SIMULATION OF NON-STRUCTURAL MEASURES TO REDUCE FLOODING IN SG. BENTONG CATCHMENT

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ABSTRACT: Flooding is a frequent and recurring natural disaster in tropical and sub-tropical regions, often exacerbated by climate change, which may increase both the frequency and severity of such events. Malaysia, due to its geographical location, topography, and climatic conditions, frequently experiences flash and regional flooding, further aggravated by improper development activities. Both structural and non-structural methods have been extensively employed to mitigate flood disasters. Structural measures include dams, levees, floodways, floodwalls, and river improvements. Non-structural measures, however, such as land-use planning and zoning, flood risk mapping, and computer-based flood modeling, are less frequently discussed in the literature. This research focuses on evaluating the effectiveness of non-structural flood prevention interventions in Bentong, Pahang. It investigates proper land-use planning, rainwater harvesting systems, and floodplain management through advanced flood modeling. The study employs HEC-HMS and HEC-RAS models to simulate flood scenarios and generate flood maps. ArcGIS was used to create detailed flood maps, simulating a 100-year, 6-hour storm event over a 99.38 km² area. The results indicated significant water depths ranging from 0.5 to 9.82 meters, highlighting substantial potential for damage. The findings underscore the importance of integrating non-structural measures, such as effective land-use planning and rainwater harvesting, into flood disaster management strategies. These measures, combined with detailed flood modeling, offer valuable insights for mitigating the impacts of future flooding events in the study area.

KEY WORDS: *Flood Management, Catchment, HEC-HMS, HEC RAS, Non-structural*

1. INTRODUCTION

In Malaysia, 189 river basins exist, with the majority discharging into the South China Sea. Flooding, increasingly severe in tropical and temperate zones [1] due to climate change and heavy rainfall [2] affects 9% of Malaysia's area, impacting around 22% of its population. The Department of Irrigation and Drainage [3] highlights that approximately 29,800 km^2 is at risk of flood catastrophes, affecting about 4.82 million residents. These events underscore the importance of understanding and mitigating flood risks in the region.

The hydrological performance of natural catchments is influenced by climate, vegetation, and surface/subsurface channels. Precipitation rates, plant interception and transpiration, and infiltration rates determine water transport. Urbanization, however, alters these processes by increasing impervious surfaces like roads and buildings, reducing vegetation, and affecting evaporation and infiltration rates. Consequently, surface runoff volumes increase, leading to earlier and more severe floods peaks in urban areas. This shift highlights the need for sustainable urban planning to manage flood risks effectively.

Floods in Bentong are caused by both natural and human factors. Natural causes include high-intensity rainfall leading to flash floods, while human activities like improper waste disposal, increased impervious surfaces, and river obstructions exacerbate the situation [4]. Urbanization in Bentong contributes to poor drainage systems, which are overwhelmed during heavy rains, leading to water stagnations and flooding. Efficient waste management and improved drainage infrastructure are crucial to mitigating flood risks in such rapidly urbanizing areas. Climate change increases flood hazards by intensifying precipitation [5] and raising sea levels due to melting glaciers and ice sheets. This results in more frequent and severe flooding, necessitating robust flood mitigation strategies.

Structural measures like dams, levees, and floodways are complemented by non-structural approaches such as land use management, flood forecasting, and public awareness programs [6]. In Malaysia, initiatives like the SMART tunnel in Kuala Lumpur and various river basin studies aim to control and manage flood impacts, demonstrating the importance of integrated and multifaceted flood mitigation efforts [7]. An integrated approach to flood modelling and mapping is essential to manage these natural disasters, prevent future flood, and minimize their impact on society, life, and the environment [8].

2. MATERIALS AND METHODOLOGY

Fig. 1 shows the overview of the methodology applied in this study.

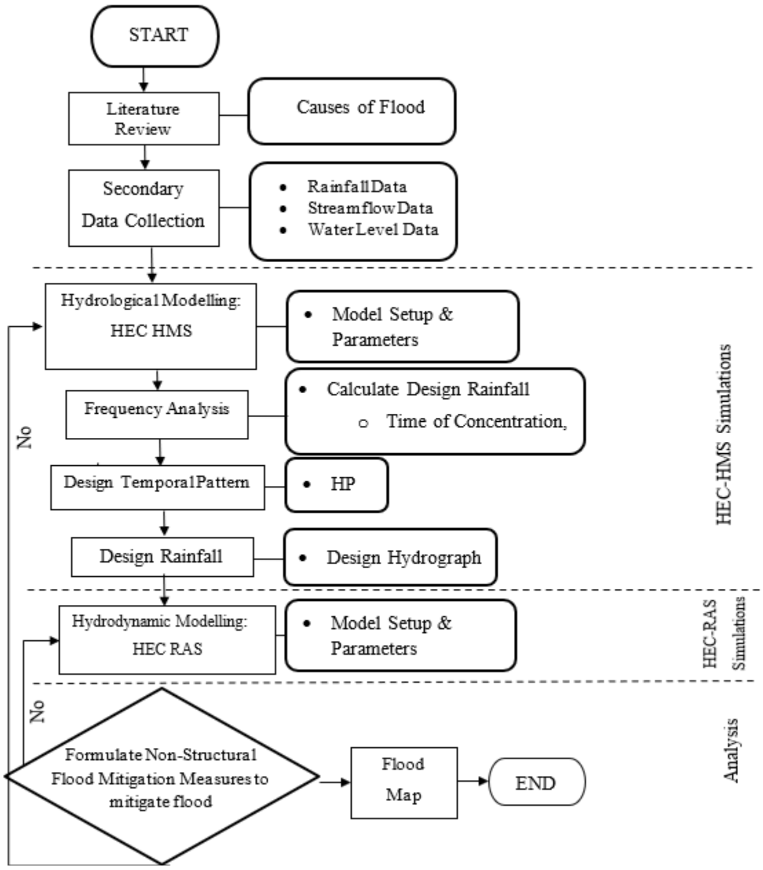

Fig. 1. Flowchart of the research.

The research had two phases. Phase 1 was a preliminary study exploring flood causes in Malaysia, reviewing literature on non-structural measures, and evaluating relevant acts and guidelines. It assessed river basin data to evaluate non-structural flood mitigation, informing potential measures and a holistic management approach. Phase 2 focused on simulation by using HEC-HMS and the Clark Unit Hydrograph method to estimate design peak flood discharge, with parameters from local catchments calibrated to match simulated and observed hydrographs.

2.1 HEC-HMS Model

HP No. 27 preferred the Unit Hydrograph Method, specifically using the Clark Unit Hydrograph from the HEC-HMS model, over the Rational Method for estimating flood hydrographs due to its adaptability to various storm patterns [9]. Catchment flow includes translation (gravity-driven movement) and attenuation (resistance from friction and channel storage). The Clark Unit Hydrograph uses a time area curve for translation, bounded by the time of concentration (Tc), and a linear reservoir model to relate outflow to inflow using Eq.
(1).

$$S = RO \tag{1}$$

Where:

S = catchment storage
R = catchment storage coefficient
O = outflow from the catchment

Detailed time area curves are not essential for accurate synthetic unit hydrograph estimation [10]. The following is the usual time-area curve relationship in Eq. (2).

$$\frac{A_t}{A} = \begin{cases} 1.414\left(\frac{t}{T_c}\right)^{1.5} \; for\; t \leq \frac{T_t}{2} \\ 1 - 1.414\left(1 - \frac{t}{T_c}\right)^{1.5} \; for\; t \geq \frac{T_t}{2} \end{cases} \tag{2}$$

Where:

A_t = cumulative catchment area contributing at time t

A = total catchment area

T_c = time concentration of catchment

HP No. 27 correlates parameters like Tc and R to the catchment characteristics like area, stream slope, and mainstream length. The formulae for the parameters are in Eq. (3) and Eq. (4):

$$T_c = 2.32\, A^{-0.1188} L^{0.9573} S^{-0.5074} \tag{3}$$

$$R = 2.976 A^{-0.1943} L^{0.9995} S^{-0.4588} \tag{4}$$

Where:

A = catchment area (km^2)

L = mainstream length (km)

S = weighted slope of mainstream

The rainfall-runoff relationship from HP No. 11 is utilized to estimate runoff volume from the design storm volume. The following rainfall-runoff relationship for catchments in Johor and the East Coast of Peninsular Malaysia are as follows in Eq. (5) and Eq. (6):

$$Q = 0.33P \qquad P < 75mm \tag{5}$$

$$Q = \frac{P^2}{P + 152} \qquad P > 75mm \tag{6}$$

Where:

P = total storm rainfall (mm)

Q = direct runoff (mm)

(Note: the above equations are like the ones in HP No. 11)

For West Coast Catchments are as shown in Eq. (7) and Eq. (8):

$$Q = 0.176P \qquad P < 75mm \tag{7}$$

$$Q = \frac{P^2}{P + 350} \qquad P > 75mm \tag{8}$$

HP No. 27 also develops a relationship between observed baseflow and catchment area, illustrated in Fig. 2.

$$Q_b = 0.11A^{0.85889} \tag{9}$$

Where:

Q_b = baseflow (m^3/s)

A = catchment areas (km^2)

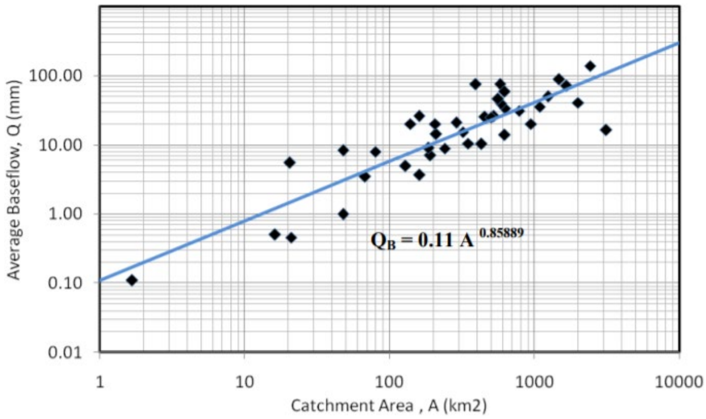

Fig. 2. Relationship of Baseflow and Catchment Area (HP No. 27(2010)).

