SUSTAINABLE FLOOD PROTECTION PLANS FOR BENTONG TOWN, MALAYSIA

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ABSTRACT

Bentong Town suffers from frequent flash flooding due to increased rainfall coupled with steep terrain and reduced river capacity. This paper presents simulated results of an integrated flood mitigation study carried out based on hillside storage facilities and minor river improvement works along the town. Hydrologic and hydraulic modellings were performed to assess a set of alternative solutions. Five main storage sites, with total capacity of about 30 MCM, were found most suitable to solve the flood problems and minimize the impact on the existing river system. A 100yr ARI flood discharge expected under future basin condition was 600 m^3/s, at the town centre. Control at the ponds offered nearly 67% reduction in peak discharge. The wet ponds shall provide additional facilities for sediment control, water supply at 50.0 MLD. Based on the simulations, the storage facilities would be able to reduce the flood peaks of 100-year return period by 85 - 92% at the impoundment sites. Such reduction would not only make the water level safe in the river, but also reduce the eroding velocity of the river water. The study also recommended various riverine amenities for the socioeconomic benefit of the community living in and around Bentong area.

Keywords: Amenity, Computer Modelling, Flood Control Plan and Storage Facility.

INTRODUCTION

Bentong town is located in the downstream valley/floodplain of mountainous Bentong River basin, about 70 km east of Kuala Lumpur City, Malaysia. The town suffered increased floodings in the recent years; mainly due to change in monsoonal rainfall severity in the upper basin areas coupled with steep terrain and reduced river discharge capacity as a result of sediment accumulation from basin deforestation and town expansion activities. Now water quality turned poorer primarily from wet-weather pollution sources, limiting water resources for drinking as well as recreation purposes.

The town is inhabited by over 70,000 people that generally demand for greater social and environmental values from the catchment.

Besides steep gradients, river constrictions, backwater effects due to Parting and Benus River, proximity of the time of concentrations of the tributaries surrounding the town causes rapid rise in flood depth in Bentong River. The river sections, on average, could contain up to 40% of the 100-yr peak flood under the existing landuse condition. Considering the geomorphology of Bentong River and its tributaries, mitigation measures by river capacity improvement only would offer short-term solutions. Extensive river training works would destroy the natural habitat, aquatic flora and fauna. Above all, the traditional conveyance oriented mitigation measures would transfer flood hazards to the downstream areas. Therefore, considering all the challenges, multiple storage oriented optimisation exercise was preferred over the increase in conveyance capacity of the river to solve the flooding issue of Bentong Town. The general goal of the project was to provide sustainable flood protection and improved social values to the citizens living in the area. The main objective of this paper is to present the storage oriented planning (DID, 2000) based on the computer simulations as well as integration of environmentally friendly elements to enhance amenity within the catchment.

THE STUDY AREA

The town is developed longitudinally along the main trunk of Bentong River. General topography of the rive basin varies from 85 m to about 1500 m mean sea level (MSL). The basin (253 km^2) is formed mainly by the subcatchments of Perting (118 km^2), Repas (28 km^2), Chamang (21 km^2) and Penjuring (20 km^2). The Benus River joins Bentong River at bout 3 km downstream of the town. Contributing subcatchments in the Bentong Town are small, mostly located on the left side of the basin and known as Pileh, Dilam and Luar streams. Tributaries on both sides of Bentong River are steep and rugged with the right side having larger catchment and longer rivers. At some locations streams are moderate and meandered through wider valleys while in the other areas channel gradient are steep with flow through deep valleys. The average annual rainfall in the basin is about 2400 mm.

METHODOLOGY

Various hydrologic and hydraulic analyses were conducted in the study, which are briefly discussed in the following sections.

Time of Concentration

Bransby-Williams' Formula (Equation 1) was used to calculate the t_c of the main rivers and tributaries (ARR, 1987).

$$t_c = \frac{F_c \,.\, L}{A^{1/10}\, S^{1/5}} \tag{1}$$

where,
t_c = the time of concentration (minute);
F_c = a conversion factor, 58.5 when area A is in km^2, or 92.5 when area is in ha;
L = length of flow path from catchment divide to outlet (km);
A = catchment area (km^2 or ha); and
S = slope of stream flow path (m/km).

Frequency Analysis

Frequency analysis for rainfall and flood records were carried out using Gumble Extreme Value (GEV) distribution. Values for 2, 5, 10, 20, 25, 50 and 100-year annual recurrence interval (ARI) were deduced from the analysis. Although twelve (12) rainfall stations are available within and nearby the study area, frequency analysis was only carried out for the four (4) automatic stations, which have records for storms less than 24 hr intervals. Intensity-duration-frequency (IDF) relationships were developed from the frequency analysis performed using the data from the automatic rain gauge stations. Annual flood peak values (1970-1999) from the only river gauging station at Kuala Marong (Stn. No. 3519426) was used to determine the flood peaks of various return periods.

