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Investigation of River Stage Simulation Before and After Bengoh Dam Construction: Case Study of Sarawak River Basin Malaysia

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Abstract- This research was conducted to study river stage behavior at Sarawak River before and after Bengoh Dam construction. The relationships of Bengoh Dam and Sarawak River stage are thoroughly analyzed and discussed based on four scenarios namely a) before dam construction, b) after dam construction and reservoir fully filled with water, c) after dam construction but reservoir empty, and d) constant flow release after dam construction. Besides, each scenario will be further analyzed with the operation of barrage gates at Sarawak River mouth, both in fully opened or closed modes. InfoWorks RS was employed to model Sarawak River using January 2000 hydrological data. The study demonstrated that after construction of Bengoh Dam, river stage level at Sarawak River at upper reach will be reduced and the flood issue can be mitigated. Besides, Sarawak Barrage also plays a significant role in influencing the river behavior. When the barrage gates are closed, the river stage level will rise to certain extent, which severely inundates multiple locations at the river downstream. In contrast, when the barrage gates are opened and sea level is lower than the river level, the river water will flow towards South China Sea at constant rate.

Keywords- *Flood, Hydraulics Structures, River Stage, Infoworks RS*

I. Introduction

Floods are inevitable natural phenomena of river catchment cycle which result in adverse impacts on countless regions around the world periodically. Floods are also disasters capable of causing tremendous loss of lives and economics, as well as catastrophic damages to private properties and natural resources in many countries. As a country with equatorial climate, Malaysia constantly experiences extreme humidity and high temperature (Selaman & Tay, 2011). Sarawak is the state that experiences the greatest amount of rainfall, about 4000mm annually and the total annual surface water runoff is about 306 billion m^3 (Morison and Yeoh, 2010). Since year 2000, Sarawak river basin has experienced five major flood events in January 2000, February 2003, January 2004, January 2009 (Mah et al., 2011) and January 2015 recently. To alleviate the impacts of floods, various flood mitigation structures have been constructed including Bengoh Dam and Sarawak River Barrage.

Sarawak River Barrage started to operate in year 2000. Throughout the years, Sarawak River Barrage had proven its efficiency for mitigating the flood problems within Sarawak River Basin. Bengoh Dam was constructed to ensure the safe yield of water supply to Batu Kitang Water Treatment Plant (BKWTP) and it is expecting insufficient to meet the raw water demand for Kuching and its surrounding areas after year 2030 (Morison and Yeoh, 2010). Besides, Bengoh Dam is also functioning to mitigate recurrent flood issues within Sarawak River Basin by retaining the water in upper catchment after heavy precipitation. However, the feasibility of Bengoh Dam to mitigate the flood is still uncertain as the progress of dam construction currently is only up to 97% completion and not in operation yet. The capability of Bengoh Dam to retain rainwater at upper catchment is still unknown (Horritt & Bates, 2002). The hydrological analysis of the Sarawak River Basin is required to have a better control of the river flow and preparation of flood mitigation measures.

Thus, it is initiated to study the Sarawak River flow behavior once Bengoh Dam is under operation with three hydraulics structures that had been constructed within the river basin including Sarawak River Barrage, Batu Kitang Submersible Weir and Bengoh Dam. The studies include hydraulic simulation of Sarawak River Basin covering river flow behavior, maximum water level, flood occurrence period and potential flood zones using the hydrodynamic modeling software, InfoWorks River Simulation (RS). The relationships between Bengoh Dam and Sarawak River flow behavior are analyzed for four different scenarios: a) before dam construction, b) after dam construction and reservoir fully filled with water, c) after dam construction but reservoir empty, and d) constant flow release after dam construction. In addition, the model will further analyzed with barrage gates operations at downstream, both in opening and closing modes using January 2000 rainfall event.

II. STUDY AREA

Naturally, Sarawak River is sheltered by robust plant covers with approximately 1400 km^2 watershed areas, and the river bed rests on the natural state of Alluvial-Plain River, almost without any artificial embankment on it (Duan, Wan & Zhao 2003). Sarawak River is divided into two major tributaries, mainly Sarawak Kiri River and Sarawak Kanan River which stem from the mountainous terrain and connects at the confluence approaching Batu Kitang, then flow towards South China Sea. The heavily forested river meanders irregularly and connects with twelve streams passing through Kuching City before discharging to the sea. Three hydraulic structures have been constructed along Sarawak River namely Bengoh Dam, Batu Kitang Submersible Weir and Sarawak River Barrage as illustrated in Fig. 1.