Urbanization increases peak flood discharges by expanding impervious areas and reducing the time of concentration. The urbanization factor for each sub-catchment is derived from various sources. HEC-HMS handles imperviousness by specifying area percentages, converting rainfall directly to runoff. Insights into imperviousness and runoff are detailed in the USGS Water-Resources Investigation Report 00-4184, which provides reduction factors correlating imperviousness with runoff values in Fig. 3.

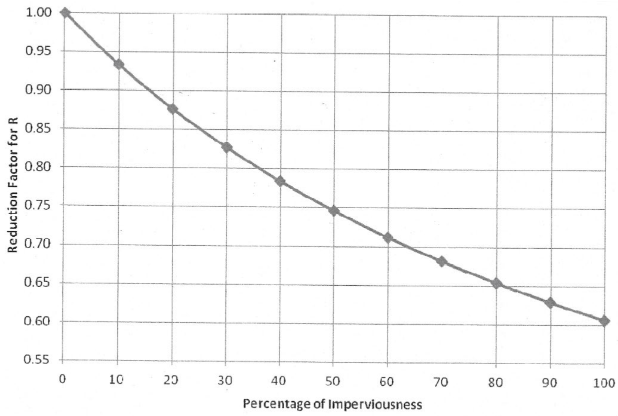

Fig. 3. Reduction Factor for R in Relationship with Imperviousness.

2.2. HEC-RAS Model

HEC-RAS 6.0.0 by the US Army Corps is used for one-dimensional hydraulic calculations on natural riverbeds, using the Saint-Venant equations for steady, gradually varied flow simulations. It also conducts unsteady flow simulations in Sungai Bentong, capable of both one-dimensional and two-dimensional hydraulic calculations for natural and constructed channels in Eq. 10 and Eq. 11.

Continuity equation:

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \tag{10}$$

Momentum equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial \left(\frac{Q^2}{A}\right)}{\partial x} + g.A(S - S_f) + g.A\frac{\partial y}{\partial x} = 0 \tag{11}$$

Where,

Q	= discharge for the overland or channel flow
A	= area of flow
x	= distance in the direction of flow
t	= time
g	= acceleration of gravity
S	= bed slope of the flow
S_f	= friction losses
y	= depth of flow

2.3. Study Area

Sungai Bentong in Pahang, located 60 meters above sea level, covers 580 km² between latitude 3˚28'0'' N and longitude 102˚4'59'' E. Fig. 4 shows the sub-catchments like Sungai Benus, Sungai Perting, Sungai Chamang, Sungai Repas, Sungai Sempeli, and Sungai Penjuring. Settlements along Tras Road are sparse on the left due to hills, while the right bank has more settlements, including Kampung Kuala Repas and Kampung Batu Satu Jalan Tras. Flooding is common in low-lying areas near the riverbank after heavy storms.

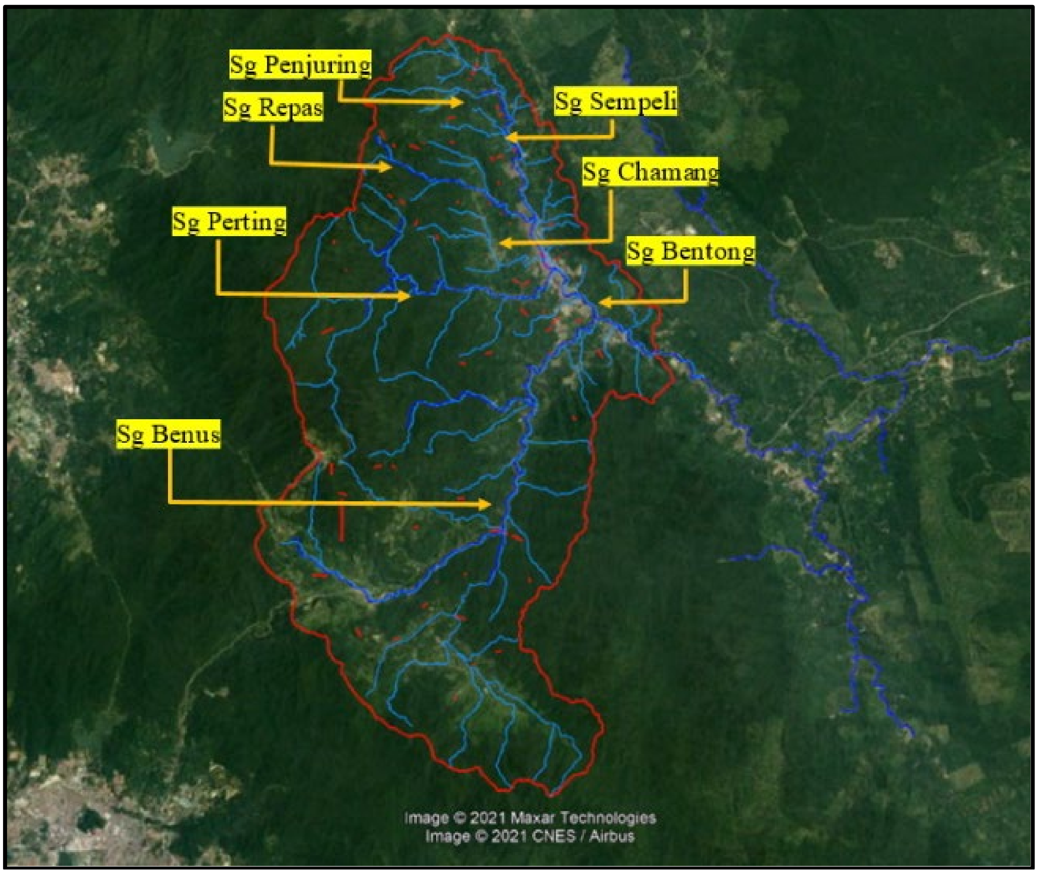

Fig. 4. River System in the Bentong Catchment.

Hydrological data for this study is sourced from TIDEDA's digital archives in JPS Malaysia, provided in various formats for analysis and modeling. Rigorous analyses ensure data consistency and reliability. Rainfall data from autographic stations as shown in Fig.

5—Station 3519125 (Kuala Marong di Bentong), Station 3318127 (Janda Baik), and Station 3420131 (Ladang Bukit Binding at Bentong)—have been acquired. Data from 1970 to present for Station 3519125 and from 2013/2014 to present for the others are used for intensity-duration-frequency (IDF) analysis. Stations with less than 10 years of data are managed to inform design rainfall analyses.

Fig. 5. Locations of Auto-Recording Rainfall Stations at and in the vicinity of Bentong area.

Understanding land use scenarios helps analyze how catchment flows change with land use shifts referring in Table 1. This study uses data up to 2018 from Town and Country Planning Department to assess previous and impervious areas in each sub-catchment. Future land use changes are modeled by adjusting pervious areas for development. The Sungai Bentong area features flat terrain near major irrigation channels, elevations below 75 meters, and small hills. Virgin forest covers the mountains, while the lowlands host rubber, oil palm, and rice paddies. Agriculture dominates, but illegal deforestation and unchecked development threaten land degradation in parts of the Sungai Bentong basin.

Table 1: Current land use area for Sg Bentong Basin

	Area (km^2)											
	Water Body	**Forest**	**Industry**	**Infrastructure**	**Institutions**	**Commercials**	**Transportation**	**Agricultural**	**Housing**	**Bare lands**	**Open spaces and recreation**	**Total**
Sg Bentong	1.6	38.8	1.0	0.1	0.9	0.4	3.6	24.6	3.8	0.4	0.2	75.4
Sg Benus	1.5	191.5	0.1	0.7	0.6	3.2	11.1	29.7	4.4	0.1	49.2	292.1
Sg Perting	0.4	81.7	0.0	0.0	0.1	0.4	0.2	28.5	1.2	0.0	1.0	113.5
Sg Camang	0.0	9.8	0.0	0.2	0.0	0.0	0.3	7.3	0.9	0.1	0.0	18.6
Sg Repas	0.0	14.2	0.0	0.0	0.1	0.0	0.1	12.1	0.2	0.0	0.2	26.9
Sg Sempeli	0.0	3.9	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	7.4
Sg Penjuring	0.3	10.2	0.0	0.0	0.0	0.0	0.0	9.1	0.0	0.0	0.0	19.6

To mitigate floods effectively, costly structural measures alone are impractical, necessitating non-structural strategies, especially in rapidly urbanizing areas like the Sungai

Bentong catchment. Proposed measures include optimal land use planning, rainwater harvesting systems, and integrated non-structural approaches, along with ensuring safe platform levels. These strategies, detailed in Table 2, address various flood scenarios. The study explores coping techniques such as relocation, floor elevation, and land use planning, considering the impact of urban development and climate change on water dynamics. Ignoring these factors can overwhelm existing infrastructure during storms. Flood mitigation involves individual preparedness and long-term infrastructure development, with rainwater harvesting as a versatile solution.

Table 2: Curve Number (CN) Value for land cover types and HSGs from Land Cover-based Asymptotic CN Regression Equations (LC-CAN-Res), NEH-4, National Engineering Handbook Chapter 4

Name of Land Cover	CN Value in NEH-4 CN Table for Individual Soil Type			
	A	B	C	D
Residential area	77	85	90	92
Manufacturing area	81	88	91	93
Regional public facility area	89	92	94	95
Recreational facility area	89	92	94	95
Road	98	98	98	98
Commercial area	89	92	94	95
Upland	62	71	78	81
Orchard	62	71	78	81
Greenhouse	62	71	78	81
Paddy	*62*	71	78	81
Pasture	30	58	71	78
Forest	45	66	77	83
Bare land	77	86	91	94

The form of SCS Runoff Equation (Eq. (12)):

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{12}$$

Where,

Q = direct runoff (mm)
P = precipitation (mm)
S = Potential maximum soil moisture retention after runoff begins (mm)
I_a = Initial abstraction (mm)

Initial abstraction can be estimated using standard equation (Eq. (13)):

$$I_a = 0.2\,S \tag{13}$$

With Equation 3.12 and Equation 3.13, equation Q (Eq. (14)) become:

$$Q = \frac{(P - 0.2S)^2}{(P - 0.8S)} \qquad (Eq. 14)$$

Where S (Eq. (15)) is related to the curve number for all land use/ land cover within the area by:

$$S = \frac{25400}{CN} - 254 \tag{15}$$

The CN scale runs from 30 to 100, with lower numbers indicating less runoff potential and higher numbers indicating increased runoff potential.