Temporal Pattern

Temporal patterns of several recent significant storm bursts of various durations were analysed for development of the design rainfall temporal patterns. Temporal patterns of the observed storms were used to calibrate and verify the hydrologic model.

Hydrologic and Hydraulic Modelling

The design flood was estimated and routed using XP-SWMM model (WP Software, 1999). For the purpose of modelling, the catchment was divided into several sub-catchments and the selection of the nodes was based on the consideration of certain aspects of the hydraulic and hydrologic characteristics of the terrain, ground profile, landuse and landcover of the catchment. Various parameters such as geometry, imperviousness, slopes, roughness and river characteristics are extracted from available data including topography maps, landuse/landcover maps, river inventory, and river surveys, etc. Several slopes of each stream in a sub-catchment were determined to calculate the stream's average slope.

Model Schematisation

Figure 1 shows the schematic arrangement of the nodes and links selected for the SWMM model. Cross-sections of the rivers are abstracted from the available survey data and those of the floodplains, both sides, are abstracted from topographical maps of the area concerned. The selection of the river cross-section locations is done carefully by taking into consideration all the hydraulic aspects that could influence the hydraulic calculations.

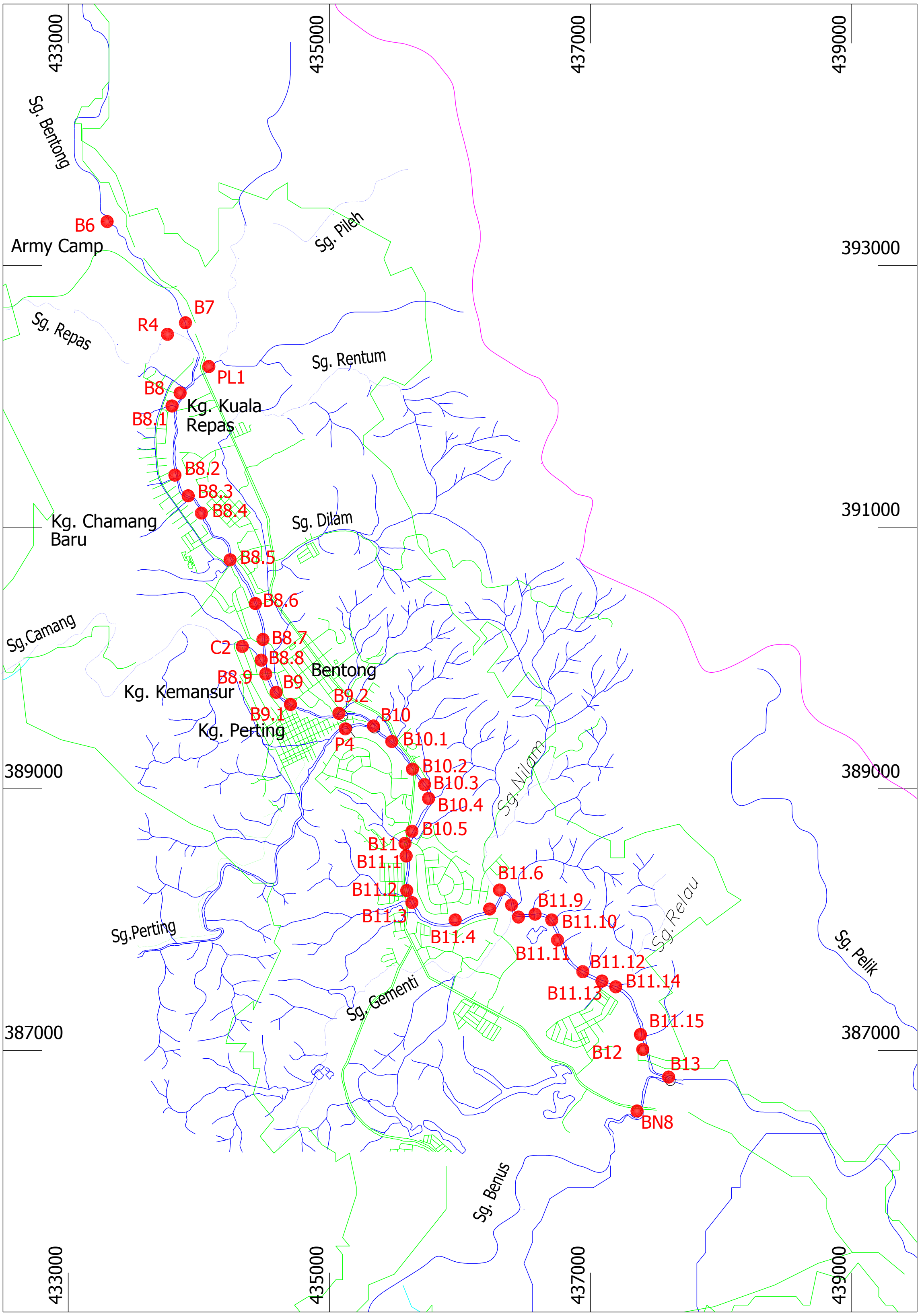


Figure 1: Schematic of the Links and Nodes used for XP-SWMM Model

Model Calibration and Verification

Calibration of the hydrologic model parameters is necessary before a detailed analysis is carried out. Calibration mainly relies on adequate amount of good quality historical data. It is quite common that values of many required parameters are not available for the site. Besides event rainfall and streamflow data from automatic gauging stations, antecedent moisture condition, spatial distribution of rainfall and other soil parameters were also considered for the calibration of the model. Events on 16/8/95 and 29/3/96 were used for calibration of the model. The model was, then, verified with the observed storm on 05/11/1998.

Calibration and Verification

Hydrographs from the hydrologic modelling were compared to calibrate with the observed flow data. The hydraulic model was, then, run to compare with the observed river water level during the particular storm event. The stage hydrograph of the event on 16/8/95 (for calibration) and on 05/11/1998 (for validation) are shown in Figure 2.

RESULTS AND DISCUSSIONS

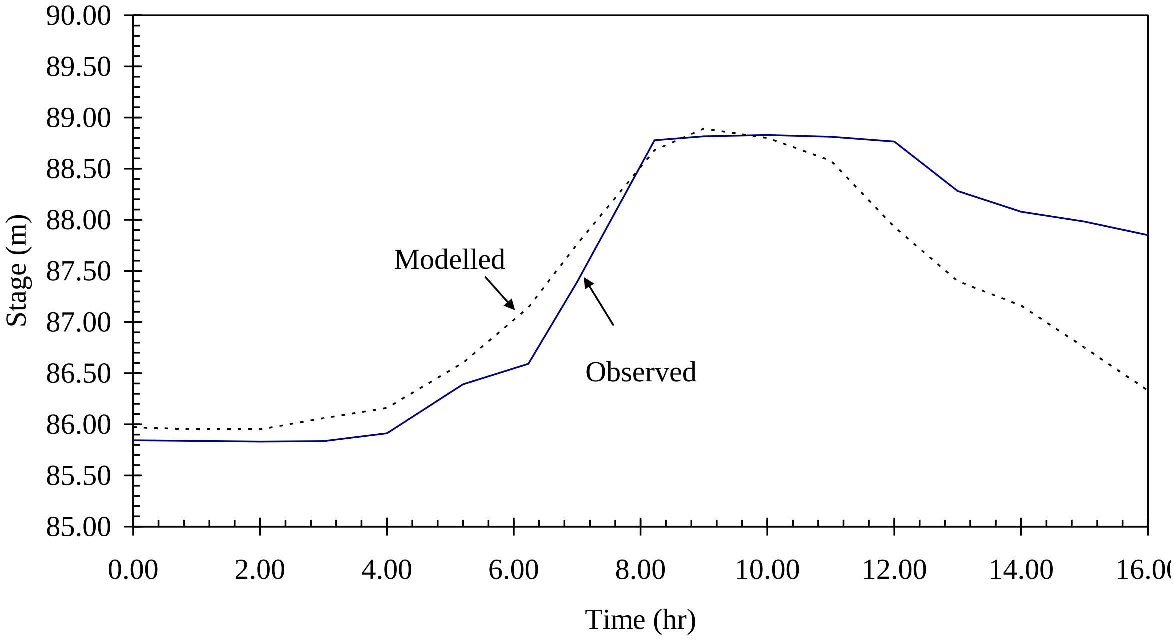
Rianfall is the main input for the river flow simulation. Design rainfall intensities for various storm durations and return periods for Kuala Marong, Bukit Fraser and Janda Baik stations were considered in the model.