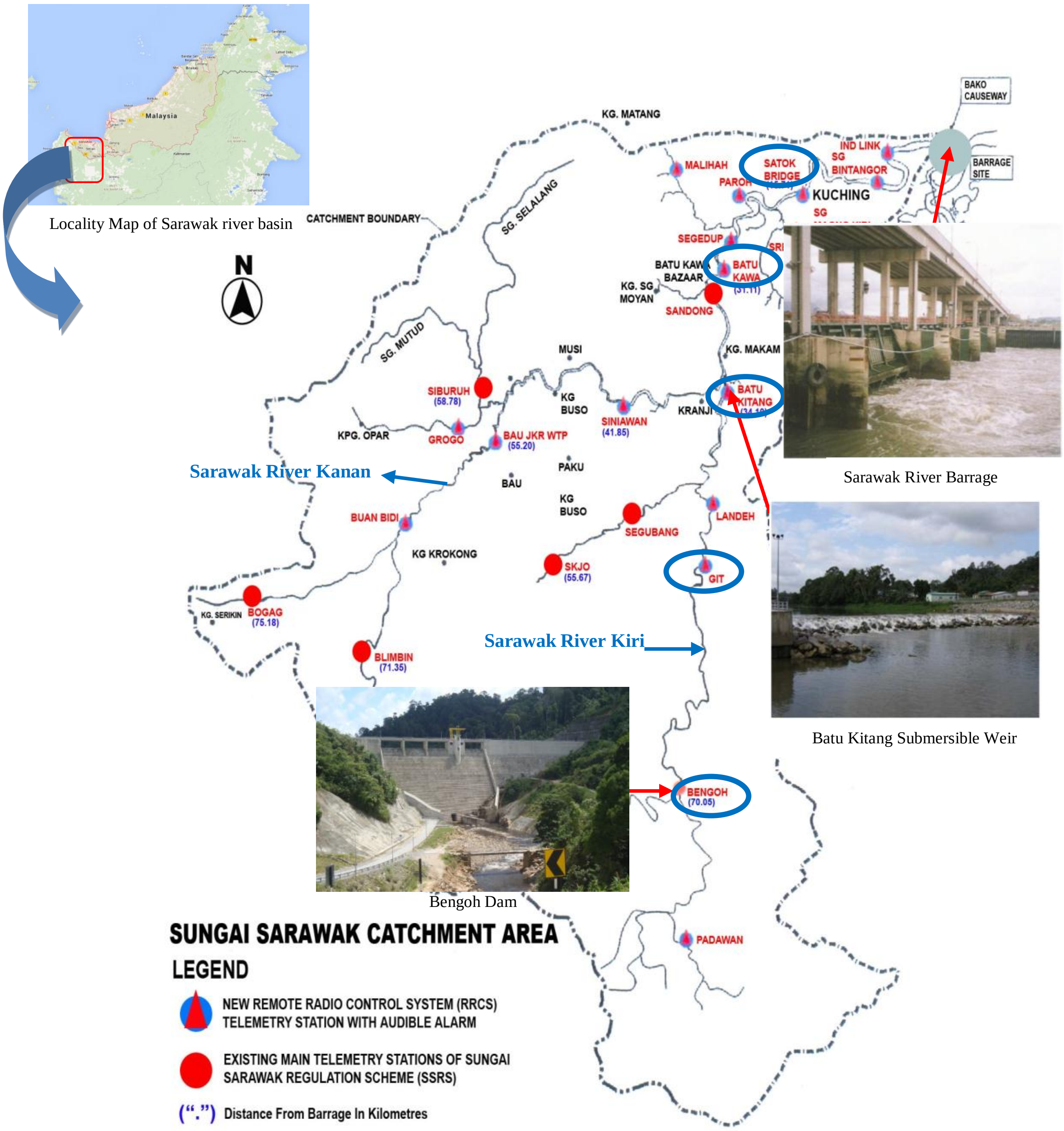

Figure 1. Location of hydraulic structures, hydrologic gauging stations available within Sarawak River Basin (Sarawak hydrological yearbook, 2007)

Bengoh Dam was built to ensure adequate raw water supply to BKWTP during drought season and also to mitigate the flood during raining season. The function of Batu Kitang Submersible Weir is to increase the safe yield of Sarawak Kiri River to ensure reliable raw water supply to BKWTP and also acted as a salinity barrier to prevent the saline intrusion reaching the water intake (Kuok et al., 2013). Meanwhile, Sarawak River Barrage was constructed to regulate the river flow and control the saline intrusion from reaching water intake point.

Besides, hydrological gauging stations are set up by Department of Irrigation and Drainage (DID) to monitor the water level within Sarawak River Basin (DID Manual, 2009). These gauging stations are Buan Bidi and Siniawan located along Sarawak Kanan River, Bengoh, Git and Batu Kitang along Sarawak Kiri River. The confluence point for both Sarawak Kiri and Kanan Rivers is located at Batu Kitang. Thereafter, the confluence of Sarawak River will flow towards Sarawak River Barrage passing through Batu Kawa, Kuala Maong and Satok gauging stations.

III. BENGOH DAM

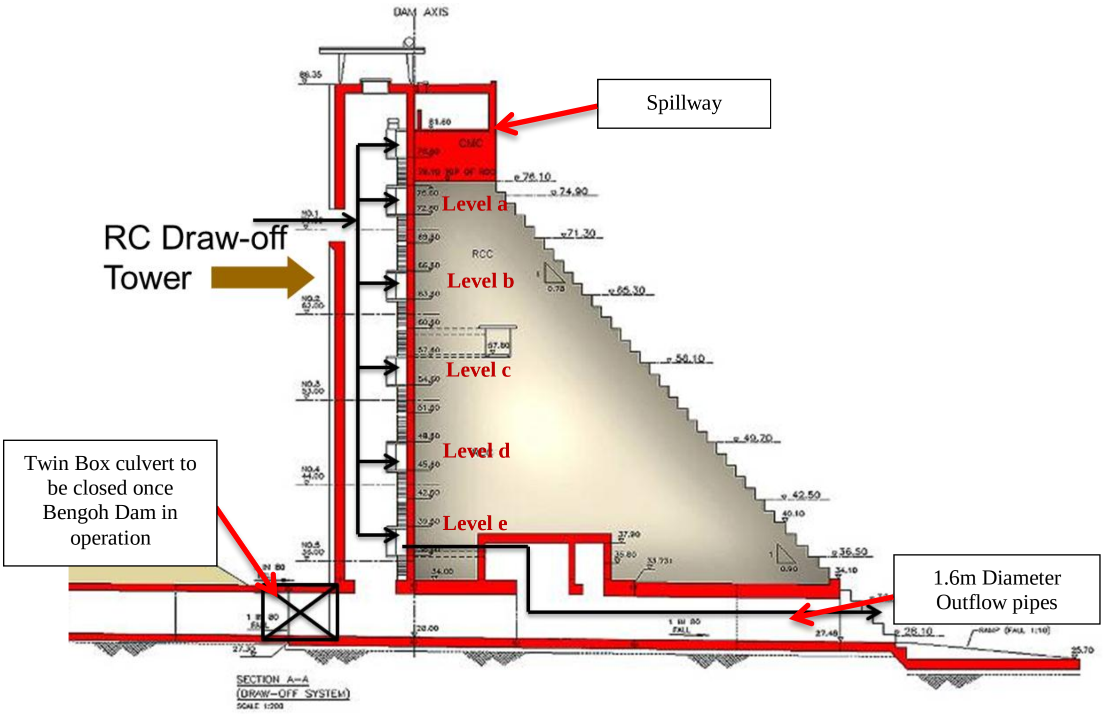

Figure 2. Schematic Diagram of the Bengoh Dam (Kuok et al.,2011)