Rainwater harvesting, categorized as a Low Impact Development (LID) approach, involves collecting rainwater runoff on-site to reduce both volume and pollutant levels in stormwater systems. According to Harvesting (2013), Asian nations like Japan increasingly adopt rainwater collection to address water scarcity and mitigate urban flooding. Installing a system entail constructing appropriately sized tanks to collect rainwater from rooftops or terraces, treated for non-potable uses like toilet flushing and gardening. The Tangki NAHRIM 2.0 v2.0.2 program was used to determine optimal tank sizes, with simulations showing a 3 m^3 tank can meet over 90% of a typical Malaysian household's water demand. However, for densely populated urban areas, a 1 m^3 tank size was considered practical, providing around 70% of water demand per household. (Fig. 6).

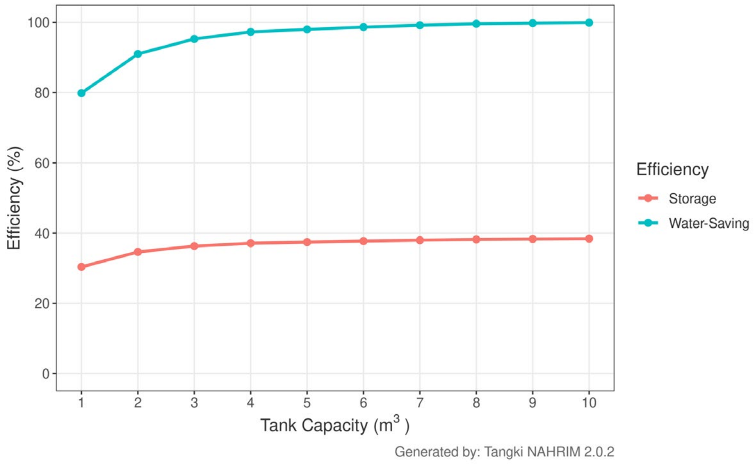

Fig. 6. Water-saving and storage efficiency vs proposed tank size

S with tank for low density residences can be calculated using Eq. 16.

$$S_{with\ tank} = \frac{V_{tank} + S_{roof} \times A_{roof} + S_{non\ roof} \times A_{non\ roof}}{Total\ area} \tag{16}$$

Where,

V_{tank} = volume of tank, m^3

A = Area, m^2

The runoff volume is computed once the final S is calculated using the IDF precipitation depth.

Floodplain development requires establishing safe platform levels to ensure flood-free conditions for a specified flood frequency. Hydraulic modeling, often with the HEC-RAS model, determines these levels. According to the Urban Stormwater Management Manual (2012), new urban developments must be protected from flooding up to the 100-

year Annual Recurrence Interval (ARI) flood level. Fig. 7 shows a typical design storm in Malaysia, with proposed safe platform levels detailed in Table 3.

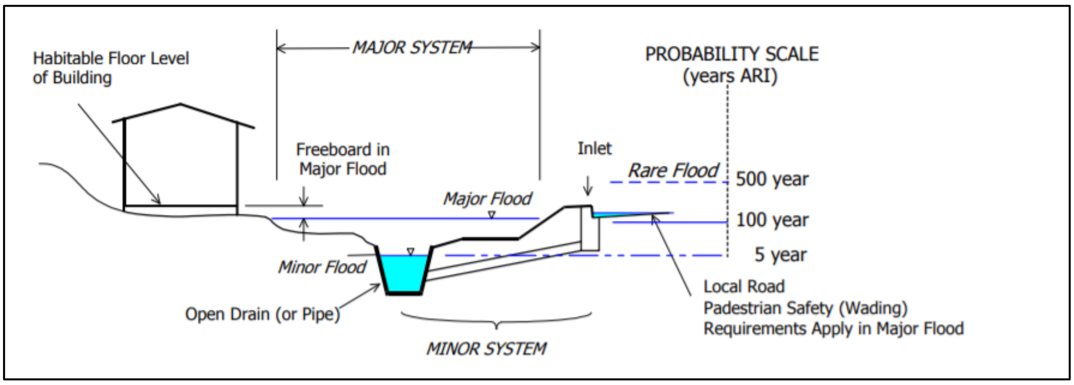

Fig. 7. Basic of design storm selection (DID Malaysia, 2012)

Table 3: Proposed Safe Platform Level

Type of development	Location	Habitable flood level
Residential	Inside flood mapping area	Maximum known flood level plus 1.0 m
	Outside flood mapping area	
Commercial/ industrial	Inside flood mapping area	
	Outside flood mapping area	

3. RESULTS AND DISCUSSION

3.1. Proper Land Use Allocation/Planning

This simulation assesses non-structural flood mitigation by modeling forested catchments to reduce flood issues. Forests enhance water retention, increasing soil infiltration and storage capacity, thereby decreasing runoff [11]. In the Sg Bentong catchment, many sub-catchments have less than 30% forest cover. Simulations with at least 30% forested land showed differences in flood hydrographs. Fig. 8, 9, and 10 present these for a 100-year ARI, 6-hour design flood with protective measures. Results shown in Fig. 11 indicate that Option 5 reduces water levels, but further flood mitigation measures are necessary.

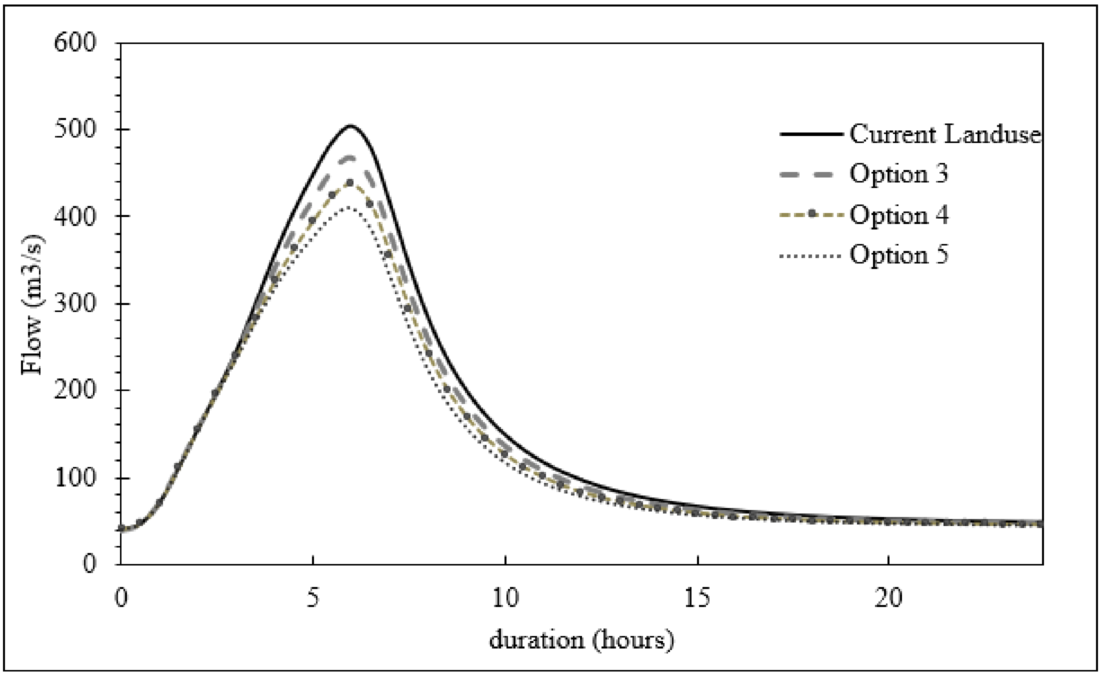

Fig. 8. Simulated Flow Hydrographs of Sg Bentong 100-year ARI 6 Hours Design Rainfall- Proper Land Use Allocation

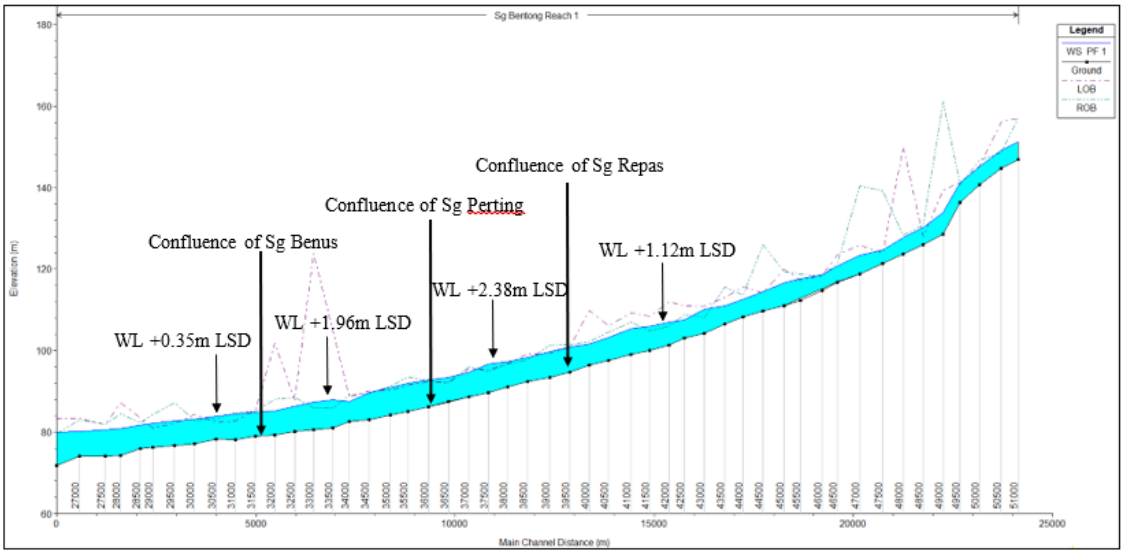

Fig. 9. Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-years ARI **(**Option 3-Proper Land Use Allocation/Planning**)**