Critical Design Storm

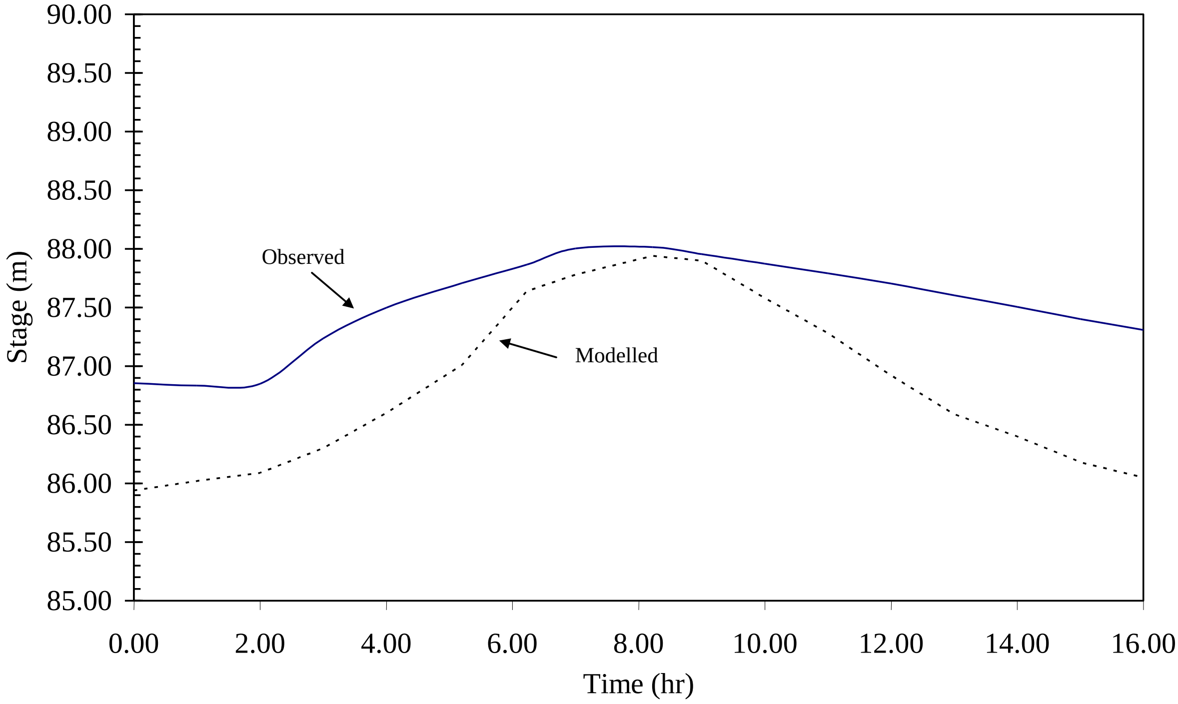
Storms of 3, 6, 9, 12 and 24 hours durations with the design temporal patterns were simulated to find the critical storm duration for the catchment. The simulated peak discharges of 100-yr design storms under existing catchment condition are graphically analysed and it was obtained that 6-hr duration storms shall produce critical floods at Bentong town.

Calibration and Validation

Hydrographs from the hydrologic modelling were compared to calibrate with the observed flow data. The hydraulic model was, then, run to compare with the observed river water level during the particular storm event. The stage hydrograph of the event on 16/8/95 (for calibration) and on 05/11/1998 (for validation) are shown in Figure 2.



(a) Calibration for Storm Event on 16/8/95



(b) Validation for Storm Event on 05/11/1998

Figure 2: Calibration and Validation of the Model

Design Flood Profiles

Flood level profiles of 6-hr 5, 20, 50 and 100-yr ARI design rainfalls were derived for present condition and are shown in Figure 3. Profiles generated by the 100yr and 50yr ARIs have shown that flood water levels are well above the riverbanks. This would cause inundation to riverine areas along Bentong Town and its downstream areas. The extent of inundation, with respect to depth or time, however, depends on width, roughness and terrain of the confining floodplain. From the 6 hr 100 yr ARI storm the maximum possible inundation postulated at Kuala Marong residential area, for a typical case, would be about 2.0-2.50 m depth and 6-8 hrs long in the absence of flood mitigation measures. The same flood would pose a flow velocity exceeding 5.0 m/s at some stretches along the Sg. Bentong and if long enough it is eroding to soft banks, dangerous to people and collapsing to some vulnerable riverine structures.

Flood Mitigation Alternatives

The traditional practice of flood mitigation is basically based on maximising conveyance capacity for accommodating increased peak discharge, velocity and water level through deepening, straightening, lining, widening and bunding works of affected river stretches. Considering the geomorphology of Bentong River and its tributaries, mitigation measures by the practice of river capacity improvement works would only offer short-term solutions. In addition, major widening and bunding of the existing river sections might require reconstruction of existing bridges to remove constrictions against the river flow during the high floods. Relocation of the existing services, including dwelling and commercial structures, that encroach into corridor along the river would be an inconvenient exercise as it is time consuming and costly. The land engineering works would certainly destroy the natural habitat, river flora and fauna. Having gone through all the agonies with substantial funding and risk against scenic river environment, there is still no guarantee that the flood problems would not recur in the future or the hazards is just transferred to downstream areas.

