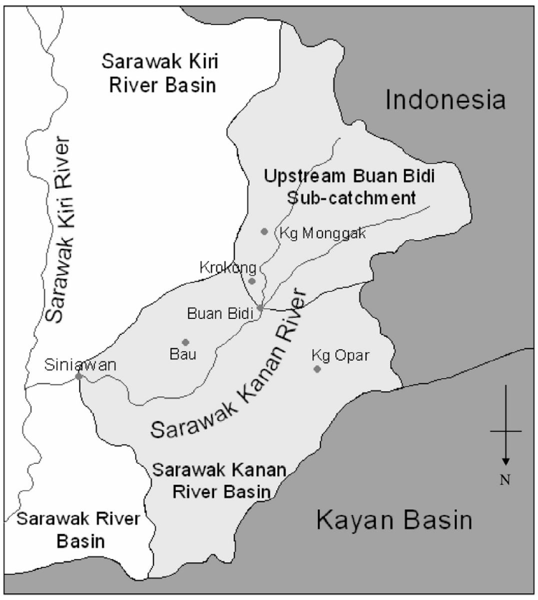

Figure 1: Sungai Sarawak Kanan system

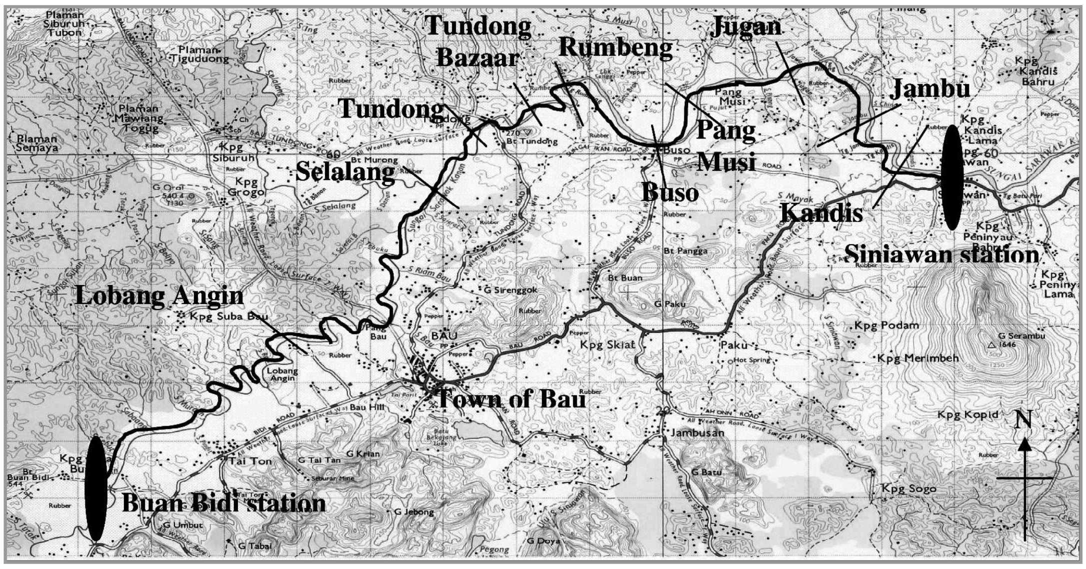

Figure 2: Topographical map of Bau area

Sungai Sarawak Kanan is one of the rivers frequently affected by flood. Over the years, land and properties development has been concentrated in the middle valley town of Bau, where it is the center of administration and commercial. Bau is targeted as a satellite town of Kuching under the Kuching Regional Strategy to accommodate a population of 40,000 to 50,000 persons [3]. The town provides a wide range of employment opportunities and acts as the district focus through the provision of essential shopping, government and other community facilities; at the same time, the focus of tourist activities in the district based on its mining past, the Bidayuh cultures and the adjacent mountains and caves.

The limited two water level monitoring stations of 23 km apart at Buan Bidi and Siniawan poorly represent any meaningful flow conditions at Bau town and surrounding areas. Records on the correlation of the water level data at the gauged site to Bau area are rare. Rivers like Sungai Sarawak Kanan, with minimal monitoring or practically ungauged are abundant in Sarawak due to its vast land area and large distribution of river networks. However, development and demonstration of InfoWorks RS modeling on Sungai Sarawak Kanan offered an alternative format for use as learning and sharing tool in this region for the afore-mentioned problem. The importance of such effort was to demonstrate the capability of a new generation hydrodynamic modeling tool in flood mitigation and management for learning and sharing of experiences in this region.

2.0 FLOODING SCENARIOS

The town of Bau and surrounding areas are well-known flood prone area, for located geographically in the floodplain of Sungai Sarawak Kanan. Major floods of February 2003 (with rainfall return period of 50 years order) [4] and January 2004 (with rainfall return period of 100 years order) [5], had Bau and surrounding areas flood-stricken. As a result of extreme rainfall events during February 2003 and January 2004 floods, much of Kuching city was affected, the worst ever registered after 1963 major flood. The devastating floods that hit Bau area were particularly severe along the middle and lower courses of Sungai Sarawak Kanan. Extensive flooding outside the main channel was observed. However, Sungai Sarawak Kanan with its limited flow gauging stations has little hydrological information to ponder with, thus indicating a need to reconstruct past flood events to provide protection, control and decision support for future development.