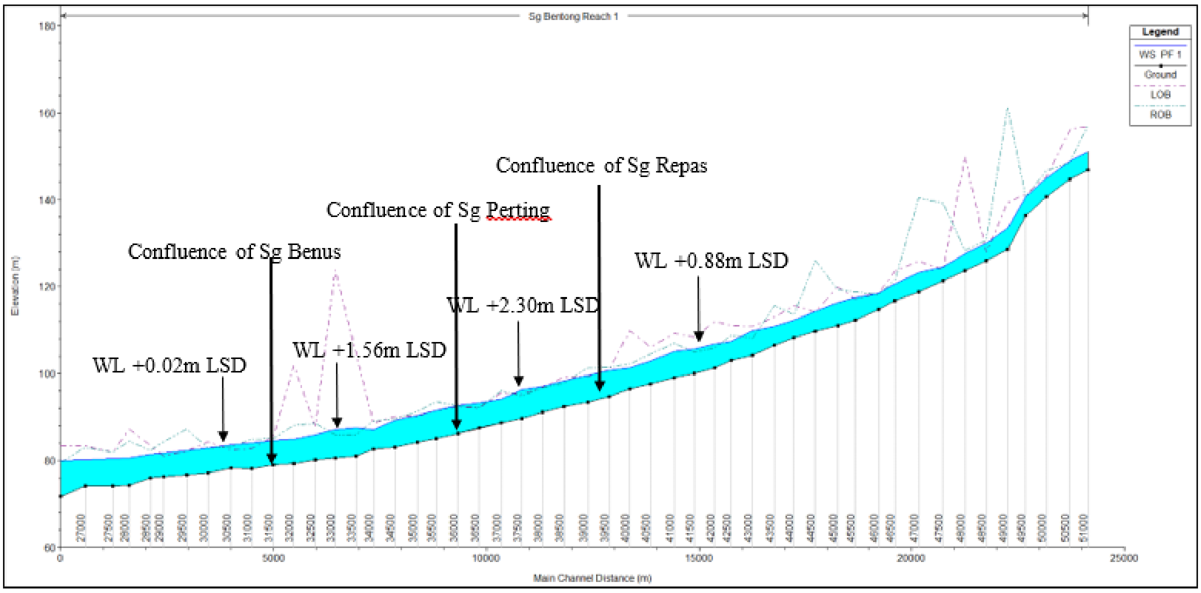

Fig. 10. Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-Years ARI (Option 5-Proper Land Use Allocation/Planning)

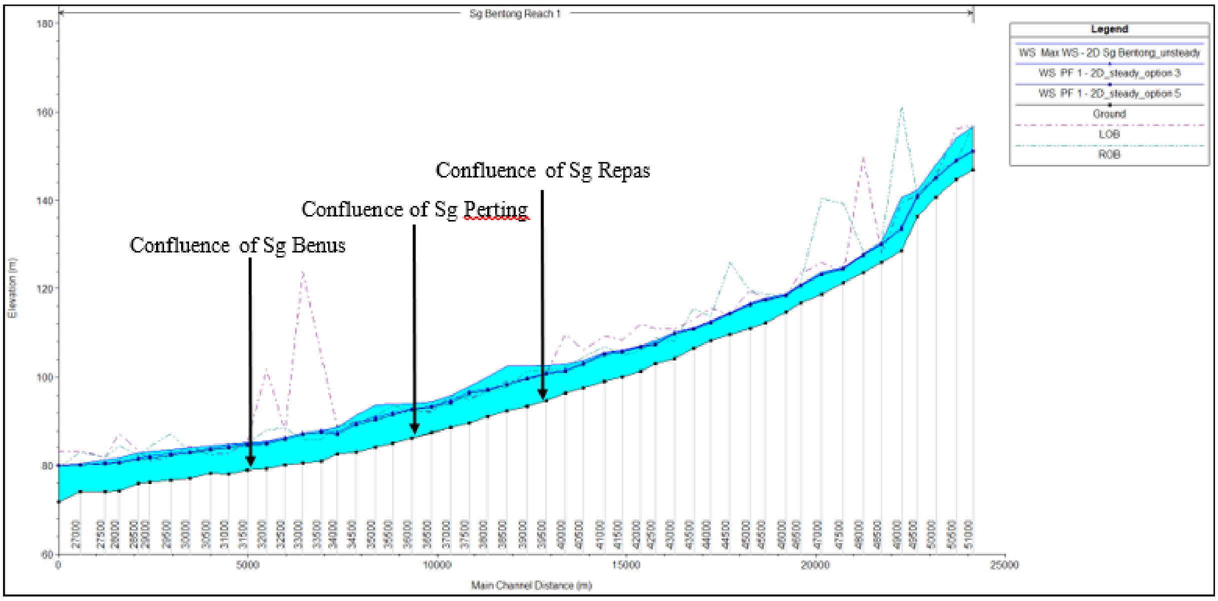

Fig. 11. Comparison of Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-Years ARI- Proper Land Use Allocation/Planning

3.2. Rainwater Harvesting System (RWHS)/ Onsite Detention (OSD)

A simulation evaluated the effectiveness of rainwater harvesting systems (RWHS) in residential areas as a non-structural flood mitigation measure. RWHS collects rainwater to divert it from drainage systems, aiming to mitigate flooding [12]. Fig. 12 displays the simulated flood hydrograph for Sg Bentong during a 100-year ARI, 6-hour design flood with RWHS. HEC-RAS simulations illustrate maximum water levels for Option 3 (Fig. 13) and Option 5 (Fig. 14), with a comparative analysis shown in Fig. 15. Despite RWHS implementation, water still overtops riverbanks in Sg Bentong town, indicating the need for additional flood mitigation measures.

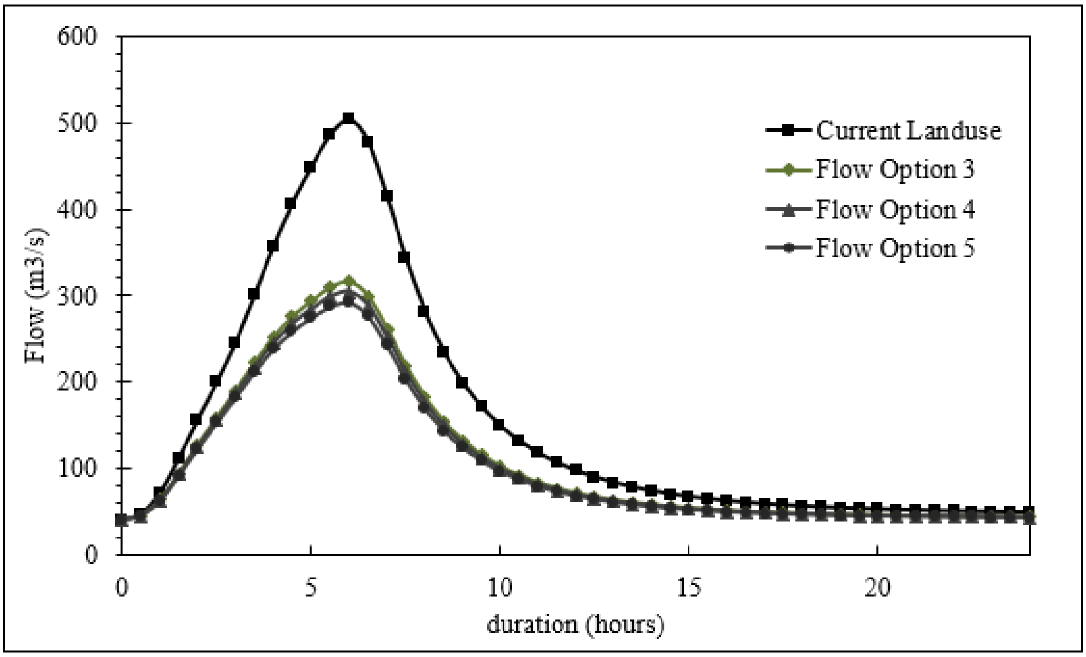

Fig. 12. Simulated Flow Hydrographs of Sg Bentong 100-Years ARI 6 Hours Design Rainfall- RWHS

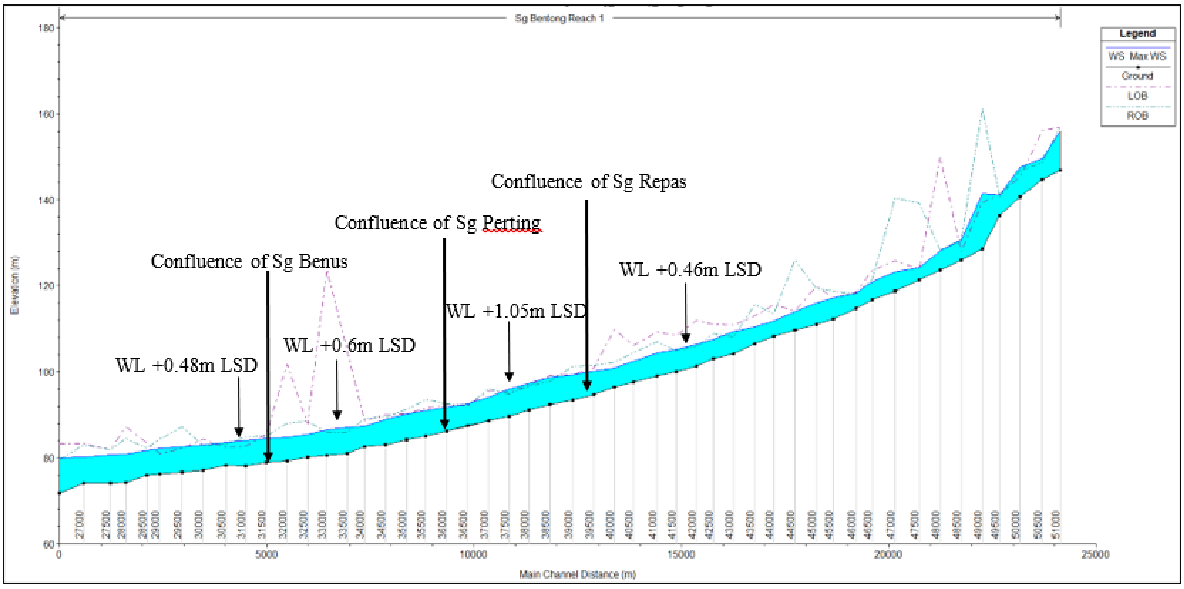

Fig. 13. Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-Years ARI (Option 3-Rainwater Harvesting System