The four sites identified for the regional storage are Upper Bentong, Sempeli with diversion from Penjuring, retrofitting and upgrading of existing Old Repas and Perting dams. Considering these possible candidate storage sites, six (6) different alternatives were formulated for simulation (Table 1). Among the criteria used to derive the alternatives include catchment contribution, flood peaking time, location of the tributaries, flood prone areas, lower embankment height, least dam sites and degree of river capacity improvement more importantly at constrictions such as in the vicinity of the Town Centre. River capacity improvement applies mainly to restoring the original capacity of the Sg. Bentong.

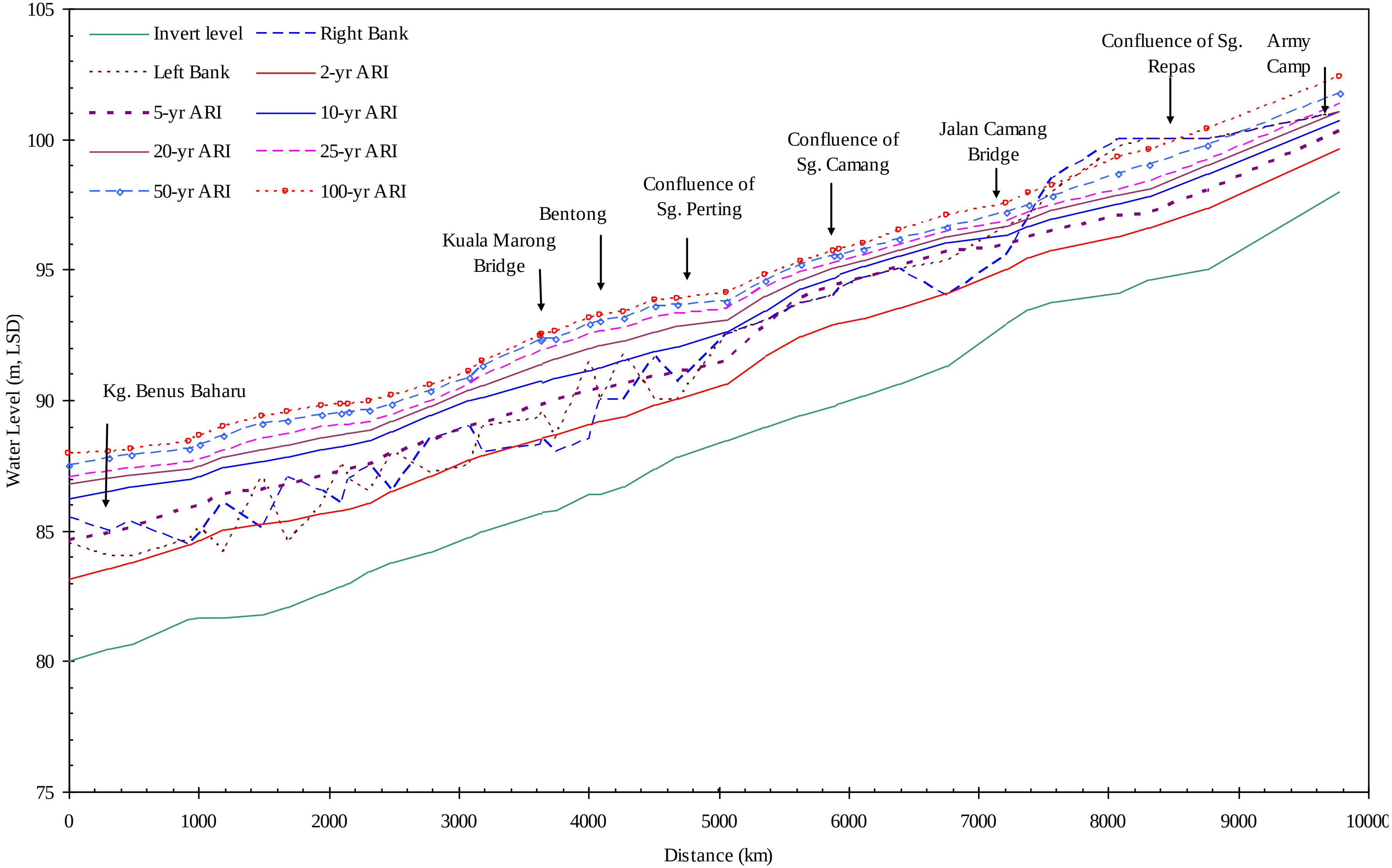


Figure 3: Water Level Profile of 100-year ARI Flood for the Best Option

Table 1: Reduction of Flood Peaks after Optimising the Release from each Impoundment