Sungai Sarawak Kanan basin natural vulnerability to flooding is significant. This project was aimed to demonstrate the reconstruction of flood events at Sungai Sarawak Kanan to obtain flood hydrographs using a UK-based modeling program InfoWorks RS on a Sarawakian river. The reconstructed flood hydrographs of both extreme flood events in Sungai Sarawak Kanan are important tools to serve as a useful indicator of flushing performance during extreme conditions. Prediction of the movement of floodwater is capable of providing explanation to the flooding of Bau town. A knowledge of hydrological information on the effect of a rise in river levels as a result of an increase in rainfall over a specific time period in Sungai Sarawak Kanan, could literally help in understanding of Sungai Sarawak Kanan to better protect its population in the future.

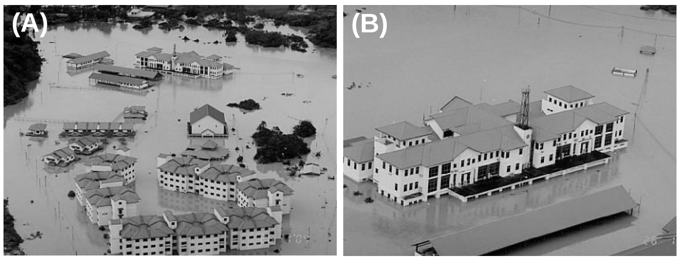

Figure 3: Inundation of Bau Police Station in January 2004, with a record of 3m flood depth

3.0 MODELING APPROACHES

Because of the morphology of the valley, it is necessary to adopt a model scheme which takes into consideration of the factors of rather flat floodplain area and ungauged condition between Buan Bidi and Siniawan.

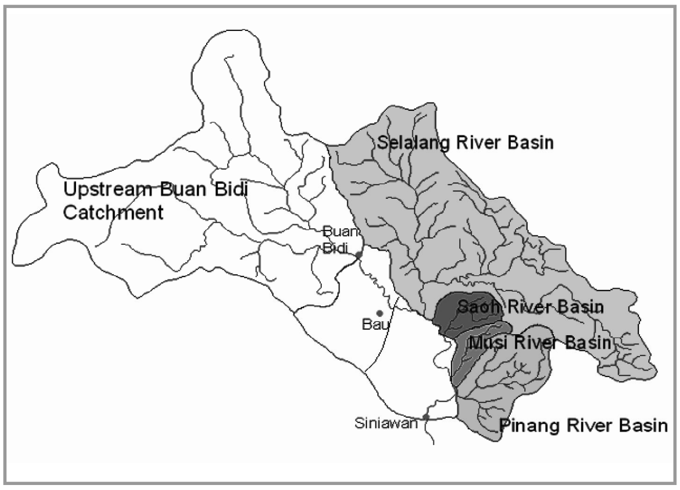

Figure 4: Hydrological sub-basins of Sungai Sarawak Kanan

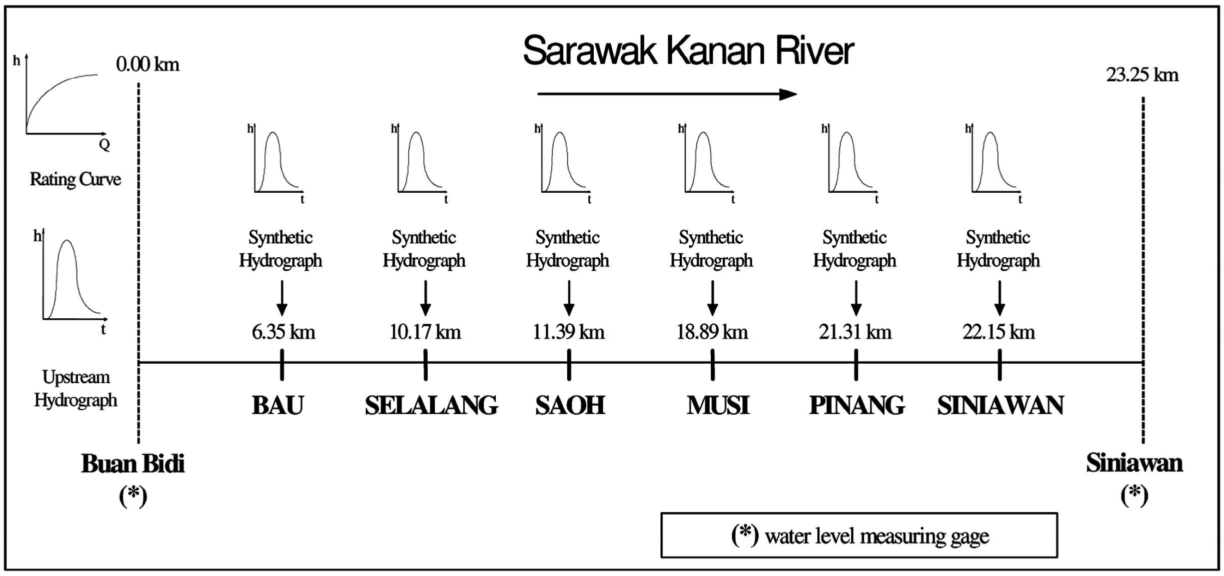

Figure 5: Schematic diagram for Sungai Sarawak Kanan model

A. FLOOD ROUTING

Due to the absence of any gauging in between Buan Bidi and Siniawan, it was resorted to 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, 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. Since the length scale of the modeled stretch of Sungai Sarawak Kanan is much higher than the width scale, a one-dimensional (1-D) model had been applied.