Bengoh Dam is a Roller Compacted Concrete dam with 63.2m height and 267m width (Morison & Yeoh, 2010). The Bengoh Dam is estimated to provide a gross storage of approximately 144Mm^3, with surface areas of 8.87 km^2. As the water level within dam reservoir reaches certain level, the water will flow into the RC Draw-Off towers and discharge into downstream through twin 1.6m diameter outlet pipes (Morison & Yeoh, 2010). Under normal condition, water will be released through a single 1.6m diameter outflow pipe. Two outflow pipes will only be utilized for releasing the water during emergency especially after an extreme rainfall event (Morison & Yeoh, 2010). In contrast, as the water level exceed the dam crest level, the excess water will surpass the spillway and the flow energy will be reduced by energy dissipation blocks. Only top part of reservoir water to be released into 1.6m diameter outflow pipes. This is to ensure only clean and fresh raw water will be supplied to BKWTP.

IV. METHODOLOGY

The river flow at upper catchment of Sarawak River before and after construction of Bengoh Dam will be simulated under following scenarios:

i) Modeling of Sarawak River before dam construction
ii) Modeling of Sarawak River with Bengoh Dam and the reservoir is fully filled with water
iii) Modeling of Sarawak River with Bengoh Dam and the reservoir is empty
iv) Modelling of Sarawak River with Bengoh Dam and constant flow is released under following conditions:
   a) Water behind the dam at full height (63.2m) with 1 gate opened and 2 gates opened
   b) Water behind the dam at half height (31.6m) with 1 gate opened and 2 gates opened

All the four scenarios will be investigated with the barrage gates in opening and closing modes. Barrage gates will be closed when the sea level is higher than the river level to avoid saline intrusion towards upper catchment. In contrast, barrage gates will be opened when river level is higher than sea level to discharge the excess water and also for flushing the sediments.

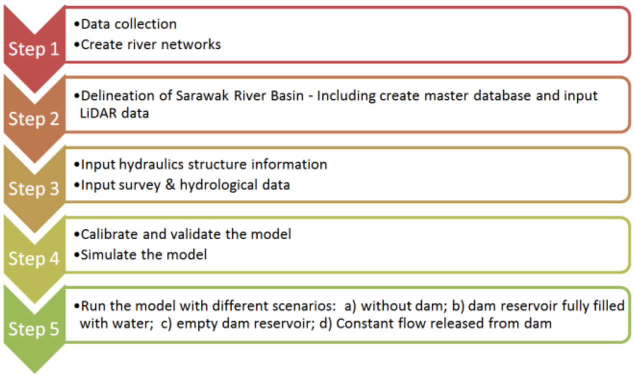

Figure 3. Modelling Procedure of Sarawak River Using InfoWork RS

The input hydrological data used for model calibration and simulation is January 2000. The reservoir size behind Bengoh dam is 144Mm^3. In this study, the time required to fully fill up the reservoir is also investigated. The procedure of this study is illustrated in Fig. 3.

Light Detection and Ranging (LiDAR) and hydrological data from Sarawak River are collected from DID Sarawak for river modelling purpose. On the other hand, details of hydraulic structures are also obtained from relevant authorities and some online scholarly papers.

The assessment of the river behaviour was carried out using InfoWorks RS. Structural data and hydrological data are then input into InfoWorks RS to delineate hydrological boundaries of Sarawak River model. The manning roughness coefficient values for river channel, left and right banks need to be calibrated to ensure the correlation between the observed and the simulated values are as close as possible. The river flow will be simulated both in steady and unsteady flow. Model performance is evaluated using Mean Absolute Peak Error and Coefficient of Correlation (R) as presented in Equation 1 and 2 respectively.

$$\textit{Mean Absolute Peak Error} = (h_{obs\text{-}max} - h_{sim\text{-}max}) / h_{sim\text{-}max} \quad (1)$$

Where, $h_{obs\text{-}max}$ is referring to maximum water level from observed data, and $h_{sim\text{-}max}$ refers to maximum water level from simulated data.

$$R = \frac{\sum_{i=1}^{N}(o_i - \overline{o_t})(p_i - \overline{p_t})}{\sqrt{\sum_{i=1}^{N}(o_i - \overline{o_t})^2 \sum_{i=1}^{N}(p_i - \overline{p_t})^2}} \quad (2)$$

Where, O_i = Observed values

P_i = Predicted values

$\overline{O_i}$ = mean of observed values

$\overline{P_i}$ = mean of predicted values

V. RESULTS AND DISCUSSION

After trial and error process, the optimal manning roughness coefficient (n) for left and right banks was found to be 0.12; while optimal n=0.065 was obtained for the river channel. The mean absolute peak error and R obtained using both optimal n values are 0.1866 and 0.85 respectively.

A. *Sarawak River Barrage Gates in opened condition*

The operation of Barrage gates helps to control the water level within Sarawak River basin. During heavy rain, radial gates are fully opened to discharge the storm water into South China Sea; meanwhile during normal flows, river water will be regulated through the smaller flap gates at barrage to maintain constant river level (Kuok et al., 2011).