Alternative	Control Sites				River Improvement
	Upper Bentong Reservoir	Sempeli Reservoir with Penjuring Diversion	Upgrading Repas Dam	Retrofitting Perting Dam	
1 (SPBR)	√	√	√	√	–
2 (SPBR + RI)	√	√	√	√	√
3 (SP + RI)	–	√	–	√	√
4 (SPR+ RI)	–	√	√	√	√
5 (SBR + RI)	√	√	√	–	√
6 (SPB + RI)	√	√	–	√	√

Note: S = Sempeli, P = Perting, B = Upper Bentong, R = Repas and RI = river improvement

Optimising Multi-level Riser Outlet

The outlet facilities are the most important components of a flood control impoundments and their sizes are determined by individual reservoir's inflow and elevation-storage, embankment heights and its outflow discharge relation with the water level in the target area. Two types of outlets were designed for all the flood control dams; primary outlet/riser to cater for frequent flood events such as at 5, 20, 50 yr ARI and secondary outlet/emergency spillway for larger-rarer events of 100yr ARI and probable maximum flood (PMF). Sizing/positioning of these outlets were accomplished using flood storage indication curve and routing procedures which are available in the Manual (DID, 2000). Table 2 provides the results of outlet sizes, positions and other pertinent data for all the dams in relation to embankment crest, reservoir storage volume, inflows and designed outflows including PMF discharges.

Table 2: Reduction of Flood Peaks after Optimising the Release from each Impoundment

No.	Site	Type	Inflow		Outflow		Reduction
			Q_p (cumec)	t_p (hr)	Q_p (cumec)	t_p (hr)	(%)
1	Upper Bentong	Dry detention pond with controlled outlet and ungated spillway.	40.0	4.5	6.0	10.7	85
2	Sempeli	Wet detention pond with controlled outlet and spillway for multipurpose uses such as water supply and Recreation.	78.0	4.1	8.0	11.0	90
3	Repas	Dry detention pond with controlled outlet.	70.0	5.2	10.0	11.9	86
4	Perting	Wet detention pond with controlled outlet and spillway.	260.0	5.8	20.0	21.3	92

Note: Q_p is Peak Discharge and t_p is time to peak.

All risers are of circular shapes except at Old Repas with rectangular geometry by vertically extending the existing rectangular spillway openings. The spillways are located in two different positions, one combined with the riser at its top as a bellmouth structure and the other separately as a side weir attached to the dam abutment. Figure 4 details derived sizes/dimensions of the riser control outlets for all the dams. Discharge outlets of risers are provided through tunnels proposed to be located at the bottom of dam embankment, generally in the form of rectangular box and circular conduit shapes. Old Repas has a twin box outlet tunnel (existing) while the rest has only a single tunnel (all new). Retrofitting of Perting dam will also provide silt removal enhancement. It is accomplished by the introduction of sediment storage and settling zones through a set of small orifices attached towards the bottom of the proposed riser. Several iterations were conducted to optimise the riser outlets to get minimum flood level in the river, without causing over spilling of any reservoir.

Assessment of Mitigation Alternatives

With a target of containing 100-yr ARI flood levels within the existing riverbanks under future catchment condition, all attenuated/reduced discharges (Table 3) within the six (6) alternatives were hydraulically analysed using SWMM model. The existing riverbanks at some places, for example at Jalan Chamang and Bentong Bridge, are low compared to the riverbed levels. Thus, all alternatives shall require localised improvement of riverbank levels for which detailed survey needs to be done during the detailed design and construction phase of the project. The summarised evaluation of the mitigation alternatives is given in Table 3.

Table 3: Qualification of Flood Mitigation Alternatives

Scenario	Remarks
Alternative - 1	Full flood proofing is not possible due to few constrictions in the existing rivers.
Alternative - 2	The best sustainable solution with minimum relocation and rehabilitation problems.
Alternative - 3	Shall require river improvement works at the Town areas resulting in relocation and social problems, One of the potential solutions.
Alternative - 4	One of the preferred sustainable solutions shall require minor river improvement works to get river's original capacity restored.
Alternative - 5	Another potential sustainable solution without any alteration of existing Perting Dam shall require significant river works at d/s of the confluence with Perting and Bentong River.
Alternative - 6	Potential sustainable solution considering the age of the existing dam across Repas River shall require significant river improvement works from the Repas River confluence to Perting River confluence.