To supply the routing model to be drawn up with the necessary inputs, Sungai Sarawak Kanan basin was divided into 7 hydrological sub-basins (See Figure 4).

B. UPSTREAM BUAN BIDI CATCHMENT FLOWS

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.

C. UNGAUGED TRIBUTARIES AND SUB-BASINS FLOWS

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 [6] has catchment parameters that can be transposed for the computation of synthetic hydrographs for the neighboring tributaries sub-basins. Previous exercise had developed a rainfall-runoff model for Buan Bidi sub-catchment using HEC-HMS to simulate single storm events. Calibrated values of Snyder's coefficient, Ct; peaking coefficient, Cp and constant loss rate were transposed, on the assumption that these ungauged tributaries are spatially correlated with the upstream Buan Bidi sub-catchment. The proposed values of Ct varied from 1.85 to 2.00 while Cp varied from 0.10 to 0.65. Constant loss rate was determined using ϕ-index, ranging from 1.22 to 5.49 mm/hr. Catchment characteristics like basin area, A; length of main stream, L and length to centroid of basin, Lc were measured from the topographical map. By applying the average values of the mentioned parameters and catchment characteristics to the Snyder's methodology, rainfall excess was converted to surface runoff [7]. 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.

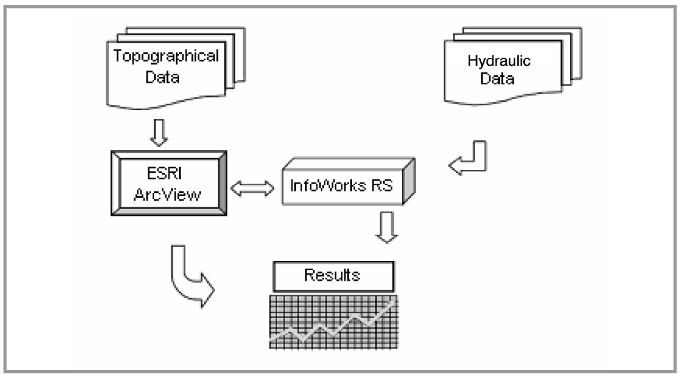

Figure 6: Schematic diagram for modeling analysis

D. MODEL STRUCTURE

The hydrodynamic routing model was used in combination with lumped discharge hydrographs for the 7 hydrological sub-basins in Sungai Sarawak Kanan, as presented in Figure 5, for the reconstruction of historical flood events.

4.0 INFOWORKS RS

InfoWorks RS is one of the modeling programs that combine the advanced flow simulation engine, both hydrological and hydraulic models, GIS functionality and