1) *Scenario 1: without Dam Construction*

From Fig. 4, it was observed that the water level patterns at Bengoh and Git are almost similar. The only difference is water level at Bengoh is about 15m higher than Git due to steep riverbed gradients in the upper stretch. However, water level at Batu KItang is almost constant starting from 1st to 21st January 2000 as raw fresh water are stored within Batu Kitang reservoir for the intake of BKWTP. The excess water will spill through top of the Batu Kitang weir after 21st January 2000. Batu Kawa and Satok are located at the downstream of Sarawak river basin. It was observed that water level for both stations are fluctuating almost evenly throughout the month due to flat and meandering river at the lower reaches.

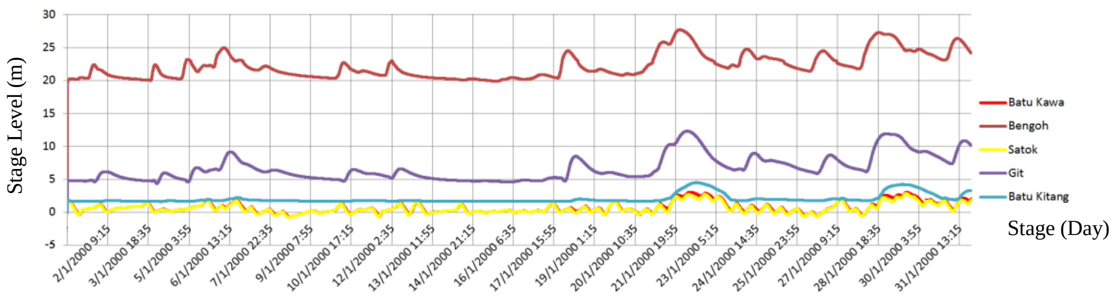

Figure 4. River Stage versus time within Sarawak River under Scenario 1

2) Scenario 2: Dam Reservoir Fully Filled with Water Condition

Fig. 5 shows the water level within Sarawak River when Bengoh Dam reservoir is fully filled with water. Since water level in the dam reservoir is at maximum storage level starting from 1st January 2000, there would be no storage capacity. Excess water will spill through the spillway and directly flow into downstream of Bengoh Dam. Therefore, water level pattern for scenario 2 is exactly the same with scenario 1.

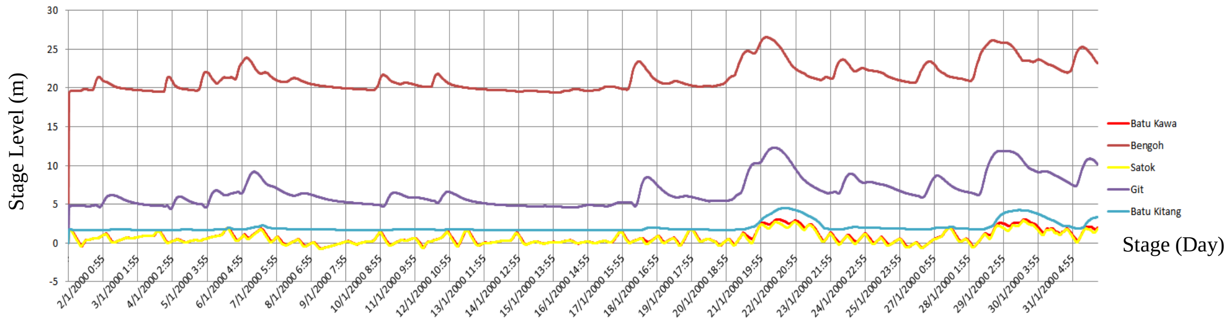

Figure 5. River Stage versus Time within Sarawak River under Scenario 2

3) Scenario 3: Empty Reservoir condition

Bengoh Dam is functioning as water storage reservoir for future supply. Thus, water will fill the reservoir first before releasing into downstream. Fig. 6 shows the river flow behaviour along Sarawak River when the dam reservoir is in empty condition. Since river flow from the upstream of Bengoh Dam was retained and stored to fill up the reservoir, it is observed that the water at Bengoh and Git stations, upper reaches of Sarawak River is low starting from 1st to 21st January 2000. As the dam reservoir was full, the water starts to overflow through the spillway and the river flow start to increase after 22nd January 2000 at Bengoh and Git stations. This revealed that the time required filling up Bengoh dam is about 21 days. In contrast, the water level at lower reaches including Batu Kitang, Batu Kawa and Satok are not much affected. This is because there are some river flows from Sarawak Kanan River gushes towards downstream.

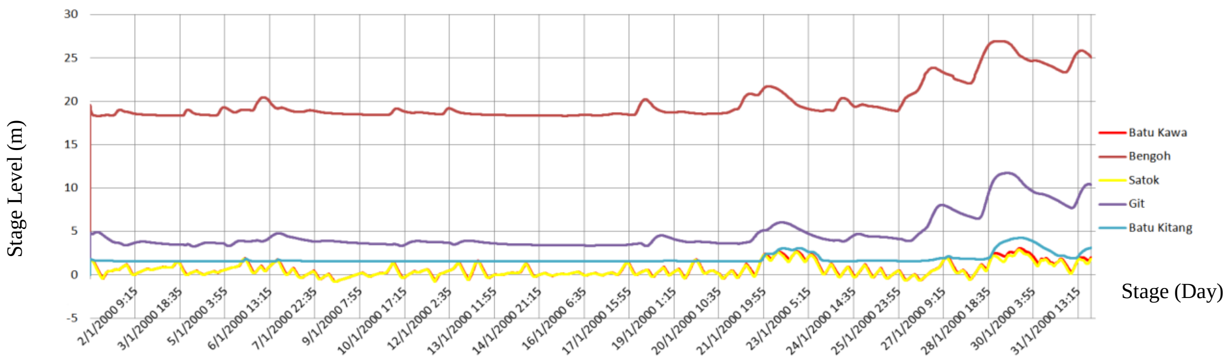

Figure 6. River Stage versus Time within Sarawak River under Scenario 3

4) Scenario 4: Constant Flow Released Condition

Bengoh Dam is constructed with two 1.6 diameter gates that allowed water to be released accordingly. The river stage along Sarawak Kiri River is studied when Bengoh Dam gates were opened and water level was released at full water level height (FH) and half water level height (HF). Fig. 7 and Fig.8 show the water level in Bengoh and Git are constant due to the constant released of water from Bengoh Dam. The minimum stage level at the Bengoh was found to be 21.46m and the maximum stage level is 23.89m. Meanwhile, the minimum and maximum stage levels at Git are found to be 5.895m and 8.30m respectively. These results revealed that water level at upper reach of Sarawak River are significantly affected by number of gates and different constant flow released from Bengoh Dam.