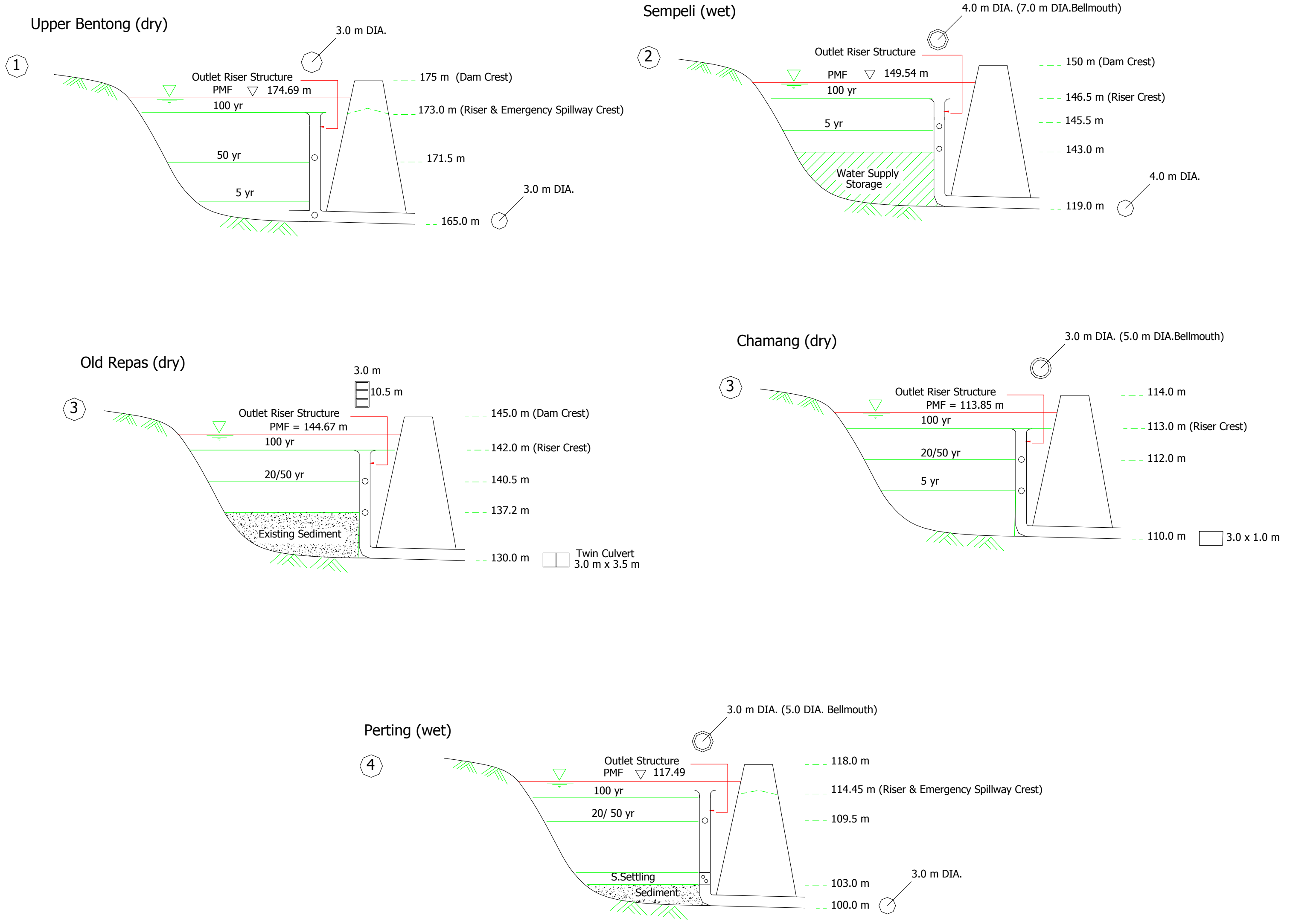


Figure 4: Dimensions of the Flow Control Risers Proposed for the Reservoirs

Recommended Alternative

The natural capacity of Sg. Bentong, over a period of time, has subsequently been reduced in many places from its natural morphology by excessive sedimentation, collapsed riverbanks and encroachment by urban development. This has resulted in the constriction of the river width along some stretches, in particular from Jalan Chamang to the town centre. Hence it has been found that it is first necessary to restore the past river widths by widening the constrictions.

Based on the analyses of flood profiles for various options and considering the socio-economic and other environmental factors, it was decided that Alternative-2 (SPBR + RI) would provide more lasting and sustainable solution with minimum negative impact along the river corridor. Other promising alternatives for the flood mitigation plan of Bentong Town are Alternatives 4 and 6. The water level profile of the best option is shown in Figure 5.