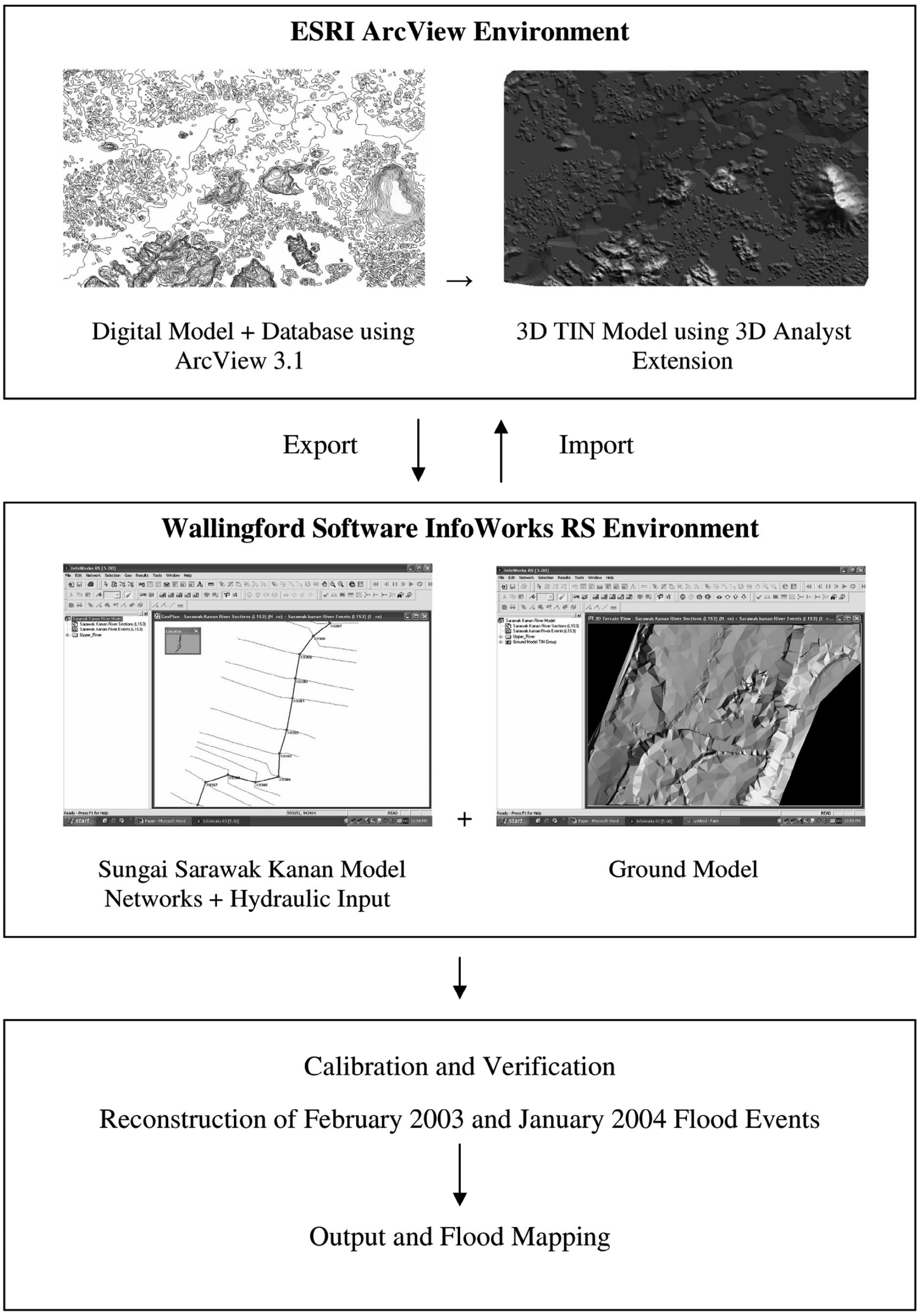

Figure 7: Schematic diagram for model building

database storage within one single environment. The basic system architecture is an "Integrated Network Model" links data storage using a GIS to hydrologic/hydraulic modeling software suite embedded in InfoWorks RS [8].

Hydrodynamic refers to the motion of a water body through its geo-morphological environment, taking into account the effects of gravity and friction at the water/bed interface [9]. A hydrodynamic model simulates these effects, giving the water surface elevation and velocity in response to tidal influence and flows from upstream river tributaries. The Wallingford Software's InfoWorks RS is an example of one-dimensional hydrodynamic model used for prediction of discharge and water level for a wide range of rivers, reservoirs, complex floodplains and narrow estuaries under both steady and unsteady conditions. InfoWorks computes flow depths and discharges using a method based on the equations for shallow water waves in open channels - the Saint-Venant equations, which consist of the continuity equation, Equation 1, and the momentum equation, Equation 2. The solution of these equations defines the propagation of flood wave with respect to distance along the channel and time.

$$B\frac{\partial y}{\partial t}+\frac{\partial Q}{\partial x}=q \qquad (1)$$

Table 2: Error estimation for model calibration and verification

Siniawan Results	Calibration Events			Verification Events	
	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

Note: * Calculated by $\dfrac{Cov\left(h_{obs}, h_{sim}\right)}{\sigma_{h_{obs}} \cdot \sigma_{h_{obs}}}$ ^ Calculated by $\dfrac{h_{obs-\max} - h_{sim-\max}}{h_{sim-\max}}$

Calculated by $h_{obs-\max} - h_{sim-\max}$

where y is stage, Q is discharge, B is stream top width, q is lateral flow into the channel per unit length of channel (e.g., overland flow or ground water return flow), x is distance along the channel, and t is time.

$$S_f = S_o - \frac{\partial y}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t} \tag{2}$$

where g is gravitational acceleration, and S_f is friction slope. The friction slope is defined as

$$S_f = \frac{Q^2}{K^2} = \frac{n^2 Q^2}{A^2 R^{4/3}} \tag{3}$$

where A is flow area, K is conveyance, R is hydraulic radius, and n is Manning roughness coefficient. The cross-sectional average flow velocity used hereafter is defined as V = Q/A.

The variables stage, y, and the discharge, Q, are the dependent variables. The dependent variables are those that are determined by the solution method. Time, t, and distance, x, are the independent variables. All other variables are functions of the dependent or independent variables.

InfoWorks model uses a four-point, implicit, finite difference approximation to solve the Saint-Venant equations in full, together with proper boundary conditions. The scheme is structured so as to be independent of the wave description specific (kinematic, diffusive or dynamic).

5.0 MODEL BUILDING

Direct links between InfoWorks RS and ESRI ArcView enable data to be converted directly into InfoWorks RS model database for model build. A 1 : 50 000 scaled topographical map of 50 ft (about 15 m) contour intervals featuring the Sungai Sarawak Kanan project area [10] together with twelve (12) surveyed river cross sectional profiles [extracted from 2] were used to create a digital GIS map, as shown in Figure 7, using ESRI ArcView v3.1 software [11]. The digital map was converted into a Triangulated Irregular Networks (TIN) surface model using ESRI ArcView 3D-Analyst Extension v1.0 [12]. This processed topographic data was exported as a Digital Terrain Model (DTM) to the hydrodynamic InfoWorks RS model.

