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Modeling of a Hydraulic Structure: Batu Kitang Submersible Weir in Kuching, Sarawak

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Abstract—**An 858 m in crest length sheet pile weir is positioned across the Sungai Sarawak Kiri near Kuching city of Sarawak State. The weir is named Batu Kitang submersible weir, after its location and the structure of low-level design. By utilizing a 1-D hydrodynamic model, the hydraulic structure is captured together with the river dynamic, and presented in this paper as case studies during flood events in the highly flood hazardous Batu Kitang area. The Batu Kitang submersible weir is first designed to increase the safe yield of Sungai Sarawak Kiri raw water sources. The hydrodynamic modeling has shown that the structure imposes flood risk around Batu Kitang during smaller event floods. Thereby, more frequent flood of low magnitudes would be expected immediately upstream of the weir.**

Keywords**:** Flood, Hydraulic structure, Hydrodynamic, Modeling, Weir

I. BACKGROUND

KUCHING water supply main resource comes from the Sungai Sarawak Kiri, a principal tributary of Sungai Sarawak. The Batu Kitang water treatment plant (see figure 1) is established about 750 m away from the river since 1957. Currently, the plant supplies over 97% of treated water to the city [1]. In order to ensure long term security of water supply, Sungai Sarawak Kiri catchments are gazette as a Water Supply Catchments Area under the Sarawak State Water Ordinance 1994.

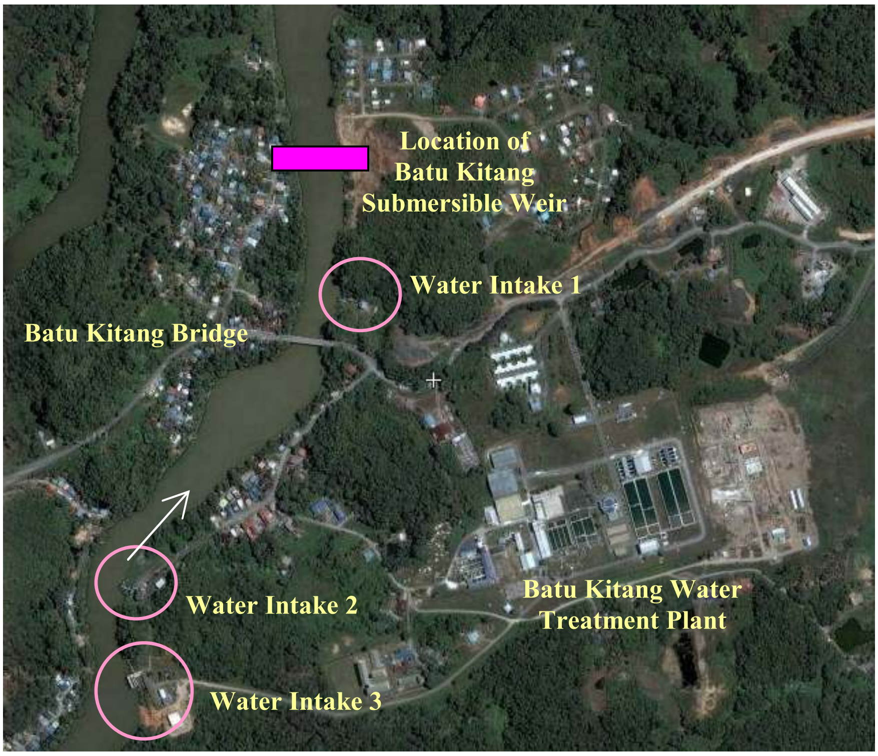

Figure 1 Imagery of Batu Kitang [2]

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The low yield of the Sungai Sarawak Kiri at the Batu Kitang intake sites was determined as 150 MLD during a 1:50 year drought. However, the Batu Kitang water treatment plant recorded daily outputs from the works had already exceeded 190 MLD which were delivered to consumers through 64,000 service connections in mid 1995 and exceeded the estimated yields of their source works during 1 in 50 years drought events. An immediate solution is needed to increase the yield to guarantee the security of supply. Therefore, a submersible weir is constructed across Sungai Sarawak Kiri just downstream of the present Batu Kitang water intakes. The weir starts operation since July 2005. The weir is capable of regulating the river to increase the safe yield to 484 MLD that secure until the year 2010 [3].