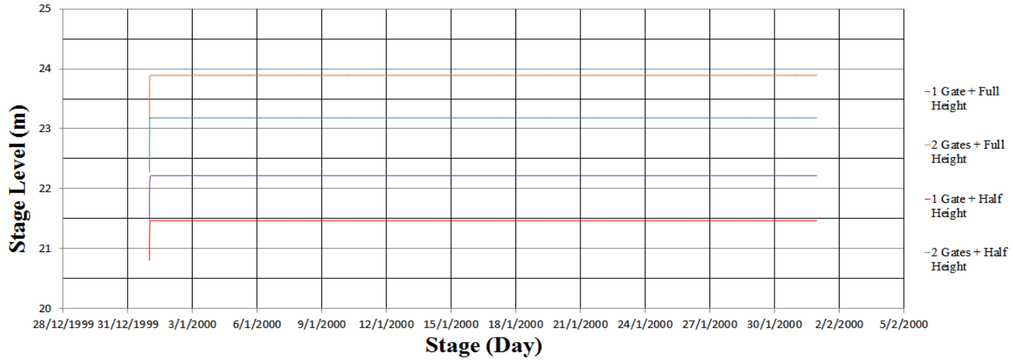

Figure 7. River Stage versus Time at Bengoh under Scenario 4

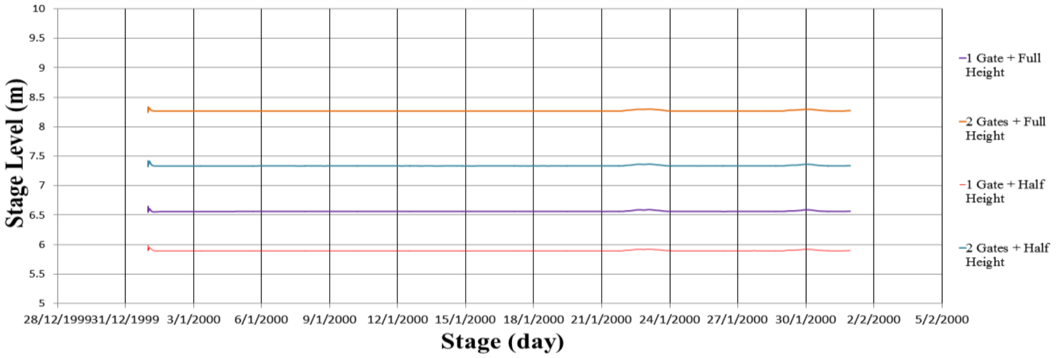

Figure 8. River Stage versus Time at Git under Scenario 4

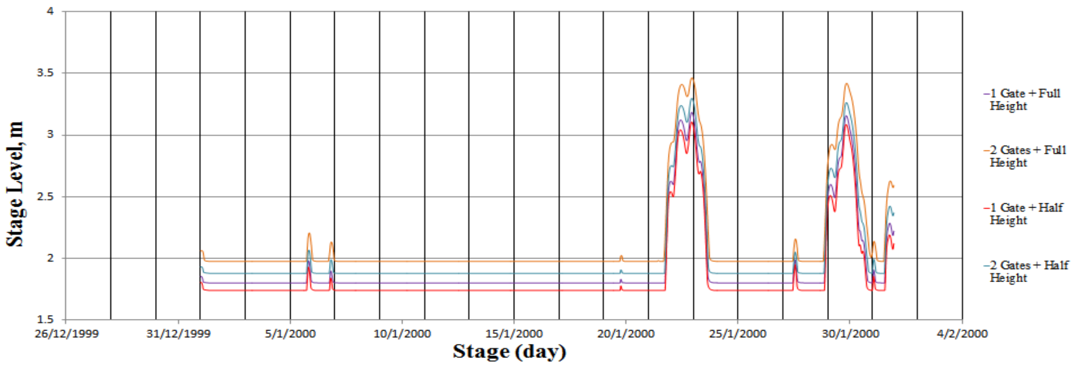

Figure 9. RiverStage versus Time at Batu Kitang under Scenario 4

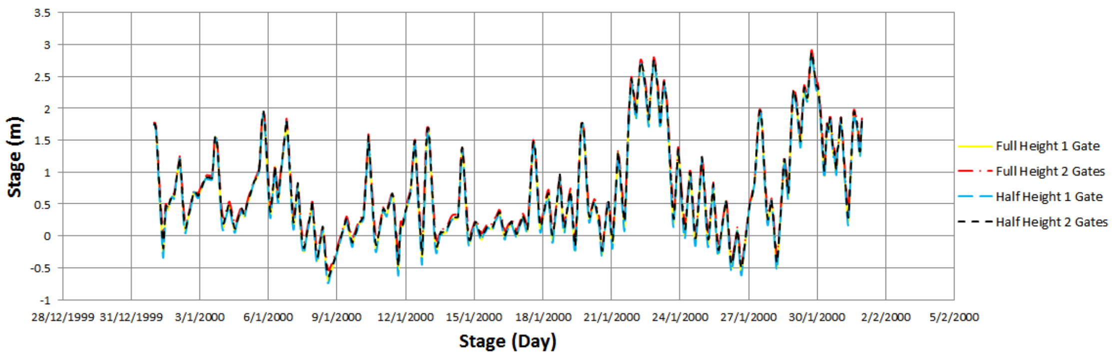

Figure 10. River Stage versus Time at Batu Kawa under Scenario 4

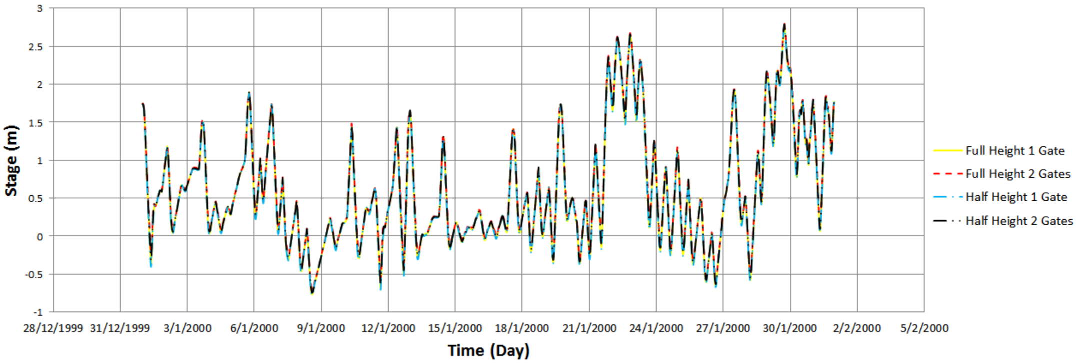

Figure 11. River Stage versus Time at Satok under Scenario 4

Fig. 9 indicates the water level at Batu Kitang almost constant starting from 1st January 2000 to 21st January 2000. From 22nd to 24th January 2000 and 29th to 31st January 2000, there are two spikes of water level. Meanwhile, water level at Batu Kawa and Satok are fluctuating and turbulence flows were observed throughout the month. The height of water to be released and gates operation at dam site do not affect the river flow at downstream of Sarawak River basin as all the simulation graphs are overlapping each other (refer to Fig. 10 and 11). This might be due to the combination of constant flow from Sarawak Kiri River with the rapid flow from Sarawak Kanan River had minimized the impact of river flow behaviour due to gates operation and different height of water to be released at dam site.

B. Sarawak River Barrage Gates in closed condition

The river stage when the Kuching Barrage Gates were closed for one month period with 4 different scenarios are presented in Fig.12 to Fig. 19. Results show that long term closure of the barrage gates will restrict the water movement towards the ocean, most probably the river water would be unable to be discharged and retained. Hence, the water level within Sarawak River will increase gradually to certain level as proved by the simulation results. However, simulation results also revealed that the closure of Sarawak river barrage for January 2000 doesn't have any significant impact to the water level at Bengoh. The reason might be backwater effect after closure of barrage gates is unreachable to Bengoh station due to the long distance and highly elevated topography.