The exported DTM into InfoWorks RS network was interacted through its embedded GIS tool - Geographical Plan (GeoPlan), where model cross sections and floodplain storage properties were extracted based on the DTM. All extracted properties formed the core of the hydrodynamic model. The DTM was used to generate and display ground level contours, and formed the basis for dynamic flood mapping.

Sungai Sarawak Kanan network was developed through the on-screen creation of model nodes and links via the GeoPlan view in conjunction with a digital GIS background map. In constructing the Sungai Sarawak Kanan model used in this study, the digital map was imported into InfoWorks RS as a background graphic. Nodes (points) are then digitally placed along each cross section at an adequate spacing to capture the sinuosity of each branch. Referring to Figure 7, a node is a point at which the shape of the river extracted from DTM; the dot is placed at the main channel center line, which is defined as the lowest mid-point of the bed. Associated with each node is a river section (thinner line). Each link (thicker line) represents the river between two nodes.

Hydraulic data like the boundary conditions and calibration parameters were directly provided to InfoWorks RS. 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.

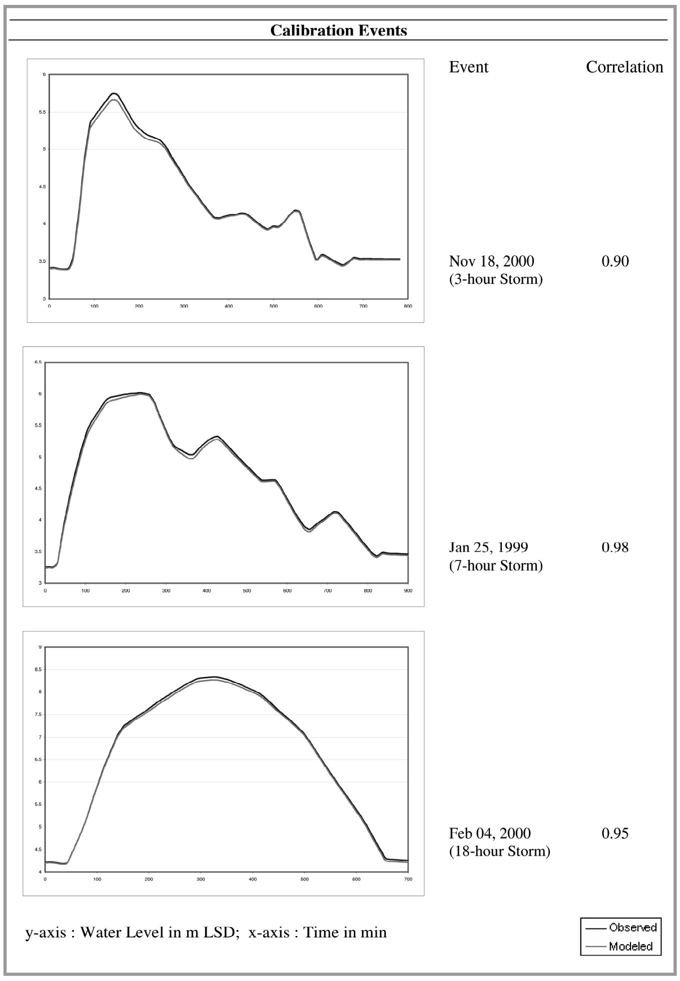

Figure 8: Best fits in model calibration and verification events

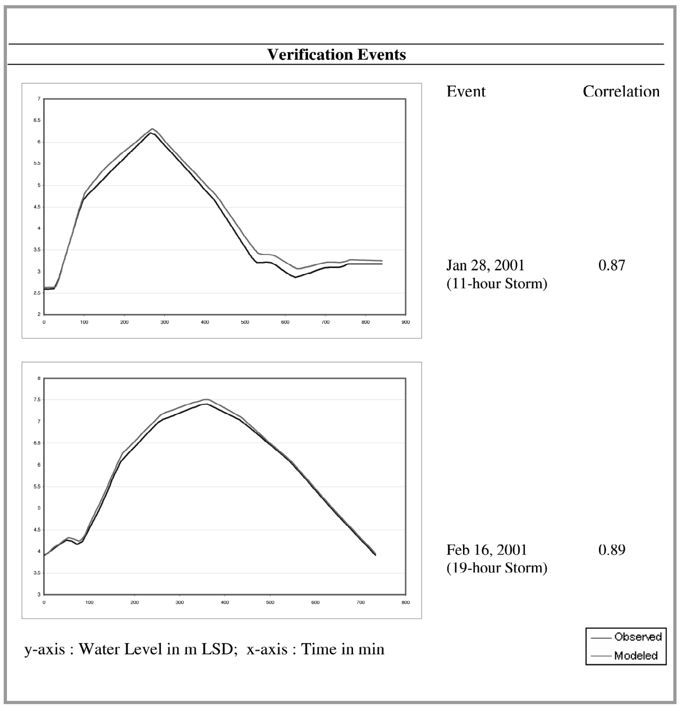

Figure 8 (continue)

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 was separated from the next by a step distance, Δx. Likewise the solution was carried forward in time by a series of discrete time steps, Δt. InfoWorks RS uses the weighting factor θ as the numerical model parameter. To satisfy the weighting factor θ 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. After the model was calibrated and verified, the model was used to reconstruct the devastating February 2003 and January 2004 floods. The results of InfoWorks RS can either be directly viewed or can be displayed over topographic data through ESRI ArcView.