Sungai Sarawak Kiri is tidal to about 20 km upstream of Batu Kitang, and saltwater is expected present in the river for a varying number of days during dry seasons, prior to 1998. This was reversed to an extent by the construction in 1998 of the Kuching Barrage further downstream at Pending, about 17 km from the sea. Kuching Barrage achieves the important goal of reducing the river saline intrusion. The present of tidal seawater is further diminished by the construction of the Batu Kitang submersible weir. Moreover, the increasingly polluted condition of the downstream urbanized Sungai Sarawak is threatening the raw water sources. The weir diminishes the hazard of such incidence as well.

II. DESCRIPTION OF WEIR

A weir is a small overflow-type dam commonly used to raise the level of a river. The Batu Kitang submersible weir is raised a total of 4 m in height, from the river bed to a crest level of +1.50 m. The weir with its crest length of 858 m spanning across the Sungai Sarawak Kiri is classified as a long weir. The assumption is that long weir crest length sufficiently allows supercritical flow to develop on the crest. The east abutment houses a navigation lock and a sediment sluice (see figure 2a).

Thirteen (13) cellular sheet pile cells are driven to refusal on the rock sand / sandy gravel river bed material. The 255 m in diameter circular cells are interlocking at each other to form a solid cofferdam where the internal is filled with compacted sand as the core of the weir. The crest surface consists of a layer of reinforced concrete laid on top of those cells. The upriver face is supported by 0.6 m thick armour stone of 1.20 m minimum thickness stone. The downriver face is supported by 1.4 m thick and 250 m down the river bed concrete-infill armour stone of varying sizes, ranging from 2.80 m to 1.80 m minimum thickness stone. The downriver armour stone can be easily seen in figure 2 b and c. The river bed level is -2.50 m on both sides.

(a) Lock and Sediment Sluice

(b) Part of Batu Kitang Submersible Weir

(c) Batu Kitang Submersible Weir in Full Span

Figure 2 Photos of Batu Kitang Submersible Weir

III. FLOOD RISK

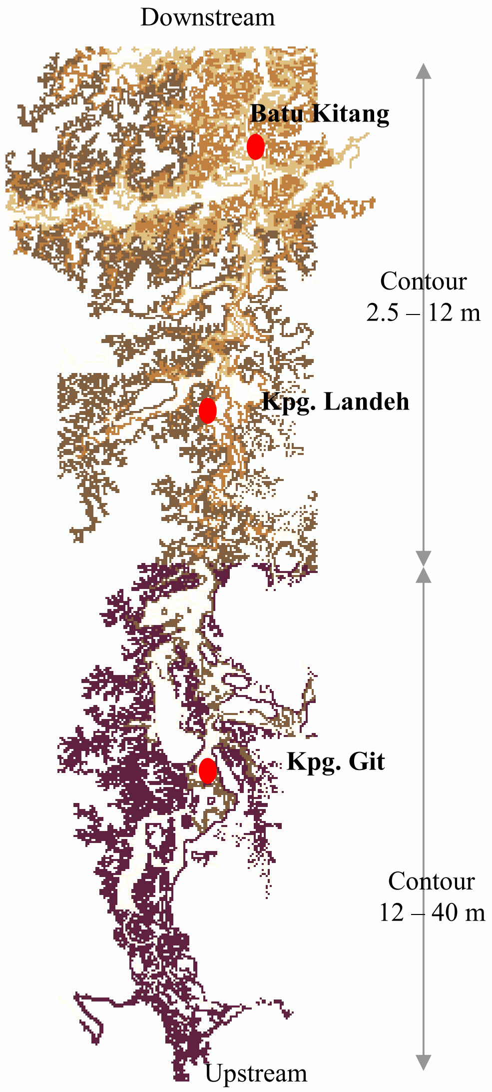


Figure 3 Contour Map of Sungai Sarawak Kiri Basin [4]

The contour map of Sungai Sarawak Kiri is presented in figure 3. It is clear that the upstream catchments consist of high ground 20 - 40 m hilly region, while the downstream catchments are low-land in nature [4]. Thus, the geographical factor in this basin would cause significant flood risk at the lower reaches that function like a water sink.

The general ground level in Batu Kitang is about +3.0 m. The estimated 100-year return period flood level in the area is about +8.04 m. During normal condition, the Batu Kitang submersible weir is function as free flow. During extreme flood event, the weir is submerged and function in drowned condition. The 100-year design flood flow at Batu Kitang is so overwhelmed with an estimate up to 805 m^3/s that the flooding at the lower reaches is classified as highly flood hazardous. The significant causal factor in Sungai Sarawak Kiri flood is therefore the fluvial event within the river.