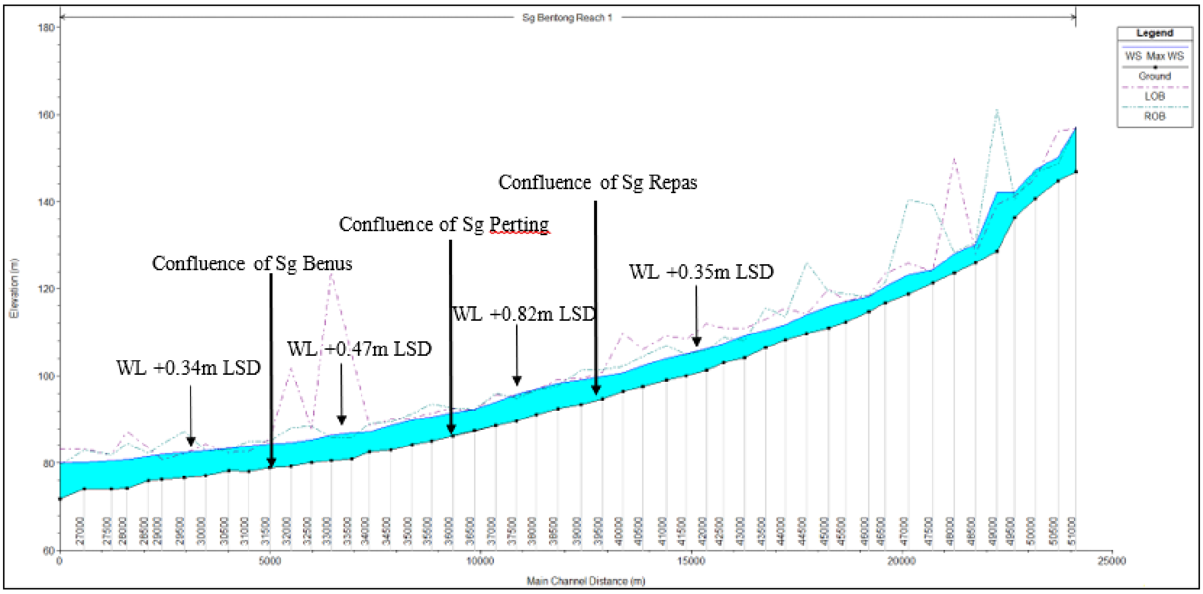

Fig. 14. Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-Years ARI **(**Option 5-Rainwater Harvesting System**)**

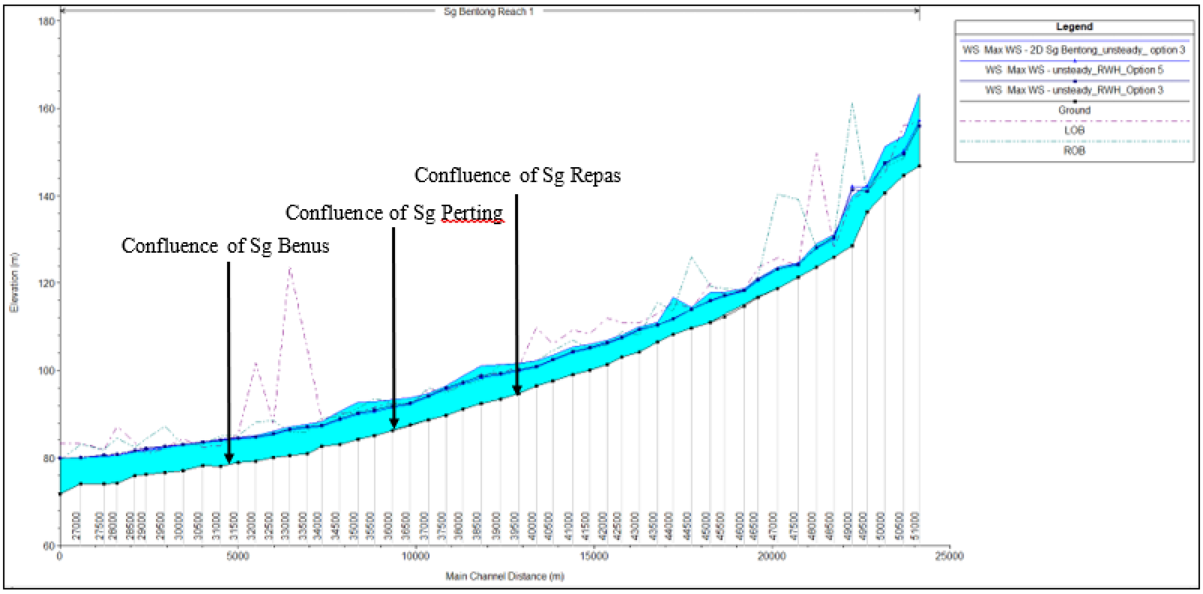

Fig. 15. Comparison of Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-Years ARI- Rainwater Harvesting System

3.3. Integrated Non-Structural Flood Mitigations

While individual non-structural measures reduce water levels, they do not fully prevent flooding in some areas. Hence, an integrated approach is needed. Major integrated measures for the Sg Bentong river system are analysed, recognizing that singular solutions may not suffice. Five options for integrated non-structural flood mitigation strategies are listed in Table 4.

Table 4: Summary of Proposed Options Considered for the Integrated Non-Structural Flood Mitigations

Option 1	Existing River + Proposed 10% of the Catchment Area is forested + 10% of the buildings got RWHS/OSD
Option 2	Existing River + Proposed 20% of the Catchment Area is forested + 20% of the buildings got RWHS/OSD
Option 3	Existing River + Proposed 30% of the Catchment Area is forested + 30% of the buildings got RWHS/OSD
Option 4	Existing River + Proposed 40% of the Catchment Area is forested + 40% of the buildings got RWHS/OSD
Option 5	Existing River + Proposed 50% of the Catchment Area is forested + 50% of the buildings got RWHS/OSD

Options 1 and 2 were modelled considering the existing 20% forest cover in the catchment area. The hydrodynamic performance for each option was assessed by simulating the hydrograph for each design rainfall event in Fig. 17. Results were presented through flood profiles, 2D simulation layouts, and summaries of 1D model simulations. Evaluation focused on the 100-year ARI, 6-hour design flood event, with Figure 17 displaying the simulated flood hydrograph for Sg Bentong in this scenario.

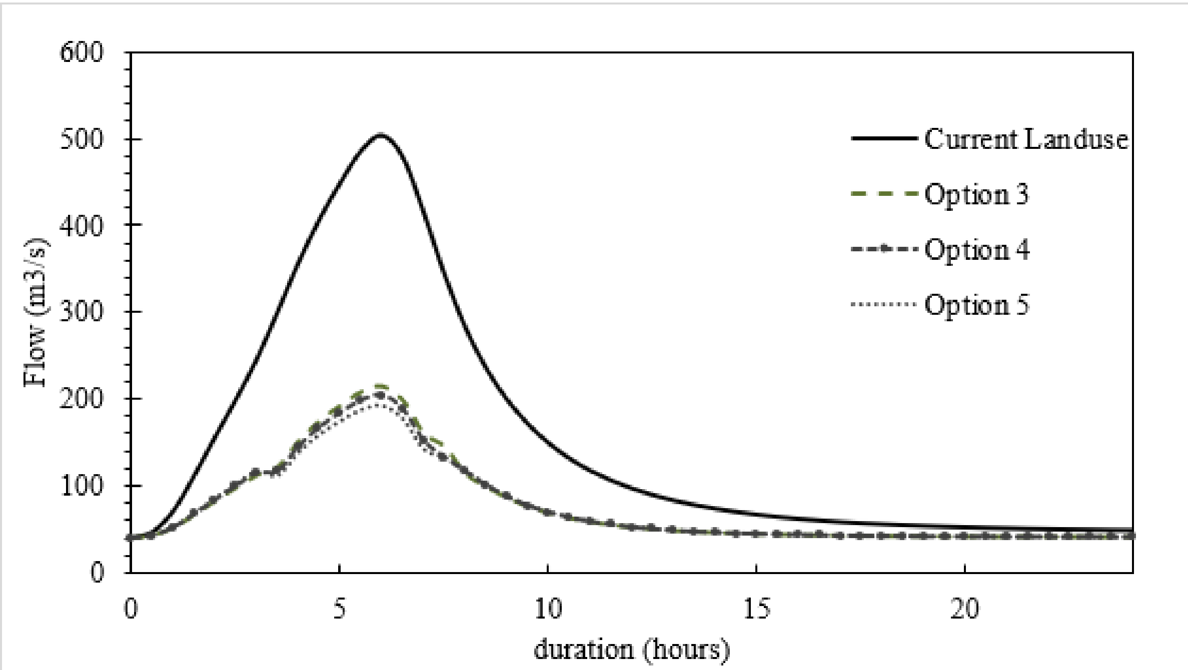

Fig. 17. Simulated Flow Hydrographs of Sg Bentong 100-Years ARI 6 Hours Design Rainfall- Integrated Non-Structural Flood Mitigations

HEC-RAS simulations for integrated flood mitigation are outlined as follows: Option 3 simulates Sg Bentong, showing maximum water levels for 100-years ARI storms with a 6-hour duration (Fig. 18). Similarly, Option 5 depicts maximum water levels (Fig. 19). Comparative analysis with current land use, Option 3, and Option 5 is provided in Fig. 20, indicating a notable decrease in water levels due to the mitigation.