6.0 CALIBRATION AND VERIFICATION

Since no discharge measurements are available along the middle reach, the efficiency of the estimated flow was calibrated and verified by matching the recorded and simulated hydrograph at the downstream end of the whole basin (Siniawan).

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 Sungai Sarawak Kanan main channel and its floodplains, a Manning's n of 0.12 was appropriate.

Calibration was carried out simulating 3 storm events:
November 18, 2000 (3-hour storm)
January 25, 1999 (7-hour storm)
February 04, 2000 (18-hour storm)

Following calibration, the model was tested to measure its performance under different 2 sets of storm data:
January 28, 2001 (11-hour storm)
February 16, 2001 (19-hour storm)

The model shown 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 [13,14]. A summary was presented in Table 2 and a graphical depiction in Figure 8.

7.0 MODEL APPLICATIONS IN FLOOD RECONSTRUCTION

After the model was well calibrated and verified, investigation on the reconstruction approach for extreme flood events of February 2003 and January 2004 in Sungai Sarawak Kanan was undertaken.

The February 2003 event lasted for up to 22 hours in Sungai Sarawak Kanan catchment area starting at about 1600 hour on 3 February 2003 and lasting until 1400 hour on 4 February 2003. The best estimates shown that the most intense rainfall over 400 mm occurred in Sungai Sarawak Kanan region. Siniawan rainfall station recorded rainfall return period of the order of 50 years. The flooding was a 1 in 50 year flood event in comparison with the 1:50 year design hydrograph of Sungai Sarawak Flood Mitigation Options Study [4].

Sungai Sarawak Kanan catchment area was flooded on 24 Jan 2004 when high rainfall was observed from 0000 hour to 0800 hour where high intensity of rainfall up to 86 mm was recorded in Siniawan, and ended on 26 January 2004. The best estimates provided a total average rainfall of 672 mm over the catchment that spanning about 65 hours. The return period of rainfall in Bau area was in the order of about 100 years [5].

The interpretation of the simulation results were made through analysis of graphics featuring:

i. The comparison of the Siniawan observed hydrograph to the one resulting from the simulation of the same section.
ii. The evolution in terms of time or reach length of the modeled parameters, in the case of this project, the flood depths.
iii. The differences between the computed maximum water heights and the level of the road or the flood watermarks.

A. COMPARISON TO OBSERVED DATA

Plots of water surface elevation vs time were provided in Figure 9 for February 2003 and January 2004 flood events in Siniawan, comparing the model simulation results to the observed gauged data.

The shapes of the hydrographs were simulated well and a good match was obtained in general. The correlation coefficient for February 2003 event was a high 0.96 while for January 2004 event, a 0.92 was achieved.

Consistent results had been obtained in terms of observed vs simulated water level and water level time occurrence at the monitored Siniawan during calibration, verification and model application stages.