Figure 4 Sungai Sarawak Kiri at Kpg. Git

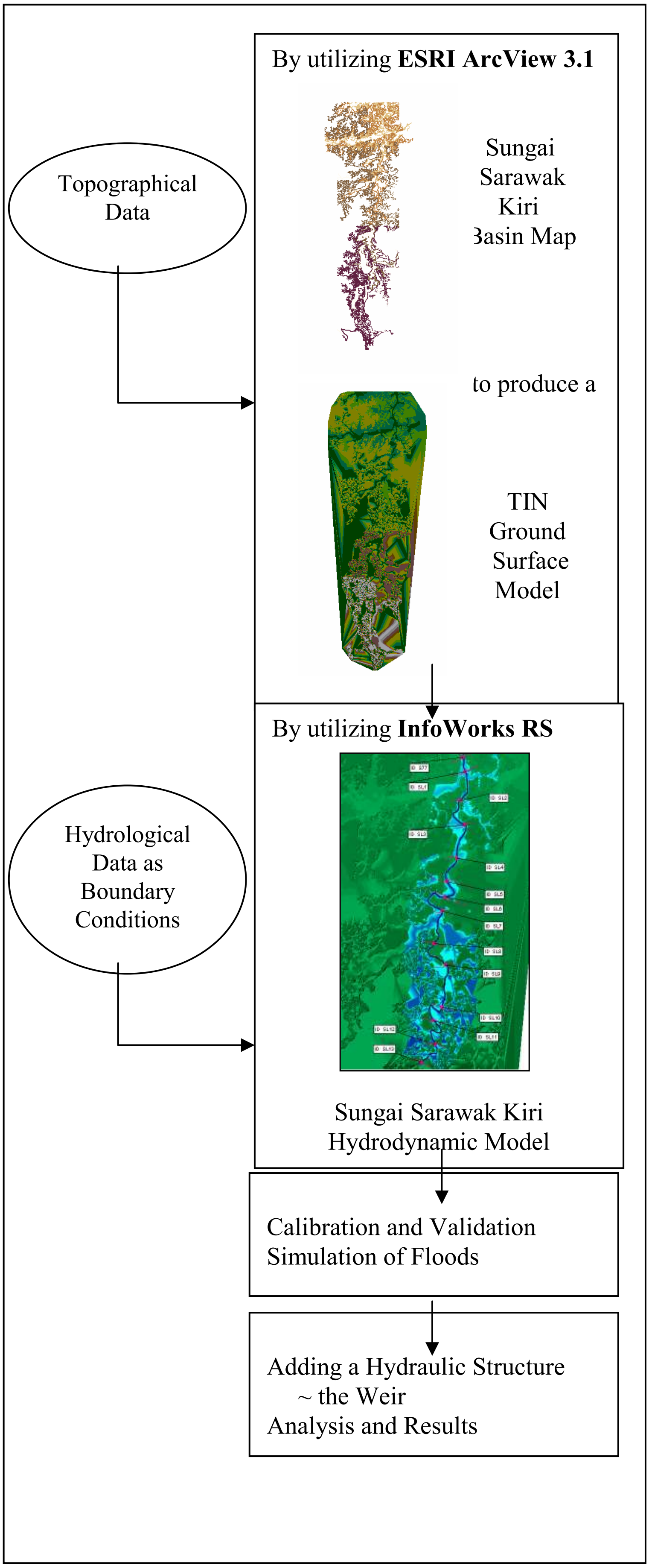
IV. RIVER MODEL BUILDING

In order to understand the weir in the flood-prone Batu Kitang, a 1D hydrodynamic river model is applied. The location considered for modeling is the Kpg. Git to Batu Kitang stretch of Sungai Sarawak Kiri. Batu Kitang has a catchment area of 657 km^2 and is situated approximately 35 km from Kuching city, while for Kpg. Git, its catchment area is 440.1 km^2 and is roughly located 51 km from Kuching city [5].

For this project, the InfoWorks River Simulation (RS), a model of the Wallingford Software Ltd., UK is selected. InfoWorks RS solves the full unsteady flow equations and capable of simulating a wide range of flow situations and channel characteristics. The methodology is based upon shallow water or Saint Venant equations, which express the conservation of mass and momentum. The equations that describe 1-D unsteady flow in open channels consist of the continuity equation, equation 1, and the momentum equation, equation 2, as below:

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

where y is river water level, Q is discharge, B is stream top width, q is the 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.



$$S_f = S_o - \frac{\partial y}{\partial x} - \frac{V}{g}\frac{\partial V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t} \qquad \text{(Equation 2)}$$

where A is flow area, g is gravitational acceleration, and S_f is friction slope.