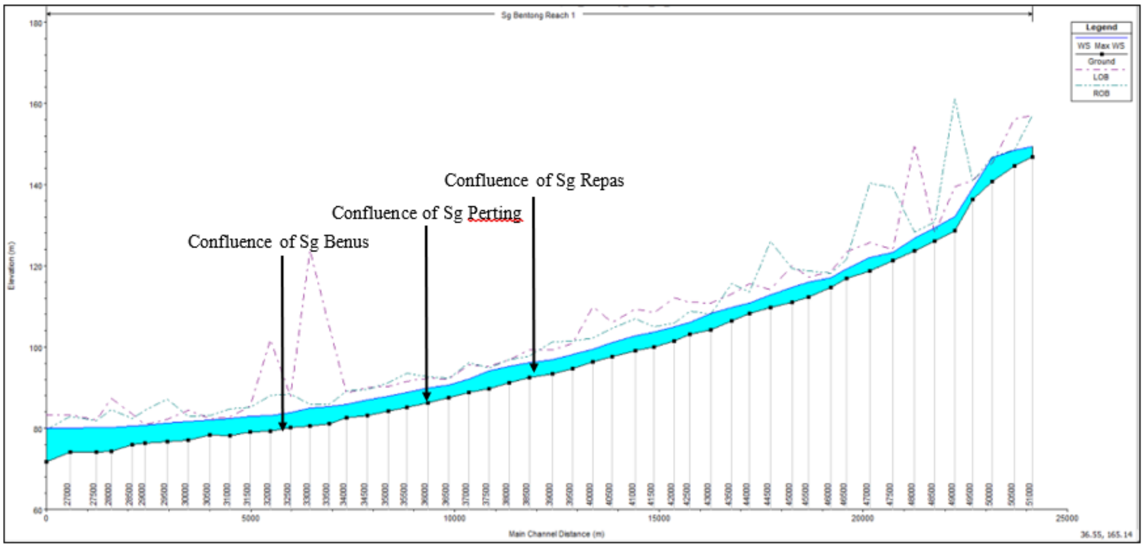

Fig. 18. Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-Years ARI **(**Option 3- Integrated Non-Structural Flood Mitigations**)**

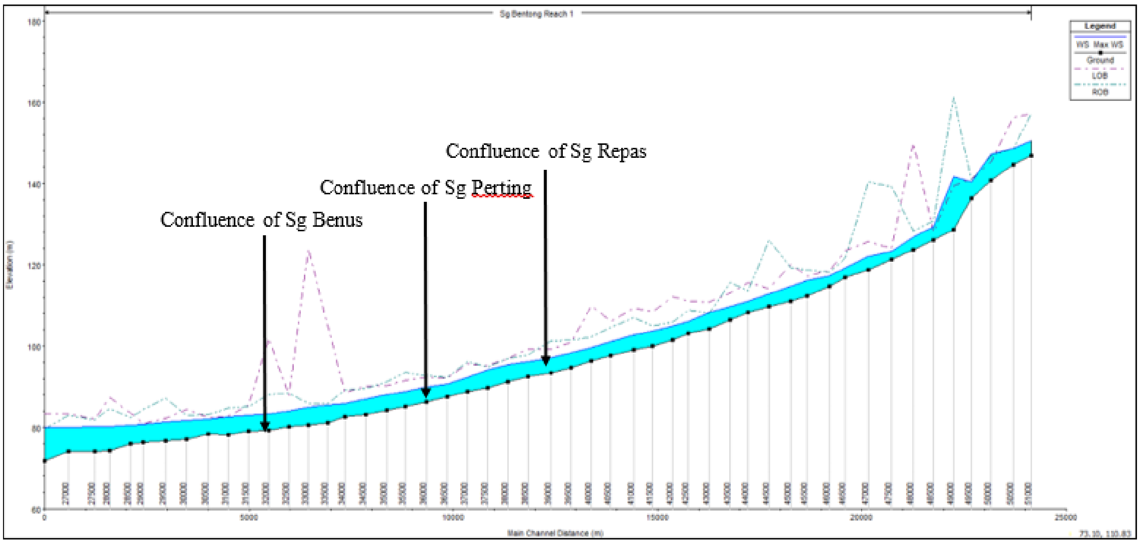

Fig. 19. Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-Years ARI (Option 5- Integrated Non-Structural Flood Mitigations)

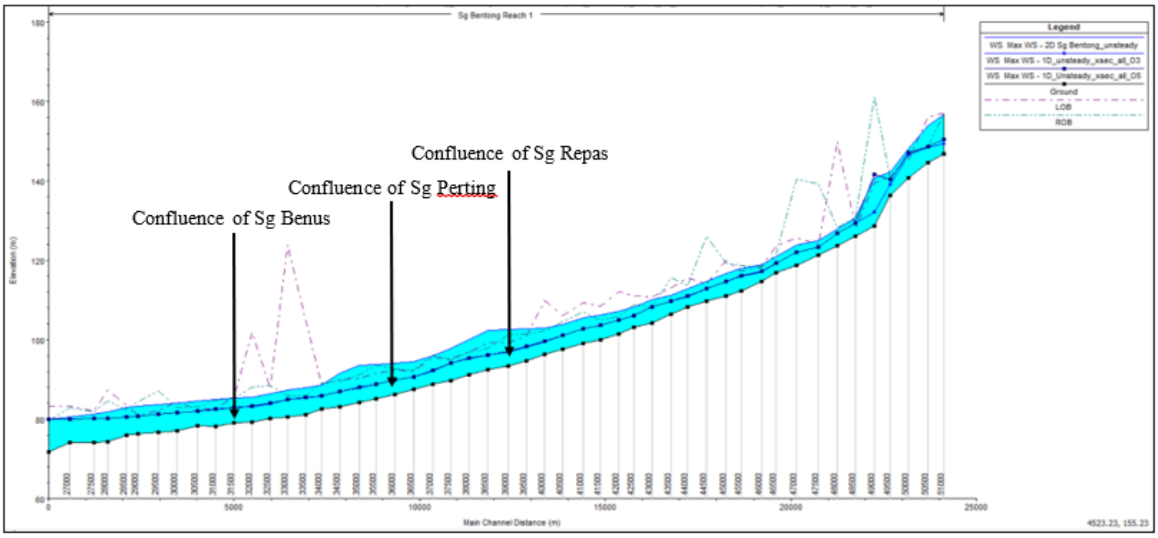

Fig. 20. Comparison of Max Water Level Profile of Sg Bentong (HEC-RAS): 6 Hours 100-Years ARI- Integrated Non-Structural Flood Mitigations

3.4. Flood Map

The Sungai Bentong flood map simulation employs a comprehensive 2D model covering the entire study area, including affected rivers and downstream reaches [13]. Fig. 21 until Fig. 24 depict the flood extent under existing conditions for a 100-year ARI with 6-hour storm durations, showing riverbank overtopping and impacts on low-lying properties, infrastructures, and housing schemes. Subsequent simulation scenarios assess potential flood maps for various non-structural mitigation measures shows in Table 5.

Table 5: Simulation Of Few Scenarios for Various Non-Structural Mitigation

Scenarios	Non-structural mitigation measures
1	Existing Conditions for 100-Year ARI 6-Hour Design Flood
2	Proper Land Use Allocation for 100-Year ARI 6-Hour Design Flood
3	Rainwater Harvesting System for 100-Year ARI 6-Hour Design Flood
4	Integrated Non-Structural Flood Mitigation Options for 100-Year ARI 6-Hour Design Flood.

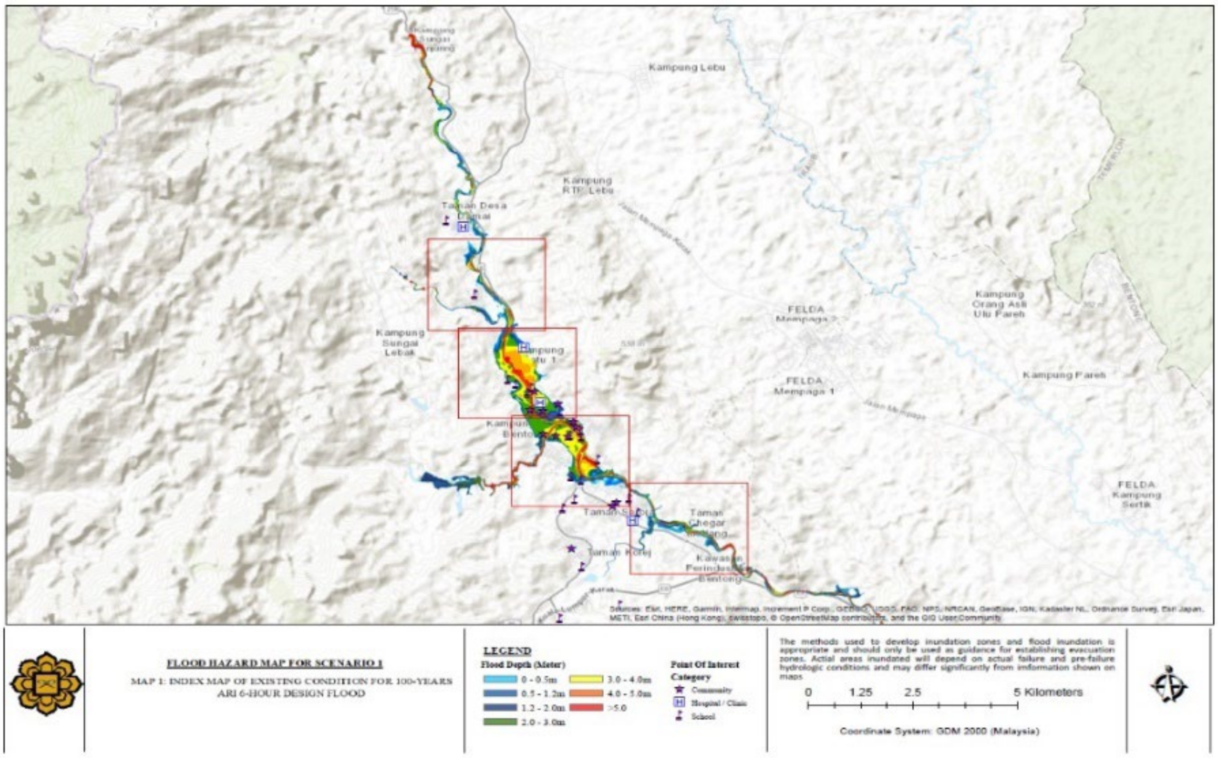

Fig. 21. Flood Hazard Map for Scenario 1.