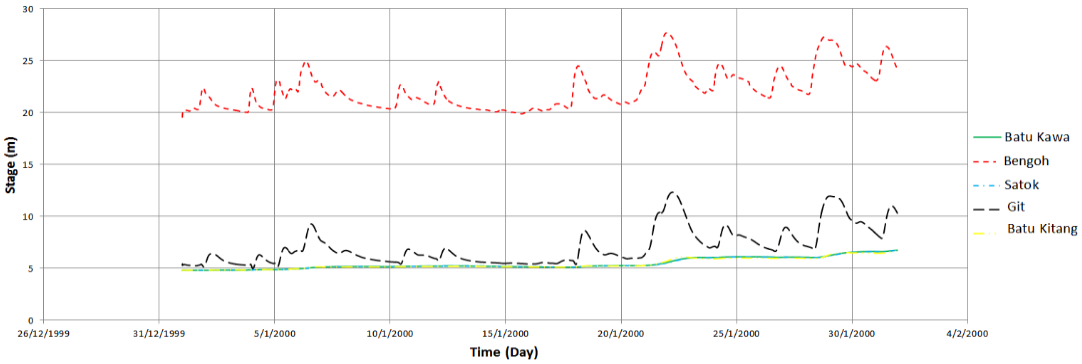

Figure 12. River Stage versus time within Sarawak River under Scenario 1

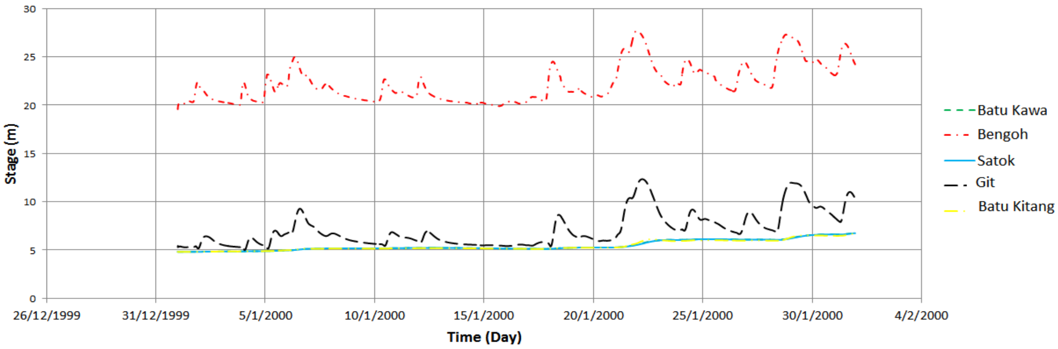

Figure 13. River Stage versus Time within Sarawak River under Scenario 2

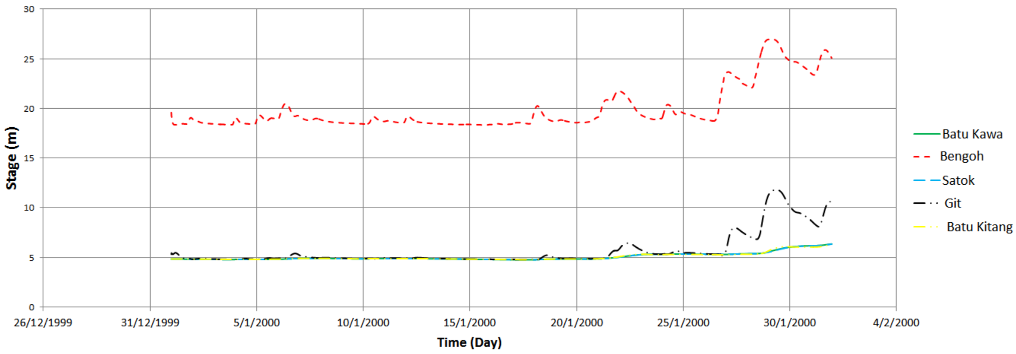

Figure 14. River Stage versus Time within Sarawak River under Scenario 3

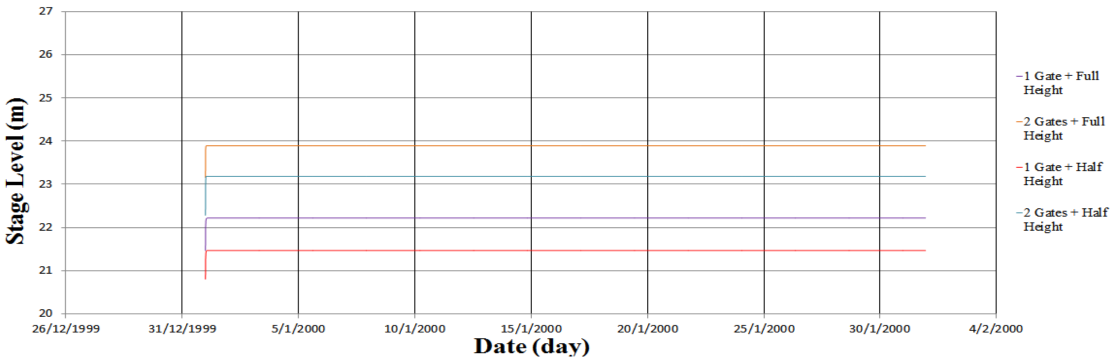

Figure 15. River Stage versus Time at Bengoh under Scenario 4

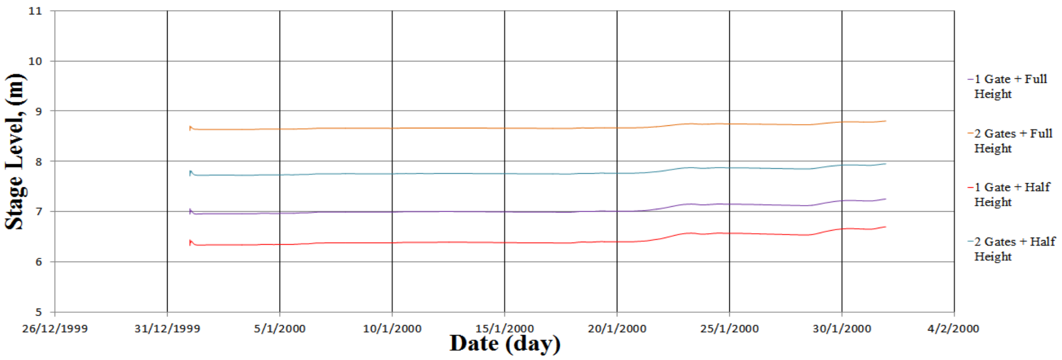

Figure 16. River Stage versus Time at Git under Scenario 4

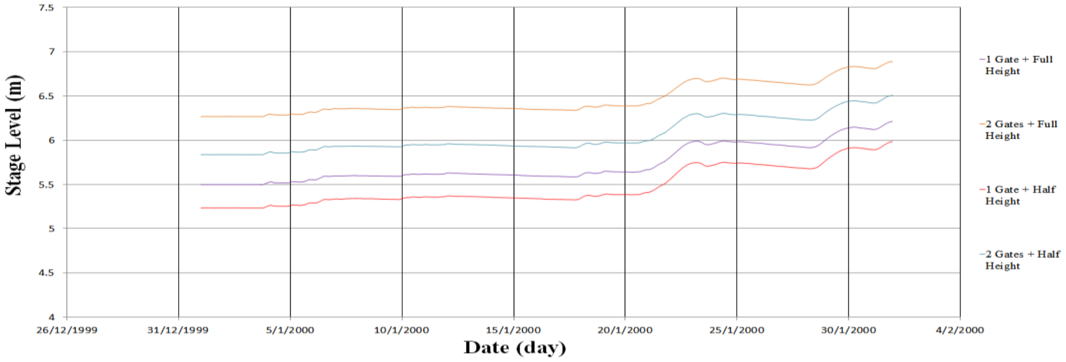

Figure 17. River Stage versus Time at Batu Kitang under Scenario 4

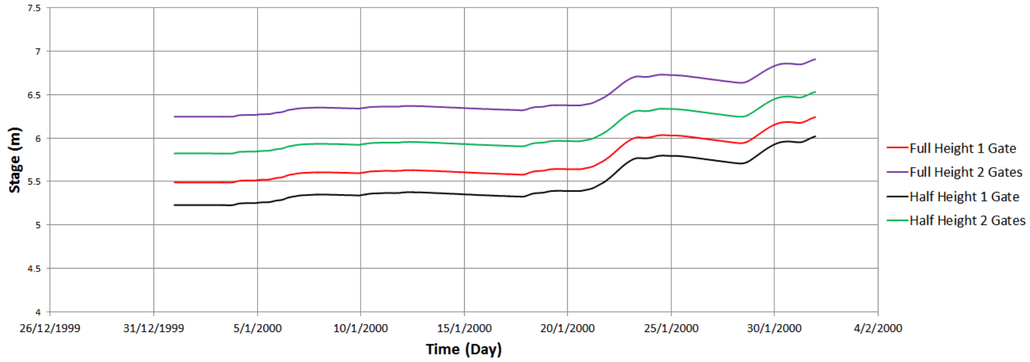

Figure 18. River Stage versus Time at Batu Kawa under Scenario 4

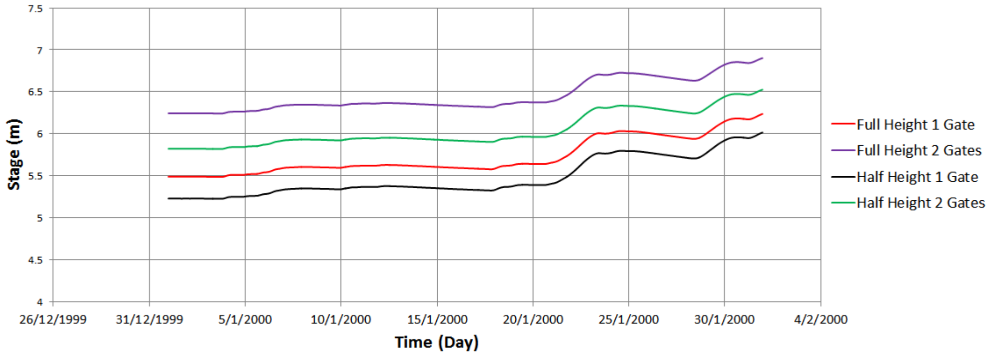

Figure 19. River Stage versus Time at Satok under Scenario 4

It can be concluded that the river flow at Sarawak River will be affected due to the construction of Bengoh Dam. As the reservoir is fully filled with water under scenario 2, the water behind the dam will overflow the spillway starting from 1st January 2000 until 31st of January 2000. It is also noticed that the river flow before Bengoh Dam construction is similar to the flow simulation when the water behind the dam reservoir is full (scenario 2).

On the contrary, as the water behind the reservoir is empty (scenario 3), it requires certain time to fill up the reservoir prior releasing to downstream. It was found the required time to fill up the dam is about 21 days using January 2000 hydrological data. Thus, when the dam reservoir is empty, the river flow and water level at Bengoh and Git (located at upper reaches) are very low. This is particularly constructive during