InfoWorks RS model uses a four-point, implicit, finite difference approximation to solve the equations 1 and 2 numerically. The scheme is structured so as in mathematical term as non-linear hyperbolic partial differential equations.

By using ESRI ArcView 3.1 software together with its 3D-Analyst 1.0 Extension, a 1:10 000 scaled key plan in AutoCad format featuring the Sungai Sarawak Kiri basin area with proper geo-referencing [4] is regenerated as digital basin map in shapefile (SHP) format, in which later a Triangulated Irregular Networks (TIN) surface model is generated (see figure 5). The TIN model is exported to InfoWorks RS environment as a Digital Terrain Model (DTM) where the ground surface information is extracted for network building. The river network is interacted through the embedded Geographical Plan (GeoPlan), where the Sungai Sarawak Kiri network is developed through the on-screen creation of model nodes and links.

Nodes (the lowest mid-point in the river cross sections) are established at convenient points along the modelled river channels to suit major geographical landmarks and suitable segmentation of the flow paths. Each node provides ground level and indication of the channel cross section. Links between nodes are given river lengths. Both the channel cross section and river length data are extracted from the Sungai Sarawak Flood Mitigation Study [4].

All hydraulic models require that internal and boundary conditions established before the flow simulation is commenced. Internal conditions are simply stated as the conditions at all points in the river at the beginning of the simulation. Internal conditions are established by specifying a base flow within the channel. Boundary condition is the known relationships between discharge and time or stage and time. Flow simulation requires the specification of upstream, downstream and internal boundary conditions.

A Stage-Time Boundary is used as the downstream boundary at downstream end of Sungai Sarawak Kiri at Batu Kitang. The Stage-Time Boundary is in essence a rating curve that allows the input of water level hydrograph as a boundary condition. While the upstream end at Kpg. Git is modelled as Flow-Time Boundary. The Flow-Time Boundary models a discharge hydrograph specified as a boundary condition. The efficiency of the river model is calibrated by matching the recorded and simulated stages at Kpg. Landeh (see figure 3).

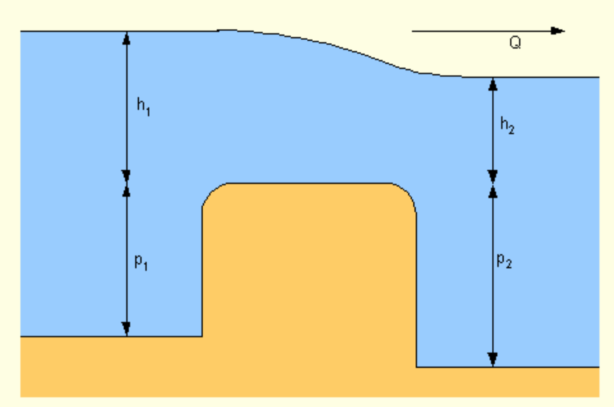


Figure 6 Broad Crested Weir

The calibration and validation events have produce a correlation of about 0.80 for the modeled and actual flows. The analysis indicates that for Sungai Sarawak Kiri, a Manning's n of 0.095 and 0.12 are appropriate for its waterway and floodplain respectively. A time step of 15 s is appropriate for the conversion of model. Then, the model is used to simulate different magnitude of floods.

Hydraulic structure is added after the errors in the network have been checked and corrected. The Batu Kitang submersible weir is modeled as a broad crested weir (see figure 6). It is modeled in two modes, i.e. free flow and drown conditions depending on the modeled flood magnitudes.

V. RESULTS AND DISCUSSION

The Batu Kitang water treatment plant is located on a small hill known to be outside the 100-year return period flood hazard zone. For such an event, the weir would be fully drowned at a water level up to 8 m high where the weir has no effect on the floodwater level of neither upstream nor downstream. The design of the "submersible" weir is in such a way to bare no added burden to the flooding in Batu Kitang. The simulation of a 50-year return period flood has shown the similar impact.

The operation of weir is often misunderstood that it is believed to cause the flow to back up and raise the water level upstream. This only happens once critical conditions are achieved on the weir [6]. In a major flood event, the water level on the weir is beyond the critical state. Therefore, the concern arises in smaller flood event when critical flow is achieved.