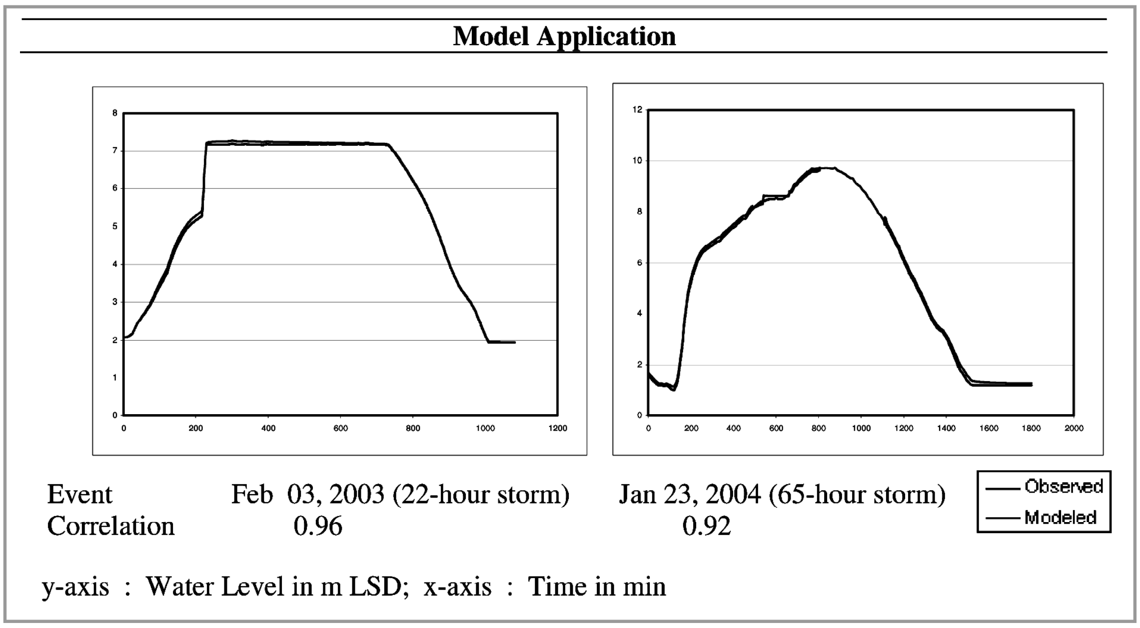

Figure 9: Comparison of observed and simulated data

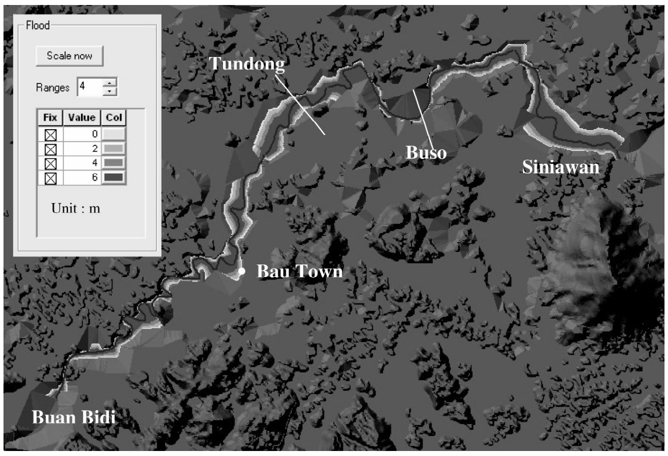

Figure 10: Flood depth map for January 2004 flood event

B. FLOOD DEPTH

During the real floods, visual observation was performed by the Department of Irrigation and Drainage Sarawak along the middle and lower courses of Sungai Sarawak Kanan. Inundated areas were identified at key locations. The efficiency of the flood reconstruction approach was investigated by matching the actual inundated areas (in terms of their locations and flood depth records).

The observed flood depth data was taken from the Department of Irrigation and Drainage Sarawak Flood Report for Kuching and Samarahan Divisions 2003 and 2004 [3,4]. Flood depths recorded were for some low laying localities in the affected area based on general visual observation. Somehow the exact locations and time of observation were not known. No reference datum was quoted in the report.

The modeled flood depth data was obtained by subtracting flood elevation from ground elevation derived from flood depth maps as presented in Figure 10. Initially the topography for the model was defined using course topographic information available at 1:50, 000 scales. The model was capable of providing a fairly reasonable estimate of flood depths. Looking at figure 10, the available resolution of topographic data was not sufficient enough to obtain results on flood heights at different locations in the model.

Tables 3 and 4 shows the comparison of modeled and observed flood depths at locations of significant importance.

Buan Bidi

The size of Sungai Sarawak Kanan above Buan Bidi is some 225 km^2. The hydrological investigations [2,5,6] indicated that the catchment response before Buan Bidi was quite quick and that the catchment had a critical duration in the order of 6 hours.

No observed flood depth data available in Buan Bidi. The developed model estimated Buan Bidi as a non-flood area for 2003 and 2004 events.

Tundong and Buso

Tundong and Buso consist mainly of old timber shophouses located on roads perpendicular to the river. Tundong consists of 20 shophouses with some converted to solely residential use. The flood liable area of Buso comprises of 10 shophouses, a school, a mosque and 12 traditional kampong houses with infill beneath. The flood hazard at both Tundong and Buso was classified as high-hazard [2]. The 1963 event flooded the bazaar areas to 4.6 and 4.2 m at Buso and Tundong respectively.

The model estimated a flood depth of 1.2 m for Tundong and 1.3 m for Buso in the February 2003 flood event, which was within the range of observed data. While for January 2004 flood event, estimated flood depth for Tundong was 1.5 m, which was in conformance with the observed data. However, estimation of 3.3 m flood depth for Buso was over estimated by 0.3 m.

Table 3: 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 4: 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

Siniawan

Siniawan is located on the south bank of Sungai Sarawak Kanan. The small town essentially consists of 44 wooden shophouses, a school, a clinic, a police station and traditional buildings. The town center straddles the old Bau - Batu Kitang Road. A recent road deviation bypasses the center.

The flood hazard in Siniawan was classed as high hazard [2]. The general ground level in Siniawan is lying low and inundation is expected frequently. In the 1963 flood, flood inundation depth was in the order of 4.2 m while in the 1976 flood, depth was some 1.8 m.

The model estimated a flood depth of 3.0 m for Siniawan in the February 2003 flood event, which was within the range of observed data. While for January 2004 flood event, estimated flood depth for Siniawan was 4.0 m, which was overestimated. However, the observed flood depth which was marked with # sign (in Table 4) was questionable. From Table 3, the actual flood peak level was 7.19 m in 2003 with observed flood depth of 2.8 – 3.0 m in Siniawan. From Table 4, the actual flood peak level rose to 9.71 m in 2004, in which the level rose 2.5 m compared to 2003 in Siniawan. Hence the observed flood depth of 3.0 – 3.2 m appeared to be doubtful.

Rural Areas

The rural areas comprise of shifting cultivation and agriculture with scattered dwellings throughout the area. The dwellings are often sited closed to the river as a convenient means of transport, water supply and waste disposal system. The flood hazard along the river bank was high-hazard [2]. This category was consistent with reports of building being washed away in the 1963 flood. The flood liable area is long and narrow (along the river bank).