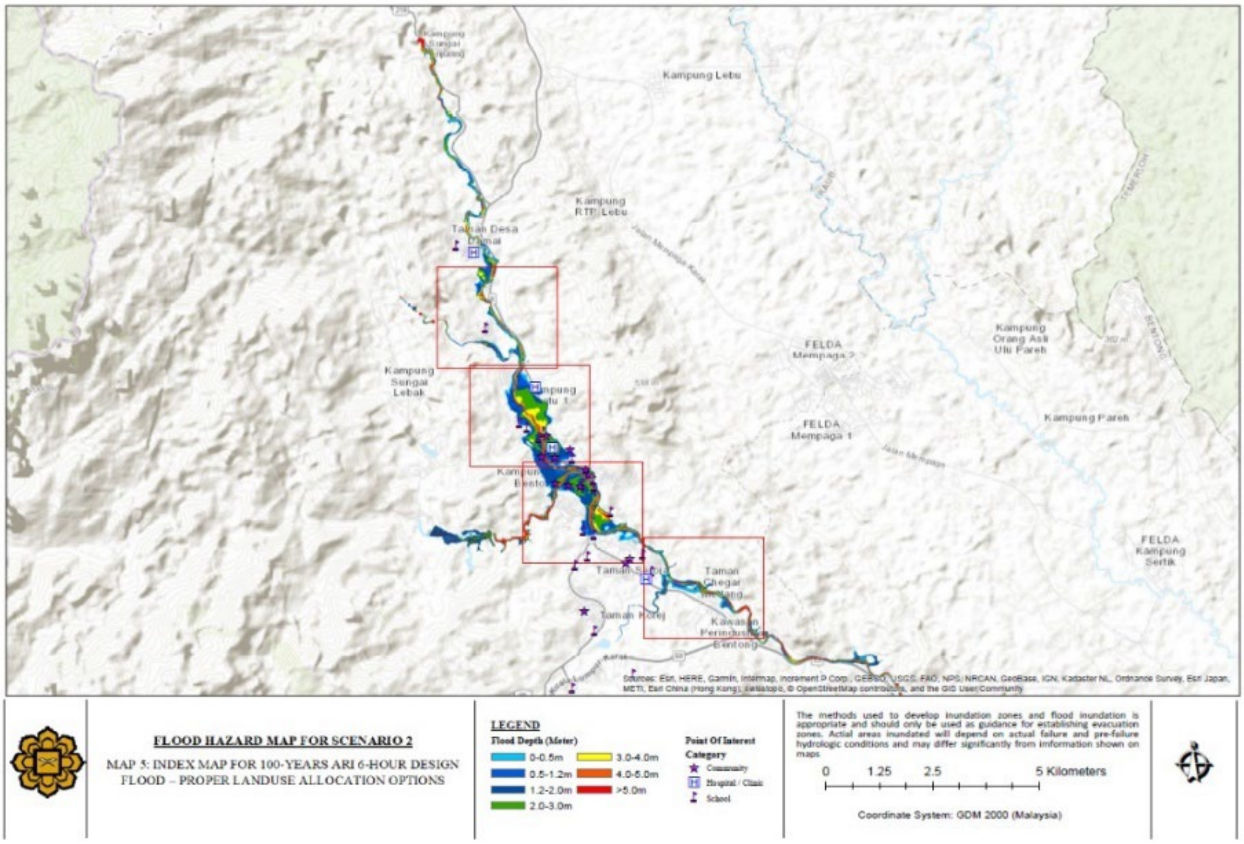

Fig. 22. Flood Hazard Map for Scenario 2.

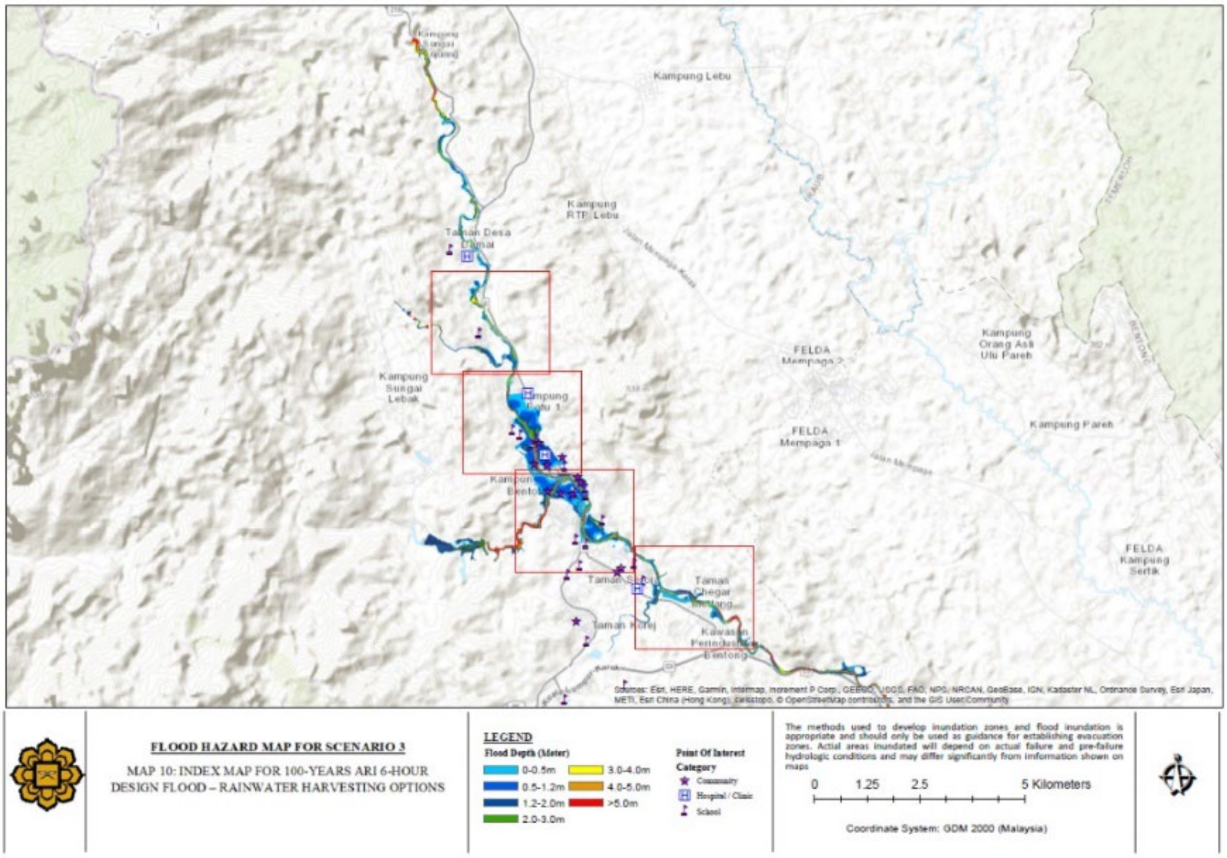

Fig. 23. Flood Hazard Map for Scenario 3.

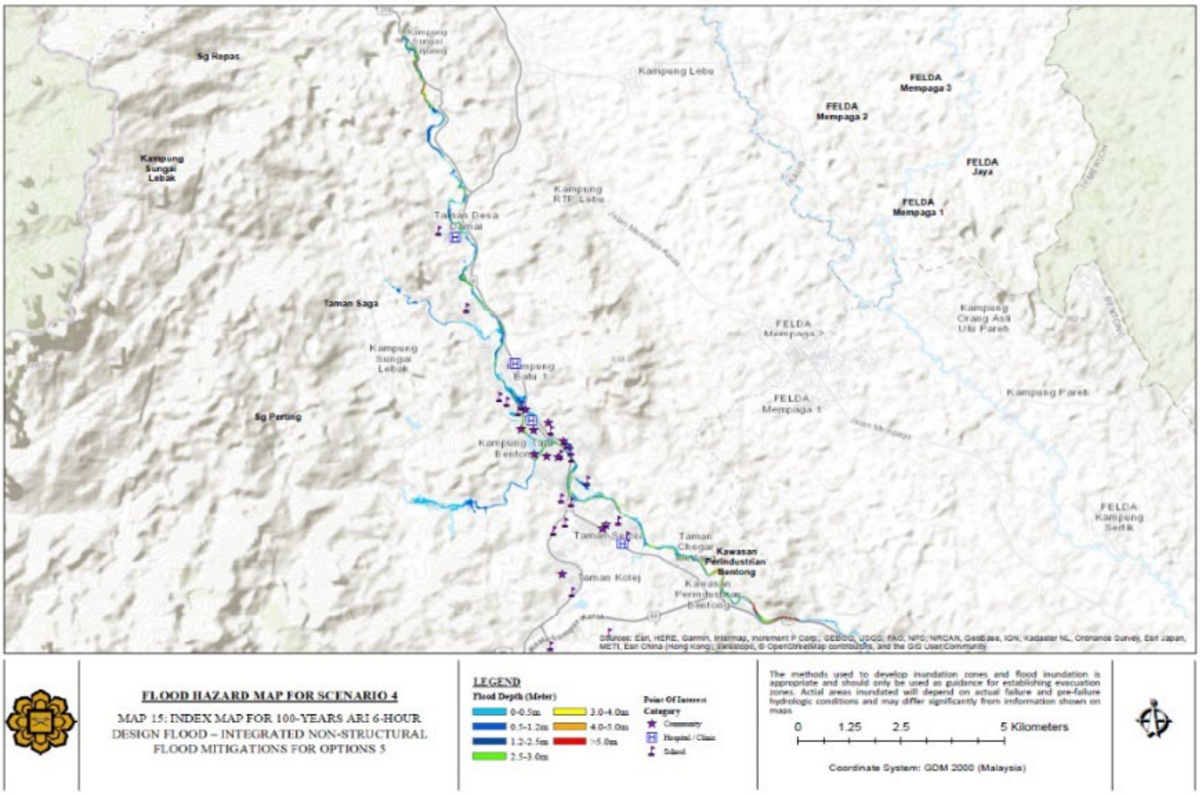

Fig. 24. Flood Hazard Map for Scenario 4.