wet season, in which the reservoir helps to store water and prevent massive river flow to the lower catchment which may cause flood. Also, Bengoh Dam will help to store and supply the water to BKWTP during drought season in future. Meanwhile, water level at lower reach such as Batu Kawa and Satok stations are not much affected by scenario 3 as some river flows from Sarawak Kanan River will discharge towards lower catchment.

Under scenario 4, as the flow is discharge constantly towards downstream, the flow discharge rate is determined by the number of opening gates and water level behind the dam. Under normal dam operation, only one gate is opened for flow discharge, while two gates are opened during emergency situation when the water in the dam reservoir is over loaded. Upper catchment of Sarawak River include Bengoh, Git and Batu Kitang, experiences the highest flow level when two gates are opened and the water is released at full height.

As the barrage gates are opened, the excess water along the Sarawak River will be discharged into barrage outlet. In contrast, when the barrage gates are closed, river water along Sarawak River will be accumulated and retained at lower catchment. It was also observed stage level along Sarawak River is increasing gradually when the barrage gates are closed and flood is more likely to occur during massive storm event. The results also revealed that the construction of Bengoh Dam is able to reduce the water level and the flow discharge along Sarawak River. The operation of Kuching Barrage gates also plays significant roles on regulating the water level and river flow within the river basin.

REFERENCES

[1] 'Sarawak hydrological yearbook', (2007), *DID Sarawak*, Vol. 34, viewed 20 October 2014.