The Town of Bau

Bau is not located directly within the river corridor but is located such that it is affected by flood water from Sungai Sarawak Kanan. Comparison of modeled and observed flood depths at different locations in the town of Bau was presented in Table 5.

The Bau Bazaar was flooded to about 4.0 m deep in 1963 flood. However, the bulk of the flood affected shophouses had been destroyed, the area filled and new shophouses constructed. Not withstanding the filling of land, a large proportion of the Bau shophouses still affected by a repeat of the 1963 flood [2].

The flood hazard in Bau was variable with low-hazard in the highest area and high-hazard in the other areas [2]. There are an estimated of 130 shophouses and some 35 residents within the flood liable area.

The model managed to estimate the flood depths in Bau within the observation range as shown in Table 5.

C. FLOOD WATERMARKS

This sub-section compares the level of the road or the flood watermarks with the estimated flood stage hydrograph at 3 locations, namely Tundong Bazaar, Buso Bazaar and Siniawan Bazaar.

Table 5: Modeled and Observed Flood Depths for Feb 2003 and Jan 2004 Floods in Bau

Locations in Bau Town	Feb 2003 Flood Event		Jan 2004 Flood Event	
	Modeled (m)	Observed (m)	Modeled (m)	Observed (m)
Shoplots (behind Shell)	1.5	1.2 – 1.5	1.5	1.0 – 2.0
Bau Police Station	3.0	2.5 – 3.0	3.0	2.0 – 3.0
Bau-Krokong Junction	1.2	1.2 – 1.5	1.2	1.0 – 1.5
Jalan Tundong	0.2	0.1 – 0.2	0.2	0.1 – 0.3

Table 6: Flood Watermarks for February 2003 and January 2004 Flood Events

Locations	Road Level (m LSD)	Feb 2003 Flood Event		Jan 2004 Flood Event	
		Flood Watermarks (m)			
		Graph	Observed	Graph	Observed
Tundong Bazaar	8.10	0.7	0.6 – 1.0	2.5	1.5 – 2.0
Buso Bazaar	6.90	1.4	1.5 – 2.0	3.0	2.0 – 3.0
Siniawan Bazaar	5.20	2.1	1.5 – 2.2	3.4	2.0 – 3.2

Tundong Bazaar, Buso Bazaar and Siniawan Bazaar are centers established on the main road stretching along Sungai Sarawak Kanan and were affected by the burst-of-bank flood water during the 2 extreme flood events. The 'graph' mentioned in Table 6 refers to the stage hydrographs that were the results of a propagation of flood wave generated by InfoWorks RS model. Flood watermarks were estimated by comparing the peak water level with the road level at the 3 bazaar locations. For such, the derived flood watermarks were compared to the observed data surveyed by DID shown in Table 6. The figures uphold the inundation of road in the mentioned areas and the derived levels were within the acceptable range compare to flood watermarks observed.

Up to this point of discussion, a conclusion was drawn, based on course topographic data, the model was capable of providing a reasonable estimation and acceptable efficiency.

8.0 MODEL OUTPUT

In the case of Sungai Sarawak Kanan with little hydrological information to ponder with, particularly during high flow events, the reconstruction effort of February 2003 and January 2004 major floods enabled the prediction of the following hydrological information at key locations:

i. Stage hydrographs with maximum and minimum water level data
ii. Flood discharge hydrographs and its parameters of peak discharge, time to peak, lag time, time base and flood volume
iii. Sub-basins flow contributions and its volume
iv. Flood cross section and long section profiles along Sungai Sarawak Kanan
v. Flood extend and flood depth maps

Further analysis of the hydrological information assists in decision support on how to manage future floods in Sungai Sarawak Kanan basin, for instances the estimation of design flood for engineering solutions. The developed model also contributes to be a valuable tool for analysing the many proposed flood mitigation options and flood risk management.

9.0 CONCLUSIONS

The flooding of Bau and surrounding areaa are critical considering that a repetition of February 2003 or January 2004 flood events would have the downstream portion, particularly from Buso and onwards submerge in about 2 - 3 m depth of over-bank floodwater.

In the absence of discharge measurements, the simulated water level hydrograph and flood stage elevation at Siniawan had to be expediently assumed as the main evaluation parameter of the InfoWorks RS flood routing model. The quality of model application had to take into account both maximum water stage and water level time evolution during the floods in order to represent both flow resistance and discharge time evolution respectively. The InfoWorks RS 1-D numerical model herein adopted was reasonably capable in these purposes and leads to consistent results. The conclusions being drawn were:-

- Model performed well with limited topographic information. The type and resolution of topographic data

currently available for Sungai Sarawak Kanan 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.
- Output of model was water levels and discharges along the direction of flow in Sungai Sarawak Kanan. However, there is flow condition due to insufficient data, for example in bends that the model can not perform.
- Water level and discharge information was only available at points where cross sections were defined. In this case, the distance between cross sections has about 1 km apart.

In the hydrodynamic model for the Sungai Sarawak Kanan, a course structure had been introduced to enable an initial description of the floodwater flow. The preliminary comparisons of measured and simulated hydrographs shown that a reasonable description of both minor floods and extreme events like the February 2003 and January 2004 floods were obtained. 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 Sungai Sarawak Kanan basin.

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