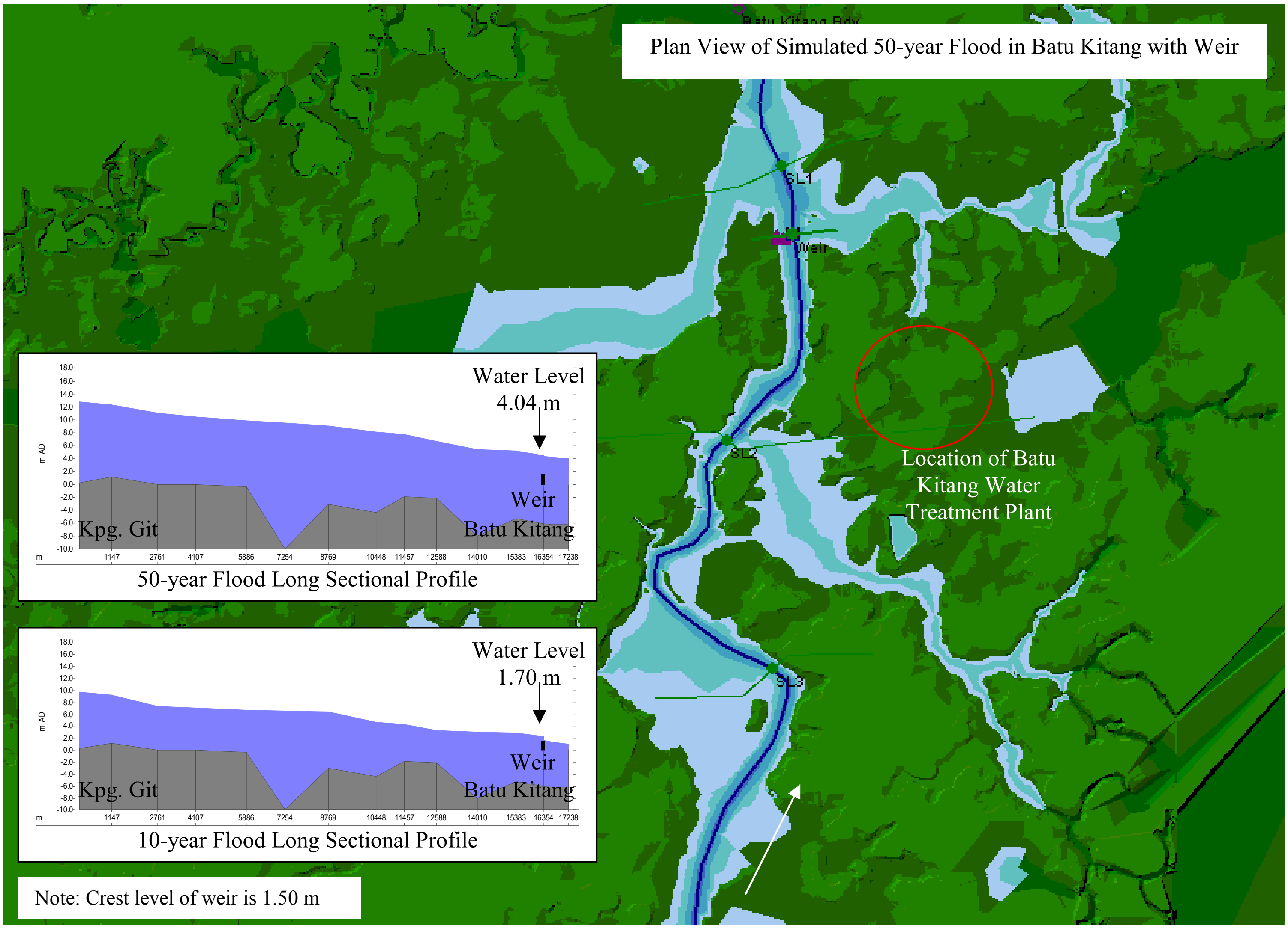


Figure 7 Graphics of Simulation Results

Table 1 Simulation Results during 10-year Flood

	No Weir	With Weir
Water level downstream weir location (m)	1.45	1.70
Water level upstream weir location (m)	2.50	2.70
Discharge at weir location (m^3/s)	390	390
Velocity at weir location (m^2/s)	0.49	0.57

Simulation of a 10-year return period flood at Batu Kitang is shown in table 1. The water level upstream of the weir increases 0.2 m, from 2.50 m (when no weir) to 2.70 m (with the presence of weir). The water level immediately downstream of the weir also increases 0.25 m after the weir is installed but returns to normal flow further downstream.

VI. CONCLUSIONS

The Batu Kitang submersible weir is first designed to increase the safe yield of Sungai Sarawak Kiri raw water sources. The hydrodynamic modeling has shown that the structure imposes flood risk around Batu Kitang during smaller flood events. Thereby, more frequent flood would be expected upstream of the weir.

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