After simulating the 2D HEC-RAS model, key outputs were extracted for discussion. These outputs include residential, commercial, and business areas, along with maximum flood depths. Four floodplain modeling scenarios were executed in Table 6, with Scenario 1 focusing on existing conditions for a 100-year ARI 6-hour design flood. Results analysis showed flood depths ranging from 0.5m to 9.82m. In Scenario 2, which explores proper land use allocation options for a 100-year ARI 6-hour design flood, analysis revealed flood inundation depths ranging from 0.5m to 8.34m, with an average depth of 1.83m. In Scenario 3, implementing a rainwater harvesting system for a 100-year ARI 6-hour design flood, analysis revealed flood inundation depths ranging from 0.5m to 7.09m, with an average depth of 1.06m. Lastly for Scenario 4, implementing integrated non-structural flood mitigation options for a 100-year ARI 6-hour design flood, analysis revealed flood inundation depths ranging from 0.5m to 6.51m, with an average depth of 1.09m. Rainwater harvesting and integrated non-structural measures effectively reduced the flood depth, with rainwater harvesting slightly outperforming in average flood depth reduction.

Additionally, specific downstream locations of Sg Bentong were impacted by flood waves, leading to the extraction of flood depths for a 100-year ARI 6-hour design flood for each location under different scenarios, documented in Table 7. The maximum flood depth decreases significantly from Scenario 1 to Scenario 3 across most location. Senario 4 with Integrated Non-Structural Flood Mitigation shows the lowest maximum flood depths where data is available, indicating effective flood reduction. This data highlights the effectiveness of various flood management strategies, with Scenario 3 and Scenario 4 showing the greatest reductions in maximum flood depths.

Table 6: Flood Depth Classification for All Scenarios

Flood Depth (m)	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)	Area (km^2)	Percentage (%)
	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
0-0.50	6.44	6.48	9.76	9.82	28.51	30.58	36.44	37.73
0.51-1.20	11.75	11.82	20.58	20.70	35.16	37.71	26.36	27.29
1.21-2.00	12.90	12.98	30.53	30.71	17.45	18.72	15.49	16.04
2.10-3.00	26.77	26.94	25.69	25.84	7.38	7.92	9.94	10.29
3.10-4.00	25.32	25.47	8.95	9.00	2.56	2.75	5.90	6.11
4.10-5.00	11.72	11.79	2.42	2.43	1.34	1.44	1.82	1.88
>5.10	4.48	4.50	1.50	1.51	0.84	0.90	0.63	0.65

Table 7: Summary of All Scenarios at Affected Location Downstream of Sg Bentong

No.	Location	Max. Flood Depth (m)			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	Taman Bentung Jaya	4.26	2.21	0.29	-
2	Kampung Baru Chamang	4.71	3.09	1.13	-
3	Taman Hussin	3.11	1.42	0.55	-
4	Kampung Chamang	4.12	3.50	2.22	0.51
5	Taman Ban Hua	2.15	1.29	0.22	-
6	Kampung Kemansur	2.32	1.24	0.68	-
7	Kampung Perting	2.85	1.77	0.77	-
8	Kampung Baru Bentong	3.11	1.59	0.04	-
9	Kampung Sungai Marong	3.81	2.52	0.83	

10	Taman Dahlis	1.84	0.79	-

3.5. Setting safe platforms levels for 100 Years ARI

The flood maps from Fig. 21 until Fig. 24 serve various purposes in flood risk management: preventing new risks during planning and construction, reducing existing risks, and adapting to changing risk factors. Stakeholders may require different content, scale, accuracy, or readability, depending on their objectives. These maps are valuable for strategy formulation, land-use planning, emergency planning, setting safe platform levels, and public awareness [14]. Furthermore, Fig. 25 illustrates recommended safe platform levels for a 100-year ARI, based on the recommendations in Table 4.

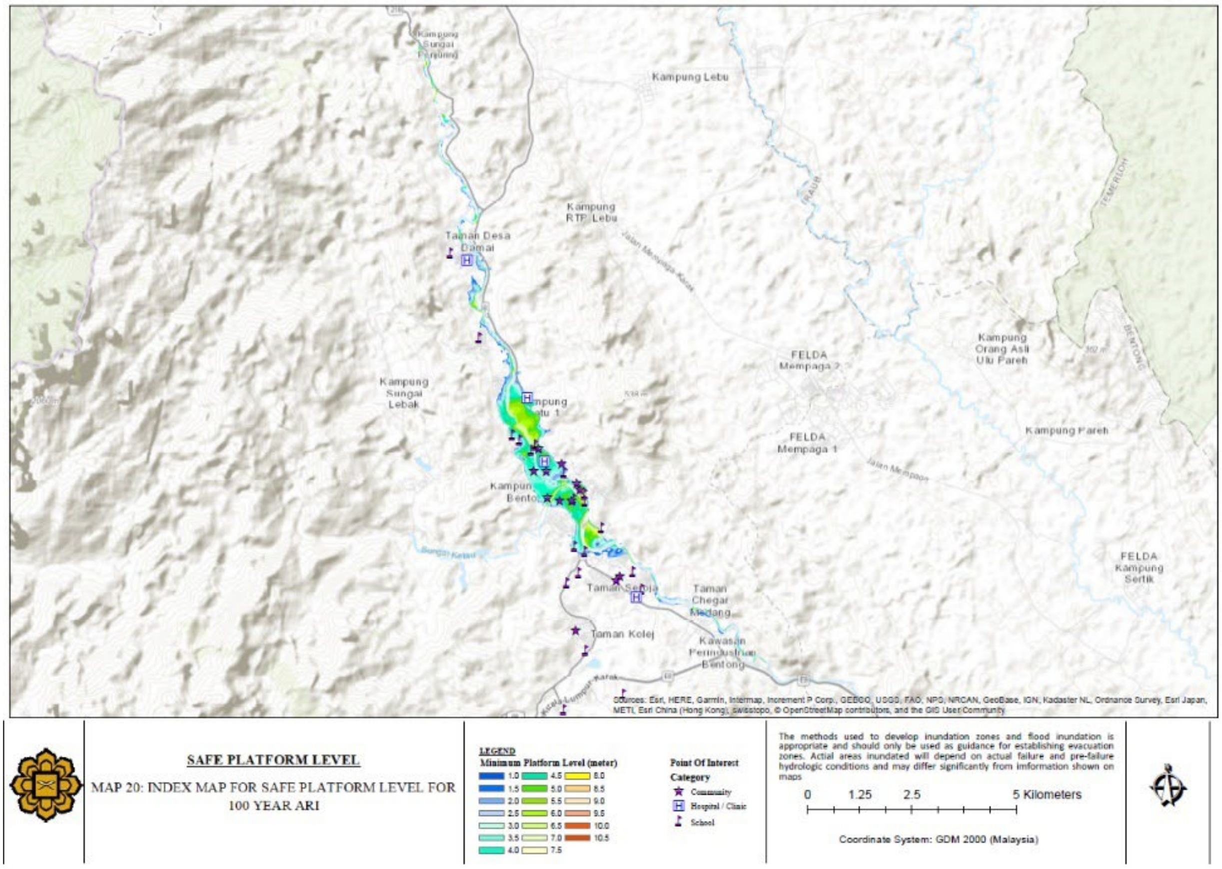

Fig. 25. Index map for safe platform level for 100 years ARI.

3.6. Planting Trees and Proper Logging

Forest ecosystems play a crucial role in mitigating CO^2 emissions by absorbing carbon dioxide through photosynthesis and storing carbon in trees and soil. Tropical forests, which cover 80% of the world's forest area, are particularly significant for carbon storage, aiding climate change mitigation while preserving biodiversity and climate balance [15]. Deforestation disrupts natural water flow, leading to increased downstream water flow and flooding. Restoring forest reserves benefits local communities through tourism and recreation. Globally, reforestation efforts aim to reclaim deforested and degraded areas. Common tree species planted in Peninsular Malaysia include *Acacia mangium, Paraserianthes falcataria, Gmelina arborea, Eucalyptus spp., Pinus spp., Teak, Sentang*, and various *Dipterocarps*.

4. CONCLUSION

Flooding, often considered the most challenging natural disaster to prevent, can be mitigated through appropriate design and management strategies. In the Sg Bentong catchment, floods can arise from various factors, including heavy rainfall, urbanization-induced poor drainage, and local conditions. To address this, recommendations for the catchment area include proper land use planning, onsite detention, rainwater harvesting, and integrated non-structural flood mitigation. This study highlights the effectiveness of integrated non-structural measures in reducing flood risks. The HEC-HMS and HEC-RAS simulation models used in the study to demonstrate potential for modelling the entire river system and show significant reductions in water levels with the implementation of non-structural flood mitigation. Moreover, incorporating non-structural measures can reduce peak flow, runoff volume, flood levels, and frequency of flood events, offering substantial benefits for the region.

Recommendations for future research to effectively manage flood risks and enhance resilience, several key recommendations should be considered. First, enhancing land use planning is crucial; increasing forest cover and optimizing land use can significantly improve natural water retention and reduce runoff. This involves prioritizing green spaces and permeable surfaces in urban development to mitigate flood risks and bolster ecosystem resilience. Additionally, implementing rainwater harvesting systems is essential. Encouraging their widespread installation can help capture and utilize rainfall, thereby decreasing runoff and alleviating pressure on existing drainage infrastructure. This not only aids in stormwater management but also provides a sustainable water source. Adopting integrated strategies is also important, as combining effective land use planning, rainwater harvesting, and other non-structural measures offers a comprehensive approach to flood risk management. Such a holistic strategy addresses multiple aspects of flood prevention, enhancing overall resilience to flood events. Lastly, it is vital to regularly update flood hazard maps to reflect the impacts of implemented mitigation measures accurately. This ensures that current and relevant information is available to guide future planning and decision-making processes.

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