CONCLUSIONS

With the improved river sections, within the town area about 9.0 km long, the controlled flood profiles were contained within the existing riverbank levels thus maintaining a bundless natural environment by integration of bioengineered channel as well as introduction of beautification and amenity elements such as bikeways, pedestrianways, water edges (handicapped accessible) and friendly crossing and outfalls along banks/corridors. Grade control structures create waterfalls while sod over ripraps (SOR) stabilize bank toe zones instream. These multifaceted approaches are expected to enhance visual quality and safety elements while protecting cultural and biological resources of the town. In general the project plan has considered fulfilling the goal to provide a sustainable flood solution integrating soft engineering and amenity elements as well as improved socioeconomic activities of the local community in the years to come.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support provided by the Department of Irrigation and Drainage (DID) Malaysia to conduct this study.

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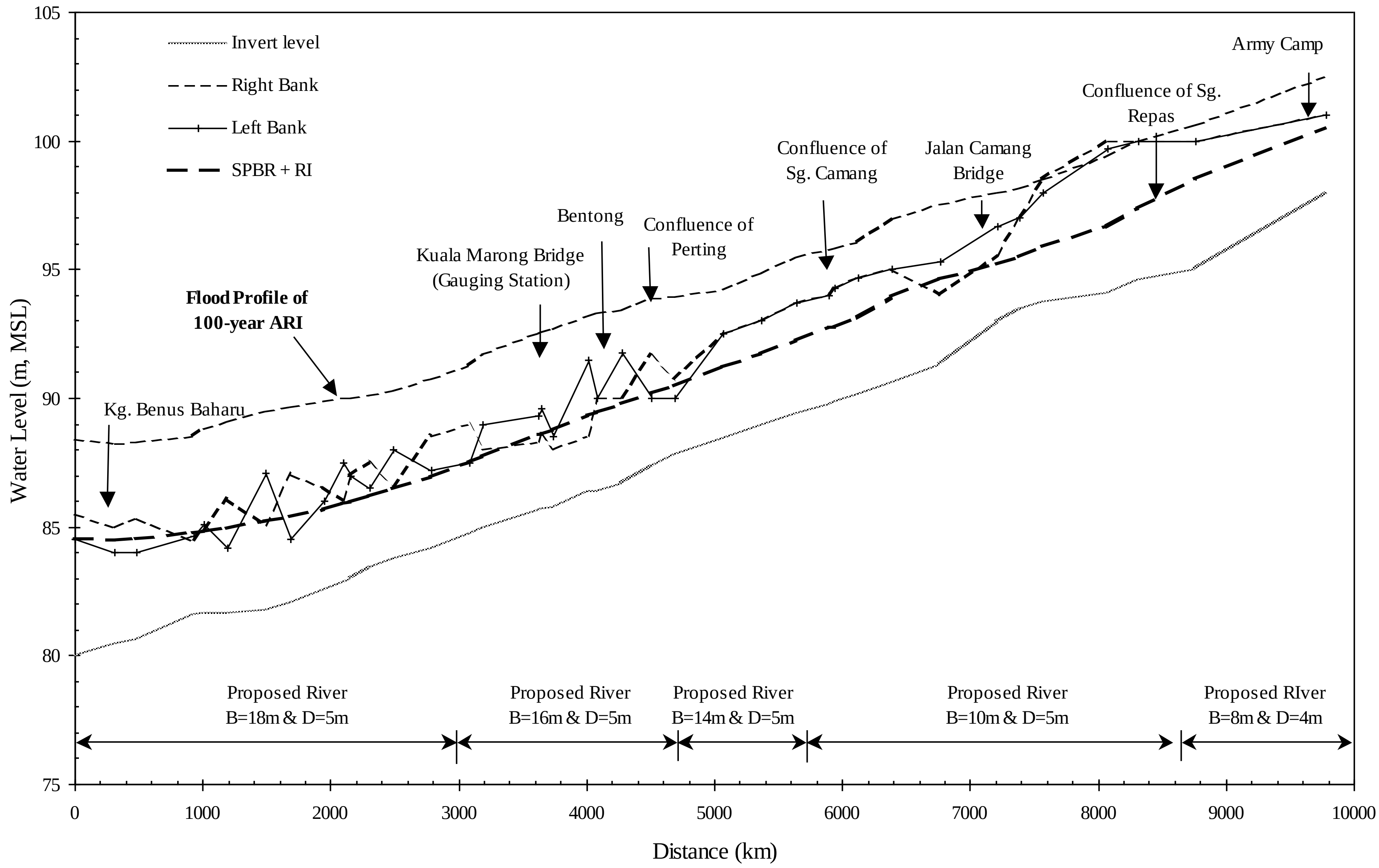

Figure 5: Water Level Profile of 100-year ARI Flood for the Best Option