[2] DID Manual (2009), Volume 1 – Flood Management, Government of Malaysia Department of Irrigation And Drainage.

[3] Duan, Z, Wan, X & Zhao X 2003, Physical model study on the Sarawak river estuary, Malaysia, International Conference on Estuaries and Coasts, viewed 23 September 2014, http://www.irtces.org/pdf-hekou/125.pdf.

[4] Horritt, M. & Bates, P., (2002), 'Evaluation of 1D and 2D numerical models for predicting river flood inundation', *Journal of Hydrology*, pp. 87-99, viewed 29 September 2014, http://www.sciencedirect.com/science/article/pii/S002216940200121X

[5] Kuok, K.K., Harun, S. & Chiu, P.C., (2011), 'A review of integrated River basin management for Sarawak River', *American Journal of Environment Science*, viewed 27 October 2014, http://thescipub.com/PDF/ajessp.2011.276.285.pdf.

[6] Kuok, K.K., Liew, Z.Z. & Chiu, P.C., (2013), *Flood map development by coupling satellite maps and three-dimensional drafting software: case study of Sarawak River Basin*, viewed 5 November 2014, http://www.ajol.info/index.php/wsa/article/viewFile/87925/77572.

[7] Mah, Y.S., Hii, C.P., Putuhena, F.J. & Lai, S.H., (2011), *River modelling to infer flood management framework*, viewed 15 September 2014, http://webcache.googleusercontent.com/search?q=cache:H3LvzmGEmOsJ:redac.eng.usm.my/html/publish/2011_16.pdf+&cd=1&hl=en&ct=clnk&gl=my.

[8] Morison, A.C. & Yeoh, J.S., (2010), '*Bengoh rcc dam, Sarawak'*, viewed 29 September 2014, http://www.britishdams.org/2010conf/synopses/6-5%20Synopsis%20-%20Morison%20-%20Bengoh%20Dam,%20Sarawak.pdf

[9] Selaman, OS & Tay, JE 2011, A study on the rainfall and landslides along Sarawak road using the antecedent rainfall analysis, Vol. 2, Journal of Civil Engineering, March 2011, viewed 15 September 2014.